Life Cycle Assessment of Marble Manufacturing

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Dedication

Dedicated to my amazing parents and beloved siblings, whose unwavering cooperation and support helped me achieve this amazing feat

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ABSTRACT

The fast increase in population is placing enormous strain on the world's manufacturing industries to meet the demands of an ever-increasing number of people. Although the manufacturing sector is vital to the growth of any nation, it also has a detrimental effect on the environment. The sedimentary and calcium carbonated nature of the limestone (raw material for marble) makes its superior and important in the in the earth crust. In many production areas, limestone is making a lasting influence, despite health concerns surrounding it. To assess and mitigate these environmental consequences, systematic measurement is required. To fill this research gap, a comprehensive environmental assessment was carried out for a mechanized and non-mechanized marble manufacturing facilities in Pakistan. The modeling software tool used was SimaPro 9.5, and Recipe 2016 methodologies were utilized to evaluate various midpoint and endpoint impacts. The results demonstrated that mechanized and non-mechanized marble manufacturing techniques had the biggest environmental impact in terms of effect categories, the most affected were terrestrial ecotoxicity and global warming, with values ranges from 128-170 kg 1,4 DCB and 60-64 kg CO2 eq, respectively. At the endpoint level, the human health category was more negatively impacted than the others in non-mechanized marble manufacturing because of Terrestrial ecotoxicity, Acidification, fine particulate matter, and global warming. The quantity of waste produced in mechanized is less as compared to non-mechanized marble manufacturing consequently making more environmental damage e-g freshwater eutrophication, marine eutrophication. The greater amount of waste in non-mechanized marble manufacturing causes more terrestrial ecotoxicity as compared to mechanized marble manufacturing with no waste and vice versa furthermore due to high waste land use and environmental impact is quite higher for non-mechanized marble manufacturing. Water consumption for mechanized marble manufacturing during extraction phase is higher than mechanized which negatively impact the biodiversity of the near-site area. Non-mechanized marble manufacturing is more hazardous due to landslide, blasting and lose rocks which negatively affect work conditions and human health category.

Key Words: Life cycle assessment, Mechanized, Non-Mechanized, Limestone, marble, manufactured

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CHAPTER 1. INTRODUCTION

The main objective of this study is to determine the quantitative analysis of both mechanized and non-mechanized processes for marble manufacturing and compare them to each other based on their environmental impacts.

1.1 Background Study

The exponential growth of the world population is leading to a prominent increase in the utilization of nature resources , resulting in their depletion. Additionally, this is putting tremendous pressure on different production and manufacturing sectors to meet the needs of every single person. The largest problem the world is currently facing because of this careless use of resources is climate change[1]. There is a positive correlation between enhanced export revenue streams and improved manufacturing capacities that result in superior quality products. Given that the world's population is expanding and that this has resulted in a notable rise in both production and consumption activities, this tendency is particularly apparent. Due to the resulting increase in supply and demand dynamics, trade balances and economic outcomes are impacted, underscoring the significance of developing industrial processes to fulfill expanding global demands [2]. It is estimated that Pakistan has 1500 processing facilities and 2000 quarries, producing 100 million square feet of dimension stone annually. Since the construction sector uses 40% of the energy produced worldwide, which is a considerable amount, it is critical to alter the methods used to reduce energy consumption. The European Commission creates an ecolabel to track the environmental harm an industry does or to assess if it meets the requirements necessary to receive the European ecolabel after consulting with LCA specialists. The categories for impact assessments are Potential for global warming expressed in carbon dioxide Total embodied energy is another category, such is the acidification potential of sulfur dioxide, the eutrophication potential of PO4, and the photochemical oxidation of ethylene. One important aspect of the quarry's sustainability is the material waste from extracted valuable material, which is not considered in impact assessments. This study considers the material waste from both processes, and decisions on the economic factor should be made using that material. The manufacturing of marble products consists of several phases initially it is quarried from reservoir either by mechanized or non-mechanized technique[3, 4]. The mechanized marble is extracted from the quarry by a wire saw which cut the marble block to a specified dimension which is more efficient in material as compared to non-mechanized and has better safety comparatively, meanwhile, non-mechanized marble extraction is extracted from the quarry by old conventional method blasting consequentially it causes noise pollution, material waste, and workers injuries usually and death occasionally [5]. It is obvious that the mechanized way is far better than the non-mechanized procedure but due to the huge number of machinery and capital requirements, very few entrepreneurs are willing to invest because the market is too competitive. To show the difference between the two methods visual representation is given with location[6]. In comparison to the automated and mechanized process, the non-mechanized marble extraction technique is less efficient and results in significant material loss. The non-mechanized method is used because it requires fewer machine installations and has a lower cost-benefit ratio, but it also results in significant material loss, which is also an economic loss. Further damaging the environment, the material waste keeps on accumulating as it is cut and shaped, producing even more material waste. There is higher machining and energy loss since there is about 2.8 tons of material waste for every ton of beneficial product gained. The method's social side is concerning as numerous individuals lose their lives every year because of mine slippage, dangerous blasting, and inadequate safety[3, 5, 7]. The technological difference between these techniques causes significant loss of energy. It reveals that marble manufacturing is energy intensive process additionally the grid energy used for cutting is 60% fuel based which emits hazardous gases to the environment, therefore solar panels are recommended to mitigate the greenhouse effects. Marble is a useful material for buildings and quite usual in modern-day architecture and Pakistan exports nearly 2% of world marble with 90% country need which is colossal, district Buner has 50 quarries exist in small area[8, 9]. The categories for impact assessments are Potential for global warming expressed in carbon dioxide Total embodied energy is another category, such is the acidification potential of sulfur dioxide, the eutrophication potential of PO4, and the photochemical oxidation of ethylene. One important aspect of the quarry's sustainability is the material waste from extracted valuable material, which is not considered in impact assessments. This study considers the material waste from both processes, and decisions on the economic factor should be made using that material. There is a positive correlation between enhanced export revenue streams and improved manufacturing capacities that result in superior quality products. Given that the world's population

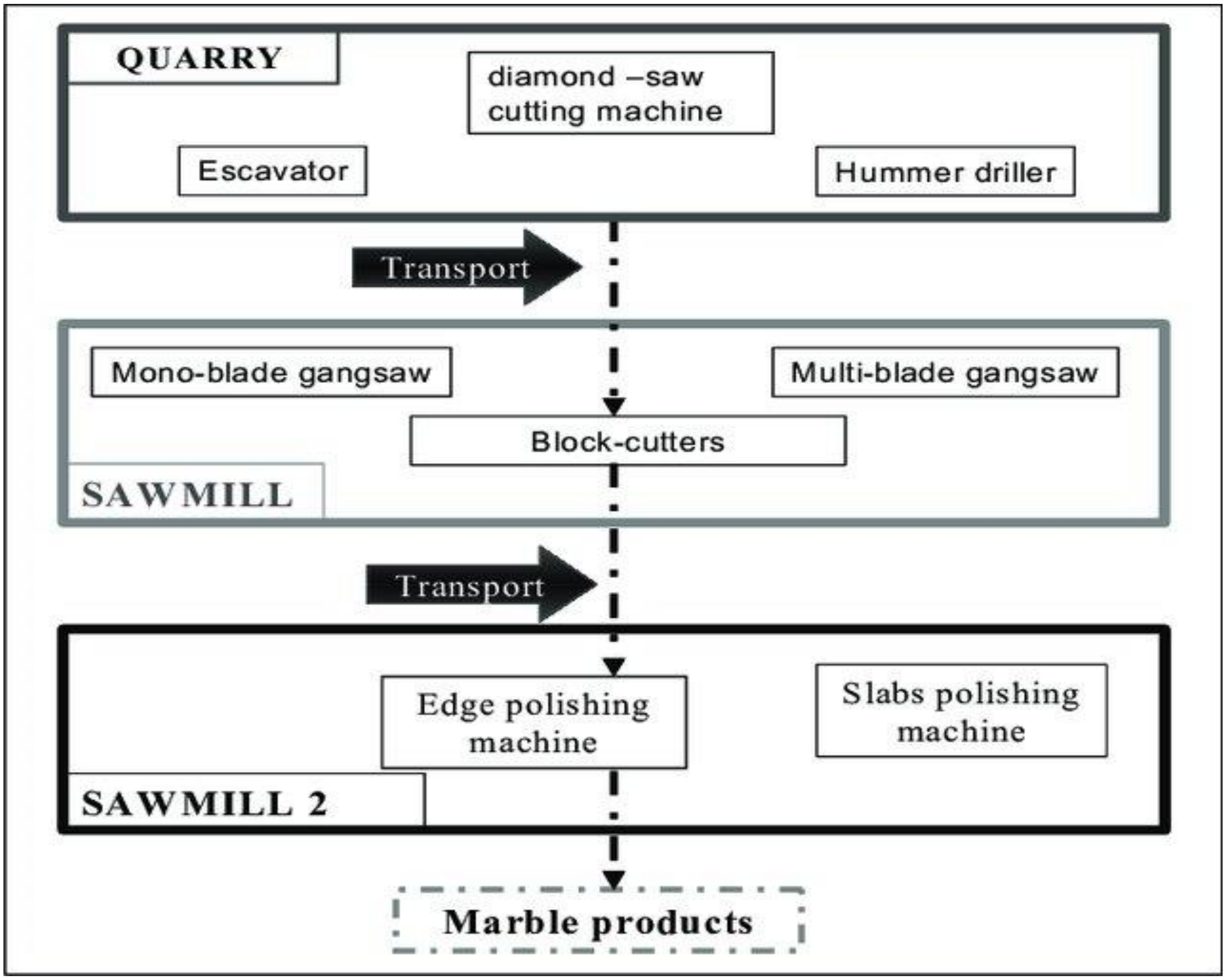

Figure 1-1: Marble Manufacturing

is expanding and that this has resulted in a notable rise in both production and consumption activities, this tendency is particularly apparent.

Gradually, the industrialization of marble mining and processing commenced, with significant facilities being created for slab cutting and polishing. To capitalize on the hydraulic energy produced by the river-water, these fabrication batches gathered at the downside of ‘valleys. At the close of the 1800s, explosives were nearly entirely replaced with helicoidal wire, a metallic cable that could remove stone, which resulted in yet another noticeable alteration to the terrain. The mountain ceased to be destructed, keeping behind mounds of debris, and instead started to be precisely "cut," shaped, producing bizarre landscapes consisting of enormous stairways and platforms known as extracted products store-place, where the stone is converted into different pieces and ready for transportation. Modern manufacturing is more technologically advanced, and its modern production shown in Figure 1[10] is more technologically advanced, and its life cycle mostly consists of quarry extraction, finishing processes including smoothing, polishing, and finishing, as well as activities related to transportation and sales [10, 11].

1.2 Environmental Impact of Marble Manufacturing

Every economic sector needs to take steps to minimize their environmental impact and use energy more wisely. The building industry is one of these industries that is widely acknowledged to be particularly energy dependent due to its accounts for over forty percent (40%) of the Europe overall total energy requirements and utilization [12]. It is obvious that consideration must be given to the energy required by the products used in construction throughout their life in addition to the energy used for air cooling and ventilating building's working or duty conditions. In actuality, both the associated pollutant emissions and the embodied energy throughout a material's life lifetime require consideration [13, 14]. Marble is a naturally occurring well-structured and shaped stone that has been used extensively in the construction industry for a long time to manufacture the floor of the room. More recently, due to its great aesthetic value and durability, marble has also been employed as an interior material[15]. The EU is presently working to make natural stone construction materials more environmentally friendly as part of its commitment to enhancing the surrounding role of natural stone life cycles, particularly their manufacture. This commitment is demonstrated by the ecological standards for granting hard covering with the EU Eco-label (for both "natural product" and "processed products"), which were recently developed by the European Commission. It is noteworthy, nonetheless, that some questions have been raised about whether these standards are actually applicable to natural products like marble[16, 17]. The marble manufacturing consists of four cycles. 1. ‘’preproduction (i.e., mining, transportation from the mine to the industrial plant, storage at the industrial plant)’’, (*2*) ‘’production (processing and polishing, packaging, and transportation to the building site)’’, (*3*) ‘’use phase, and (*4*) end of life (either landfilling or recycling/reusing’’) [18]. The impact assessment categories are modified to global warming potential in terms of Co_2, Acidification potential of So_2, Eutrophication potential of Nitrogen oxides, material waste of calcium carbonate and total embodied energy[19]. In addition to the air pollution emissions from the energy used by the mechanical systems in extractions and industry setups, as well as the fuel engines of the extractions working systems, the following factors also need to be considered when analyzing the environmental effects of marble quarrying and processing operations: noise, vibrations, and the formation of dust and waste (solid and liquid) [20].

A screening method is used to identify and evaluate potential negative effects on the environment before deciding if an environmental impact assessment (EIA) is required. Here is a summary of the primary consequences for future research. Following screening, the scoping step identifies and prioritizes significant environmental issues so that the EIA focuses on them. Next, forecasting consequences, looking into alternatives, and developing mitigation and monitoring plans are all part of the impact analysis step. Here are some ways for doing environmental impact assessments: LCA, material and substance flow analysis, carbon footprint analysis, and water footprint analysis.

1.2.1 Life cycle assessment (LCA)

The LCA approach is a widely used analytical technique for estimating environmental impacts, primarily in the context of products. Nonetheless, current research indicates that it may also be used as a tool for process analysis and design[21].

1.2.2 3D 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 [22].

1.2.3 Attributed 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 [23].

1.2.4 Substance Flow Analysis

Measuring the amount of a product or ‘substance’ or set of ‘substances’ that enters and exits a system is 4 done through substance flow analysis. It facilitates comprehension of their environmental impact [24].

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 [25].

1.2.6 Water Footprint Analysis

Water footprint is a term used to measure the specific environmental impact of water use[27].

1.2.7 Risk Assessment

Risk assessment determines the likelihood that specific actions could have an adverse effect on the environment right away[28].

1.3 Marble Sector in Pakistan and Its Impact on Environment

The two primary components of marble, calcite and dolomite, are utilized mostly in construction. Globally, marble is classified as several forms of rock, including granite, schist, and limestone[29]. Due to their contribution to the manufacturing of tiles for the regional construction sector, the stone and marble industries are vital to a nation's economy. The export of superior marble tiles to other nations creates jobs, and marble is being utilized for both inside and exterior construction[18]. Marble is the sixth most exploited material in Pakistan. More than 100 different colors and marble variations may be found in Pakistan, which has reserves of about 297 billion tons of the material. Large quantities of marble are found in Pakistan's Khyber Pakhtunkhwa and Baluchistan provinces. There are about thirty different kinds of marble in Pakistan's Khyber Pakhtunkhwa province[30, 31]. Approximately 1.37 million tons of marble and granite are produced annually, with 97% of that amount being used locally in Pakistan, according to SMEDA 2006. Marble tiles go through several stages of production, including extraction and cutting in the quarry, moving the marble to the processing facility, resizing, polishing, and cutting the stones and tiles there, and shipping the completed tiles to markets and the leftovers to landfills[30, 32]. Water and energy resources are used extensively in the marble producing process. Like this, a lot of explosives are needed to remove the marble slabs and stones from the extraction site. The production of marble releases a lot of trash, which has an adverse effect on the environment[32, 33]. Numerous organic and inorganic contaminants, including copper, arsenic, cadmium, mercury, cobalt, zinc, chromium, nickel, and lead, are found in wastewater[34]. The physio-chemical characteristics of freshwater that receives this effluent released from marble units are so impacted

[35]. Approximately 70% of the important minerals in freshwater are lost during the extraction, processing, and refining processes of the marble industries, which rank among the top production chains that generate wastewater[36].

One of the biggest global environmental issues is the fine powder that the marble industry discards of its waste. Forty percent of the excess marble produced during the mining process is discarded, resulting in environmental contamination of nearby riverbeds, farms, and infrastructure. Given that water is needed for the marble life cycle at every stage of its production chain, water scarcity is both an ecological and environmental concern[31, 36]. Most of the workers' exposure to dust comes from grinding, polishing, and quarrying operations. Workers in the marble business are also exposed to contaminated water containing silica and calcium carbonate, which increases their risk of developing lung cancer, renal illness, cardiac disease, and reparable crystalline silica. One-third of Pakistan's total water resources come from the groundwater basin, which serves as the main supplier of water for large cities. In enterprises where industrial effluents are transported to rivers by drains and exacerbate water pollution issues, groundwater is also utilized[31, 33, 37]. Marble is mostly used in construction, and it is one of the key hotspots for environmental problems related to energy use and the depletion of natural resources[38]. Nearly 70% of waste materials are produced during the marble production chains' mining, processing, and polishing steps; 40% of trash is produced in the form of broken rock during the quarrying phase. In addition to causing hydro spheric and lithospheric pollution in the atmosphere, most of these waste materials are dumped near agricultural farms, roads, vacant pits, and water bodies. Turbid wastewater from marble units and the massive amount of water needed to process marble tile also have an immediate negative impact on all kinds of water bodies[39, 40]. To assess and monitor the pollution levels in the air, soil, and water from the marble tile production chain, as well as to calculate its environmental impacts, water footprints, and cumulative energy demand, LCA(LCA) is applied. LCA is a widely recognized tool for assessing the environmental sustainability of a product or process. Environmental deterioration not only negatively affects flora and fauna, but it can also negatively affect humans [41-44]. Figure 2 [45] summarizes the contribution of various input materials and processes of one-ton marble tile production to environmental consequences in Pakistan. The findings showed that one ton of marble tile produced in Pakistan had a total GWP of 388 kg CO2-eq. The main source of greenhouse gas emissions (GWP) is the electricity used to

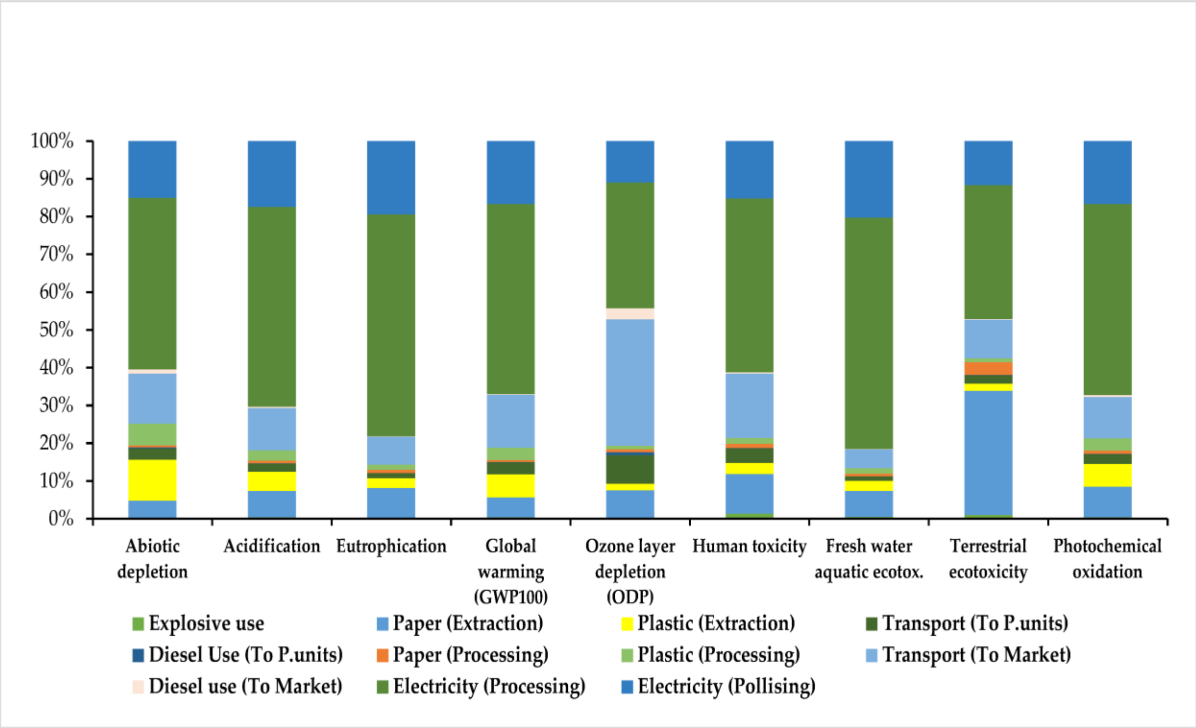

Figure 1-2: Percent Contribution of various Units and Processes on Environment [45]

process and polish marble tile, accounting for 68% of the total. Transporting marble to processing facilities and the market accounts for 18% of the GWP [39]. The manufacturing chain for marble tiles was shown to have the largest contribution to GWP, AP, EP, and HT out of the nine (09) environmental impacts generated by the marble industry. These findings are consistent with the findings of the current study, which was conducted in Pakistan, and are displayed in Figure 2[45].

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 environmental impacts[46]. Furthermore, there aren't many studies examining how manufacturing affects the environment, particularly in sectors like the mechanized and non-mechanized production of marbles 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 marble production and can direct the nation toward more environmentally friendly practices.

1.5 Research Objectives

- Proper collection of information and data to develop inventory for the marble industry.
- Identify the associated issues and hotpots related to the environmental impacts of mechanized and non-mechanized marble manufacturing.
- Identify the associated impacts with mechanized and non-mechanized methods of marble in selected areas of KP province (Buner, Malakand, Mohmand)

CHAPTER 2. LITERATURE REVIEW

Several recently developed methods for assessing how human activity affects the environment were discussed in the chapter that came before this one. The applications and ranges of protection of these techniques vary. Because LCA has so many uses, it has been widely adopted by academic and policymaking groups worldwide. The goal of this chapter is to provide a thorough overview of LCA, including its importance and suitability for usage in many disciplines, its stages, and the approaches employed in its execution. Additionally, several studies and publications on the LCA of the manufacturing of mechanized and non-mechanized marble have been provided in chronological sequence. Many research publications on LCA of mechanized and non-mechanized marble manufacturing have been presented to get a grasp of its application in the marble sector and identify prospective research needs.

2.1 Background study of Life cycle Assessment

Most products have a lengthy lifespan, and practically everything influences the environment in which it is used. A life cycle assessment, or LCA, is essentially a method or analysis that may be used to determine the environmental impacts connected to nearly every stage of a product's life cycle. It covers every stage of the procedure, from the extraction of the raw materials to their transformation, production, delivery of the finished items to markets, and, at the end, the usage of the products by clients[47]. LCA is a tool that may be used to assess and contrast the negative environmental effects brought about by different kinds of materials and processes. The LCA technique takes three types of ecological hazards into account: the health of humans, the state of the ecosystem, and resource use. The LCA is a valuable tool for determining opportunities to enhance and optimize the environmental performance of products across their entire life cycle[21]. 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[48]. The preservation of the environment has emerged as one of humanity's top priorities as time goes on and the ecosphere continues to decline at an alarming rate. By using techniques that are also good for the environment, life cycle assessment, or LCA, helps companies and manufacturers produce environmentally friendly goods. The main objective of implementing LCA is to safeguard people and their environment[49].

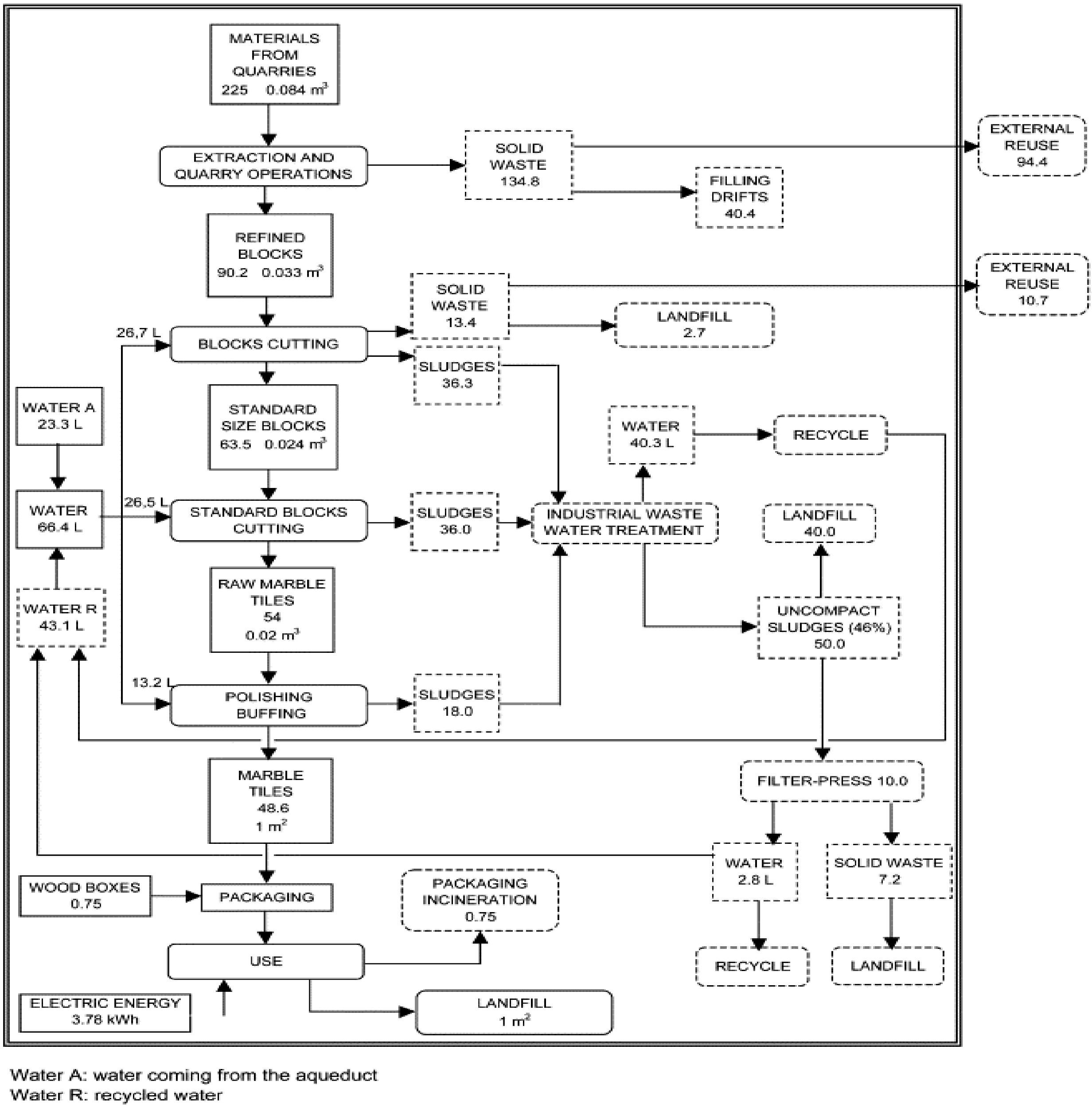

Figure 2-1: Life cycle Marble tile production (kg).

Apart from this advantage, the LCA method helps produce goods of superior quality at a reduced cost. By guaranteeing that all raw materials and completed commodities are used to the fullest extent possible before being discarded, it lowers the cost of production[50]. The LCA is a crucial part of the integration of waste management and pollution-related issues. Life cycle assessment's primary objectives are to measure inventory data and assess how any industrial operation or product affects the environment[51, 52]. This is accomplished by determining and quantifying the materials that enter and exit any process, as well as the outcomes of that material flow. The information acquired facilitates the selection of environmentally friendly goods and practices, which ultimately leads to more deliberate and prudent decision-making[53, 54]. The schematic diagram depicted in Figure shows the life cycle of marble tile and its production along with the flow of masses in Kilogram[55].

2.2 Different Phases of Life cycle Assessment

LCA is a useful tool for organizations to evaluate the environmental effects of their goods, services, or even industrial facilities. The purpose and scope, inventory analysis, impact assessment, and inventory analysis are the four primary phases of the LCA approach as shown in Figure 2-2 [56].

2.3 Goal and Scope Definition

Goal and scope definition is the initial stage of LCA which outlines the main objectives, the functional unit, the various data sources and data collection methods, and the system's limitations [57]. 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 planned and proper utilization of the analysis.
2. The need and demand to conduct the analysis
3. Target customer or audience of the analysis

The results of an LCA can be used for a variety of goals, including the development of new environmentally friendly products, the formulation of environmentally conscious political platforms, and frequently the regulation of existing products. On the other hand, the following elements should be considered before outlining the LCA study's scope[58]. Because LCA is carried out through an iterative technique, the scope can be adjusted in response to the study's conclusions[59].

It also describes the function of the system under investigation and is applicable to all inputs and outputs that will be used in the LCA analysis. The functional unit can also be used to examine the parallels and discrepancies among the systems under consideration. Because of this, it is highly

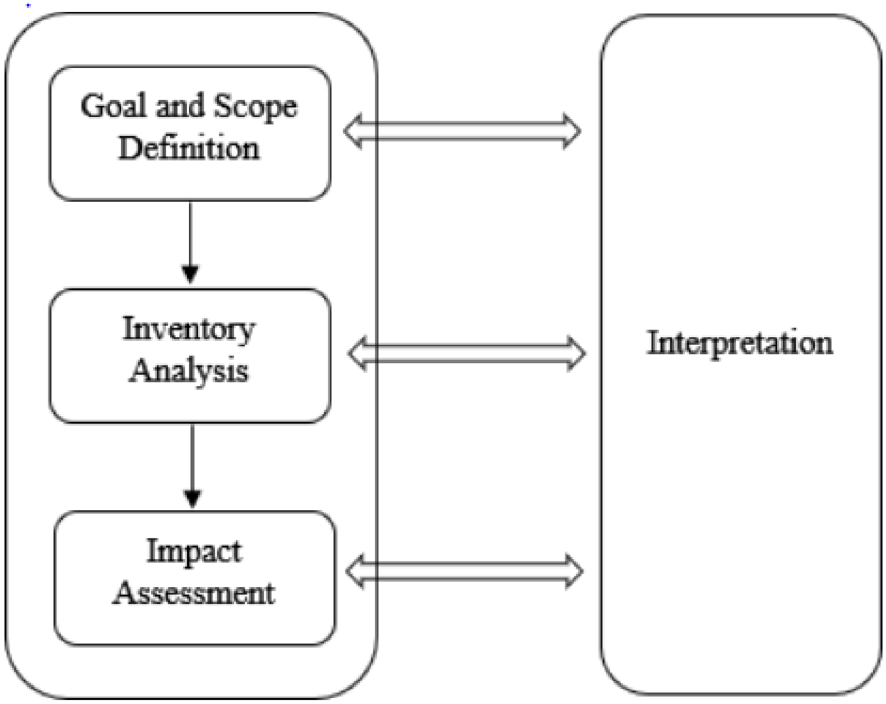

Figure 2-3: Four Phases of LCA [56]

advised that the functional unit be specified extremely carefully and with attention to detail before moving further with the analysis, data collecting[56].

2.4 System Boundary

This is essentially used to determine and select the life cycle stages of any product or process that is to be investigated. The technological system's relationship to the length, location, and boundaries between its current phase of life and the life cycles of other connected technical systems must all be considered before establishing the system border[60, 61].

2.5 Choice of LCA Technique

The next step in the procedure is to decide which approach will be utilized to do the LCA. This phase follows the system boundary definition right after it. There are now many different approaches to impact assessment, and each has a special relevance of its own; therefore, the approach to impact assessment needs to be carefully considered in relation to the region that is being protected[61, 62].

2.6 Impact Categories

The impact categories list the potential environmental effects of a process or product at different phases of its life cycle, as well as those resulting from a specific facility's operation. An extensive amount of data is obtained on emissions throughout the LCA. These consist of emissions from the generation of raw materials, energy, waste, and so forth[63, 64]. Because the emissions created during the extraction of raw materials differ greatly from the emissions produced during the generation of energy, these emissions can take on a wide range of shapes and configurations. This has the effect of combining several distinct environmental effects into a single overall impact under the impact category. Most of the time, the evaluation's life cycle impact assessment technique is followed while selecting the effect categories. In general, emissions are mapped into many endpoint categories (resource depletion, ecosystem health, and human health) after being split into multiple midpoint categories (ozone depletion, global warming, and human toxicity)[65, 66]. 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[67, 68].

2.2.5 Data Acquisition

Several visits and surveys should be carried out to determine the necessary data and to have a better understanding of the process on which LCA will be performed before beginning analysis and data gathering [69, 70].

2.2.6 Assumed Data

Each assumption about the product or process under analysis should be included in the definition of the aim and scope. The assumptions may concern several things, including the system's limitations, assessment techniques, input data, and the inclusion or elimination of life cycle phases[64, 71].

2.7 Inventory Analysis

The LCA, a comprehensive process that accounts for the environmental burdens during a product's life cycle, includes the Life Cycle Inventory Analysis (LCIA)[72]. Inventory analysis is a methodical, objective, and step-by-step approach for calculating the amount of energy and raw materials needed, as well as the emissions into the atmosphere, water, solid waste, and other sources, during a product's whole life cycle, packaging process, material, or activity. The goal of the LCIA method is to quantify the inputs and outputs of a product system through data collecting and computation. The resources used as well as releases into the air, water, or land are examples of these inputs and outputs[73]. The fundamentals of inventory computation are simple, but the process of collecting the necessary data may require a significant amount of effort. Modem 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. Most primary data is obtained directly, such as through in-person interviews, factory data verification, and site visits[74]. Secondary data originates from a variety of sources, including databases, surveys, and prior research[75, 76].

2.8 Phase of Impact Assessment

The aim of impact assessment is to evaluate the extent and importance of the environmental impacts that were measured during the inventory stage. The classification of emissions into multiple intermediate effect categories is the first of several discrete steps that make up this phase. After that, these are further connected to the endpoint to provide a thorough picture of the effects related to any procedure or product, as was previously said[77, 78]. The Life Cycle Impact Assessment process involves grouping similar LCIA outcomes with similar effects into an intermediate level called the midpoint impact category[79]. 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[80]. 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[81, 82].

2.9 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[83].

2.10 Additional LCA Procedures

Apart from the four fundamental stages of LCA, there exist three supplementary alternative procedures that may augment the understanding of environmental impacts. To improve comprehension of the extent of the harm, a normalization process is carried out that gives the impacts per functional unit in proportion to the overall effects in a certain impact category. Standardizing the damage indicators is often preferable to concentrating on intermediate effects[84]. 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[85]. During the weighing stage, based on 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 [86, 87].

2.11 Impact Assessment Phase

Emissions are classified according to their corresponding compartments using the critical volumes method, one of the early techniques in LCA[88]. The analysis of the effects of emissions was first done by the CML (Centrum voor Milieukunde Leiden) 92 method, which also set the stage for several other advancements[89]. For a while, the CML 92 method was very popular in Europe. After being modified to fit the CML 2002 approach, the guidebook on LCA was created. It is a detailed manual that offers detailed directions for performing LCA in a methodical manner[65, 79].

2.12 Software Packages for LCA

LCA is a widely used method to assess how a process, product, or facility will affect the environment. It has been acknowledged over time as a flexible technique with a variety of applications, including improving processes and/or goods, putting environmental labeling into place, and assessing regulations[90]. Owing to its broad acceptance and multitude of uses, several software packages for LCA have been developed to aid in the process. These tools or software have been widely accepted and utilized by seasoned LCA practitioners and users[91]. I'll give a brief overview of two popular LCA software packages below.

2.13 SimaPro

SimaPro is a software program that PReConsultants created and distributed in the Netherlands in 1990. Modeling and evaluating product systems are two uses for it. A software program called SimaPro collects, analyzes, and ratings data about how well various goods, processes, and services work[92]. This software program has many applications, such as building items and processes, gathering information on long-term viability, and evaluating environmental and carbon footprints. It's not restricted to these applications, though. Comprehensive access to several online databases and unit activities is another benefit of SimaPro. This function is especially helpful for doing environmental analyses and pinpointing important regions where there are adverse environmental effects[93].

2.14 GaBi

GaBi is a software tool used for process and product system modeling and evaluation. It was developed and published in 1992 by PE International, a German organization. The GaBi software package, like SimaPro, has several uses, such as life cycle assessment, life cycle pricing, functioning condition analysis over a product's life cycle, and the creation of thorough life cycle reports. It also has often updated content databases that include comprehensive details about the items being researched, including price, energy usage, and environmental impact. By streamlining decision-making procedures, GaBi's capabilities help to improve the sustainability performance of products[94, 95].

2.15 Overview of Marble Manufacturing

The conventional methods and techniques employed in the process have resulted in an underdeveloped marble industry in Pakistan, which faces numerous challenges from the beginning stages of extraction at the quarry to the final product. The most important aspect determining the quality of the marble product during the pre-manufacturing phase is the extraction procedure. In a quarry, there are typically two methods used to harvest marble: mechanized and non-mechanized[96]. The following sections will cover the literature related to mechanized and non-mechanized methods of marble manufacturing.

2.16 Mechanized Marble Manufacturing

Pakistan possesses an abundance of various natural resources and minerals, including but not limited to marble, gypsum, silica, iron ore, rock salt, silver, diamonds, copper, coal, graphite, charcoal, and fire clay. The marble industry in Pakistan made a significant contribution to the country's GDP. The process begins with the selection of raw material from deposits based on the desired physical properties of the finished product, such as color, texture, and hardness. Both mechanized and non-mechanized techniques are used to extract the raw material in the form of blocks or boulders, which are then transported to the processing industry where they are cut and sized into finished products with specific dimensions[96, 97]. When marble is extracted through mechanized method and manufactured using mechanical techniques, it is first quarried using drilling and blasting[98], then it is cut with gang saws or diamond wire saws, and finally it is transported to a processing facility[99]. The blocks are cut into slabs there using automated gang saws or crosscut saws. The slabs are then polished and calibrated for consistent thickness using automated polishing machines, and various finishing procedures are applied using mechanized equipment. Marble blocks and other items are moved throughout the process by loaders and transporters[100], while CNC machines carry out the complex cutting and shaping. High-quality marble products are produced for a variety of uses, from building to ornamental elements, thanks to this automated method, which also lowers labor costs and improves safety conditions[101, 102]. it is obvious that the mechanized method is far better than the non-mechanized but due to the huge number of machinery and capital requirements, very few entrepreneurs are willing to invest because the market is too competitive[103]. The schematic shown in Figure 2.3 is taken during a site (quarry) visit for data collection in Bemboka which is in Buner Khyber-Pakhtunkhwa. Furthermore, there are two more categories that are mainly concerned with economic and environmental perspectives which are total embodied energy and material waste the values for mechanized tiles are 886 MJ/ton and 2.8 tons respectively[104]. The majority of Pakistan's marble reserves are found in Khyber Pakhtunkhwa (KPK), primarily in the regions of Mohammad, Swabi, Nowshera, Buner, Mardan, and Malakand[105, 106]. Researchers claim that although the province produces some of the best and purest grades of marble products, the business is unable to meet demand from the domestic and global markets because of outdated technology and processes in the quarry phase[107]. According to estimates, almost 85% of the trash generated during the

Figure 2-4: Mechanized Marble Extraction

marble extraction process exceeds the international standard of 45 percent. The mining industry is looking for quicker and less expensive ways to extract minerals because of rising profit margins and demand from global markets [108].

2.17 Non-Mechanized Marble Manufacturing

Marble blocks are manually extracted from the quarry site using hand tools such chisels, hammers, and wedges as part of non-mechanized marble extraction and production processes[109]. After that, the blocks are brought to a workshop where knowledgeable craftspeople shape, polish, and cut the marble into the necessary shapes using hand saws, chisels, and abrasives. To smooth the marble's surface, the process uses manual labor and age-old methods including hand-carving, scratching, and rubbing. This typically produces one-of-a-kind, handcrafted goods with a particular personality. This time-consuming method, which calls for exceptional talent and workmanship, is frequently utilized for specialized or custom marble work where the human touch is needed, such as sculpture, architectural details, or decorative components[110]. The mechanized marble is extracted from the quarry by a wire saw which cut the marble block to a specified dimension which is more efficient in material as compared to non-mechanized and has better safety comparatively, meanwhile, non-mechanized marble extraction is extracted from the quarry by old conventional method blasting consequentially it causes noise pollution, material waste, and workers injuries usually and death occasionally[111, 112]. The schematic shown in Figure 2.4 picture has been taken during a visit for collecting data in Bemboka Buner Khyber-Pakhtunkhwa. For non-mechanized marble tiles, the corresponding values of total embodied energy and material waste are 1026 MJ/ton and 0.25 ton respectively. This comparison shows that in each category the non-mechanized marble has more environmental, social, and economic flaws than mechanized marble tiles which concludes to make a shift towards mechanized marble tiles. It is evident that marble manufacturing is an energy intensive process so installing solar panels would reduce the environmental burden. Pakistan energy max is comprised of 60% fossil fuel which contribute to huge environmental pollution[10, 113].

Figure 2-5: Non-Mechanized Marble Extraction

2.18 Summary

This is the first LCA study for two different extraction techniques in Pakistan which shows the economic and environmental aspects of both processes. It shows that the non-mechanized technique is less efficient compared to the mechanized technique, there is enormous material loss that occurred in the non-mechanized marble extraction technique comparatively. The non-mechanized method is adopted due to less machine installation and little cost-benefit but on the other hand causes huge material loss, which is also economic loss and furthermore polluting the environment, the material waste further continues down the line in cutting and shaping causing more material waste. There are approximately 2.8 tons of material waste per ton of useful product gain which means more machining and energy loss. The social aspect of this method is alarming each year dozens of people die due to mine sliding, unsafe blasting, and poor safety. The technological difference between these techniques causes a significant loss of energy. It reveals that marble manufacturing is an energy-intensive process. Additionally, the grid energy used for cutting is 60% fuel-based which emits hazardous gases to the environment, therefore solar panels are recommended to mitigate the greenhouse effects. Marble is a useful material for buildings and quite usual in modern-day architecture and Pakistan exports nearly 2% of world marble with 90% country's need which is colossal, district Buner has 50 quarries in a small area.

Table 1: Literature Findings

Sr No.	Description	Results	Limitations
1.	The main objective of this paper is to analyze the sustainability of the marble sector in Buner , Pakistan. The study aims to assess ‘the environmental, economic, and social impacts of marble extraction and processing in the region, and to explore ways to make the sector more sustainable	The ‘study finds that marble mining and processing in Buner have significant environmental impacts, including deforestation, soil erosion, water pollution, and loss of biodiversity .	The study is limited by the availability and quality of data, particularly about environmental and social impacts. The paper does not include a long-term assessment of the sustainability trends in the marble sector, which could have provided more comprehensive insights.

2.	The main objective of the paper is to evaluate the physical and mechanical properties of Buner marble from Pakistan to assess its suitability for use in construction. The study aims to provide a detailed characterization of the marble in terms of its strength, durability, and overall performance in various construction applications	The study provides data on the marble's density, porosity, and water absorption. These properties are crucial in determining the marble's durability and performance in different environmental conditions. The paper reports on the compressive strength, flexural strength, and other mechanical parameters of the marble. These results indicate the marble's ability to withstand various loads	The study focuses on marble samples from a specific region (Buner, Pakistan), which may limit the generalizability of the findings to other types of marble or regions.
3.	The main objective of the paper by Liguori, Rizzo, and Traverso is to analyze the environmental impact of marble quarrying, focusing on the energy consumption and waste generation associated with this activity. The study aims to provide insights into the inefficiencies and environmental concerns of marble production, particularly in terms of resource use and waste management	The paper highlights that marble quarrying is a highly energy-intensive process. The extraction and processing of marble consume significant amounts of energy, leading to considerable environmental impact. The study finds that marble quarrying generates substantial amounts of waste, including marble dust and slurry, which pose environmental challenges. The paper quantifies the waste produced and discusses its potential effects on the environment.	The study is based on data from specific quarries, which may not be representative of all marble quarrying activities. This limits the generalizability of the findings to other regions or types of quarries.

4.	To analyze and evaluate the environmental impact of marble mining activities, with a specific focus on a marble quarry in Sicily, Italy. The study aims to identify the key environmental concerns associated with marble extraction, assess the sustainability of the quarry's operations, and propose measures to mitigate adverse environmental effects.	The research may have employed a Life Cycle Analysis approach to quantify the environmental burdens of the quarrying process, including energy consumption, carbon footprint, and resource depletion.	Findings might be specific to the Sicilian marble quarry and may not be directly applicable to other marble quarries or different mining contexts.
5.	The main objective of the paper is to analyze the stone and marble industry focusing on its sustainability and environmental impact. The study aims to explore ways to make the sector more environmentally friendly while maintaining economic viability. The authors seek to identify the challenges and opportunities for sustainable development in this important industrial sector.	The paper suggests that implementing sustainability practices, such as waste recycling, water management, and cleaner production techniques, could mitigate some of the environmental impacts. The adoption of these practices would also enhance the sector's competitiveness.	The study notes limitations in the availability and accuracy of data related to the environmental impacts of the stone and marble sector. This affects the ability to conduct a comprehensive environmental impact assessment.
6.	The main objective of the paper by Akbulut and Gürer (2007) is to investigate the feasibility of using aggregates produced from marble quarry waste as a material in asphalt pavements. The study aims to determine whether these waste materials can be a suitable and sustainable alternative to conventional aggregates, potentially reducing environmental impacts associated with waste disposal and the extraction of natural aggregates.	The study found that marble quarry waste has acceptable physical and mechanical properties that are comparable to those of conventional aggregates used in asphalt mixtures.	The results are specific to the characteristics of the marble waste from the particular quarries studied, and the findings may not be directly applicable to other regions with different types of marble waste.

7.	The main objective is to investigate the environmental and occupational health impacts caused by marble industries in District Mardan, Pakistan. Specifically, the study focuses on water pollution resulting from the marble industry's activities and assesses the associated health hazards faced by workers in these industries.	The study found significant levels of water pollution in areas surrounding the marble industries. The pollutants included high concentrations of heavy metals and other harmful chemicals that exceeded permissible limits set by environmental standards	The study is limited to District Mardan in Pakistan, and the findings may not be directly applicable to other regions with different environmental conditions and industrial practices.

2.19 Overview of Literature review

The LCA concept was presented in this chapter along with an analysis of previous studies on LCA related to the production of marble manufacturing through mechanized and non-mechanized methods. The chapter's conclusions highlighted areas for future research, how LCA tools are used in the manufacturing of marble 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 the marble industry is that developed European countries are the main users of LCA for environmental impact assessments. This analysis leads us to do a comprehensive environmental impact assessment of the marble manufacturing sector and compare mechanized and non-mechanized methods in Pakistan.

CHAPTER 3. RESEARCH METHODOLOGY

The LCA methods was discussed in the last chapter 2 in detail with all the included phases. For this research study, the comprehensive LCA of mechanized and non-mechanized marble manufacturing has been carried out in the respective districts of Khyber Pakhtunkhwa Province. Three Major producers of marble in the region are being selected: Buner, Mohmand, and Malakand.

3.1 Marble Manufacturing Industries: Selected for Study

A set of marble manufacturing industries situated in three districts (Buner, Mohmand, and Malakand) of Khyber Pakhtunkhwa Pakistan were selected for this study by their consent. However, the name and the information regarding industries are not discussed here due to confidential agreements. The goal and scope are then determined to determine the environmental impacts associated with the current fabrication methods of the industries . After these 4 more potential alternatives after discussing their feasibility of them with the plant manager were also evaluated based on an environmental and economic basis. The methods for extracting marble involved using the minute fissures that separate the various layers of the stone with caution. The marble blocks were effortlessly separated from the mountain by hand-operated workers utilizing iron chisels and water-inflated wooden wedges that were inserted into the natural fissures. Due to the abundance of unskilled labor and available labor, this was made possible. The use of explosives and non-mechanized approach during the excavation process resulted in significant debris buildups around 70%, which saw a significant loss of marble products as a result of the explosions. Additionally, the mechanized extraction process replaced explosives nearly entirely and produced another noticeable shift in the environment by using helicoidal wire, a metallic cable that could be used to dig out the marble stone. The mountain was actually "cut," molded with precision, and ceased being demolished, leaving behind piles of debris. This resulted in bizarre landscapes composed of enormous flights of steps and platforms known as quarry warehouses, where the stone is cut and ready for transportation.

Today's production is more technologically advanced, and its life cycle mostly consists of the quarry extraction process, finishing operations including smoothing, polishing, and finishing, as well as the activities related to shipping and sale.

3.2 Goal and Scope Definition

This study's primary objective was to evaluate the environmental effects of the mechanized and non-mechanized marble industries manufacturing. 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. Mechanized and non-Mechanized limestone (Marble) are sold by the designated manufacturing facility based on product amount. The average production is around 950 Ton of marble were produced on average per month, using 24 kwh of electricity. Therefore, a functional unit of 1 ton Limestone (Marble) was chosen for better understanding. The scope (in terms of system boundary) of this study was cradle-to-gate (starting from the acquisition of limestone marble to the production of marble in finished form). 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.

3.3 Life Cycle Inventory Analysis

Several visits during March, April and June 2022 were done to understand every process separately and to get the required data for the analysis. To prepare life cycle inventory of mechanized and non-mechanized marble extraction processes primary data were collected every 2 months for 6 months long the data is shown in Table 2. Quarry marble is extracted from the quarries using different techniques depending on the rock quality and availability. First, a big piece of marble is cut from the mountain either by blasting or wire saw. Usually blasting is more common but some quarries use a wire-cutting technique that uses diamond wire with coolant water. The removal of cut marble is moved by the excavator and loader to the truck for further operations. The raw block is dispatched to the cutting facility where the finishing facility also exists. ‘Concerning the quarry operations, we considered all different types of energy consumption (energy, diesel oil,) for each step of the marble manufacturing (extraction and squaring phases).

Two different kinds of solid waste are generated in the quarry. The spoils come from the quarry when a big block of marble is extracted from the mountain. It is difficult to precisely control the block to remove from the mountain a huge amount of material is lost. Other solid waste like sludge is generated when the block is undergoing for square shape, fine solid particle mixes with

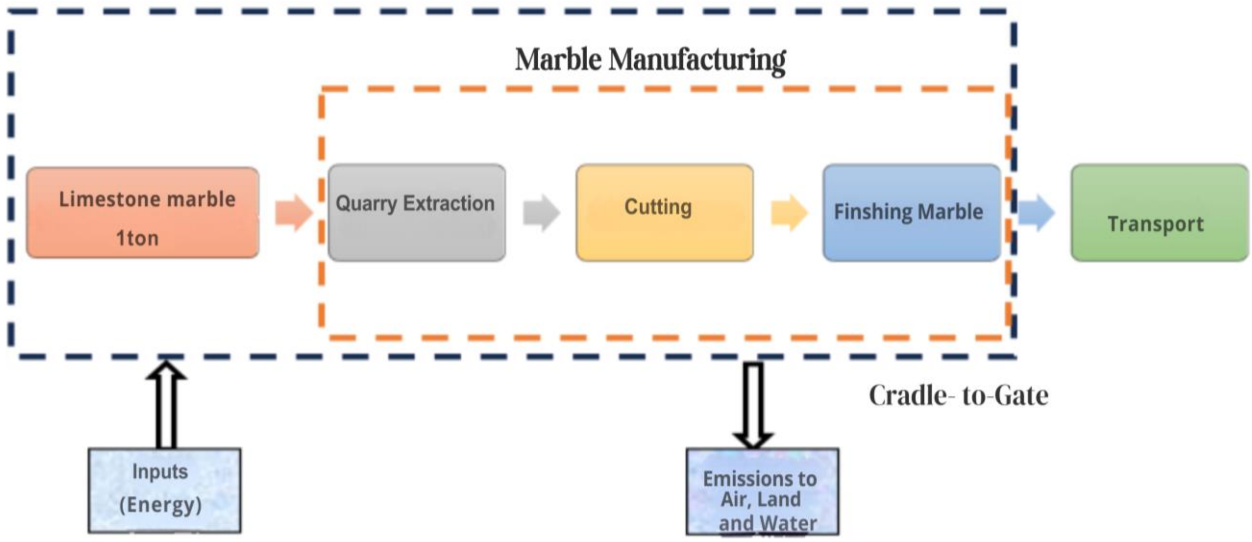

Figure 3-1: Scope of the study

water forming a solid paste it is also found in mechanized technique due to wire cutting with water as a coolant.

This data is collected for entire manufacturing plant starting from quarry to cutting units and manufacturing. It is known that there are two methods for extraction of marble blocks namely mechanized and non-mechanized blocks. Extraction of non-mechanized marble happens by drilling holes in rocks and then it is filled with gun powder to blast, after blasting the extracted material is carefully inspected to sift crack material aside and useful material for further processing. The energy requirements reportedly depend on the geology and blasting procedure but the technical staff told approximately two to four liters of diesel equivalent energy is consumed which mainly include excavator, loader and drilling machining. However, the mechanized quarry works on wire cutting technique initially three holes are drilled perpendicular to each other for wire installation. The mechanized marble blocks require 12-litre diesel oil per ton marble which is comparatively more than non-mechanized marble blocks, but the environmental social and material resource aspects of mechanized marbles are extremely beneficial furthermore one other downside of mechanized marble is water consumption the wire cutting requires continuous water for cooling and dust removal. The cutting phase consists of two processes initially the block is cut down into slabs and next it is polished to obtain a fine surface. The above tables 3 shows the statistical data of the Manufacturing unit of marble manufacturing.

Table 2: Inventory data for mechanized and non-mechanized marble

Block Type	Drilling Diesel	Extraction Power	Water Usage	Shaping Electricity	Loading Transportation	Material waste
Mechanized	1.13litre	15.5 KWH	1000litre	0	5.3tkm	25%
Non-Mechanized	0.14litre	0KWH	0	7.5 KWH	11.3tkm	70%

*This data is calculated for one ton of marble block extraction.

As shown in Table 3 `the data shows non-mechanized marble consumes twice the power as mechanized marble because of cutting an extra 30 to 40% of materials, the Gangsaw machine requires a square or rectangular block shape marble block, so they have to precut the boulder to that shape, hence requiring more power. The water consumption is the same for both mechanized and non-mechanized marble manufacturing, but the consumption happens at different phases, for example, non-mechanized marble uses water in the cutting phase, and it is not recyclable while mechanized marble consumes water in the quarrying phase, and it too is not recyclable, so the water consumption is equivalent in both techniques. The wastewater causes huge environmental issues especially aquatic and agricultural, furthermore, there is material waste which causes huge landfills or dumps imagine 70% of the material is going to waste at each extraction despite the authorities warning they are using the same blasting technique, while mechanized block extraction has a total of 25% waste which is way less than the non-mechanized block extraction. During wastewater recycling the mechanized block manufacturing facility recovers the calcium carbonate in powder form from cooling water while the non-mechanized block manufacturing lacks that facility due to fewer resources of the owner or simply ignorance.

3.4 Life Cycle Impact Assessment

Now to conduct a lifecycle assessment of mechanized vs non-mechanized marble manufacturing we need a functional framework where each process is evaluated carefully so that there is no missing data of sub-processes. marble manufacturing starts from the quarry, initial marble block is extracted that consists of various processes like drilling, blasting, wire saw cutting and transportation from quarry to the manufacturing facility. Blasting and wire saw cutting are two

Table 3: Statistical data for marble manufacturing

Factory Type	Cutting Power	Water Usage	Material waste	Slurry Recovery	Functional Unit (FU)
Mechanized Marble Slabs	83 Kwh	(10lit/FU) R*	410kg/FU	100%	1Tonne
Non-Mechanized Marble Slabs	94 Kwh	10litre/FU	50kg/FU	20%	1Tonne

* This symbol indicates the reusing of an element or process.

Table 4: Emission factors of used fuel: Electricity and Diesel

Emission factors (g/MJ)	CO_2	NO_x	SO_2	CO	HC	Particulate	VOC
Electricity	200.5	0.2	0.52	0.19	0.002	0.38	NA
Diesel	74	0.79	0.02	0.20	0.002	0.06	0.210

different techniques which got their name from their processing techniques, so we have to categorize these two processes separately and put energy consumption, water usage and transportation in each process separately and then define each sub-cutting process for both techniques. When conducting the final comparison, the mechanized marble block process would be input material for finished mechanized marble slabs or products similarly it would be same for non-mechanized marble slabs or products. After defining each process and putting the relevant data into each block it is ready for the conclusion the method used is the European recipe endpoint method which is commonly used for environmental and economic analysis.

The following diagram shown in Figure 3.2 the methodology of the lifecycle assessment of marble manufacturing through both processes.

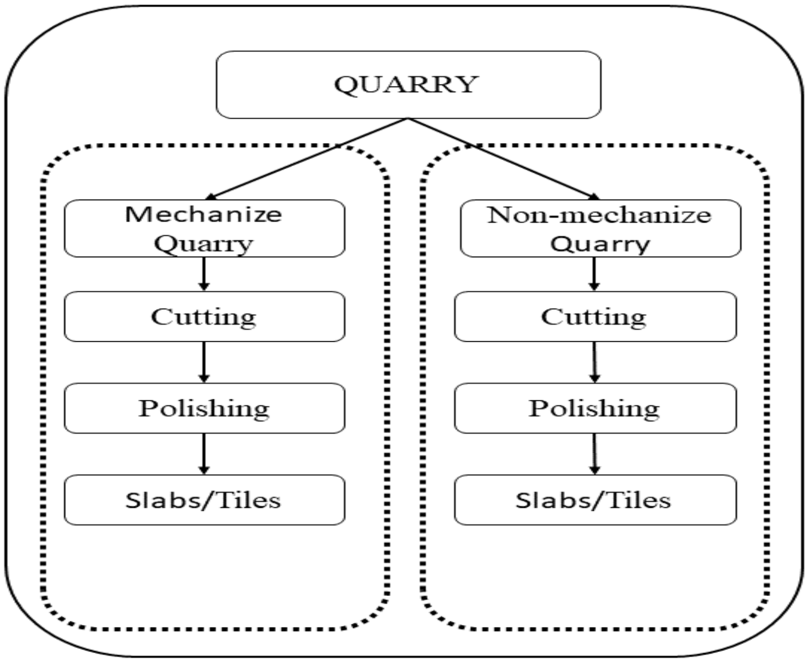

Figure 3-2: Life Cycle Assessment

3.5 Summary of chapter

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. Tables 3.1, 3.2, and 3.3 quantifies the data according to 1 functional unit. The complete methodology used for the study is also depicted in Figure 3.3. The results obtained from the analysis are discussed in the next chapter**.** The wastewater causes huge environmental issues especially aquatic and agricultural, furthermore, there is material waste which causes huge landfills or dumps imagine 70% of the material is going to waste at each extraction despite the authorities warning they are using the same blasting technique, while mechanized block extraction has a total of 25% waste which is way less than the non-mechanized block extraction.

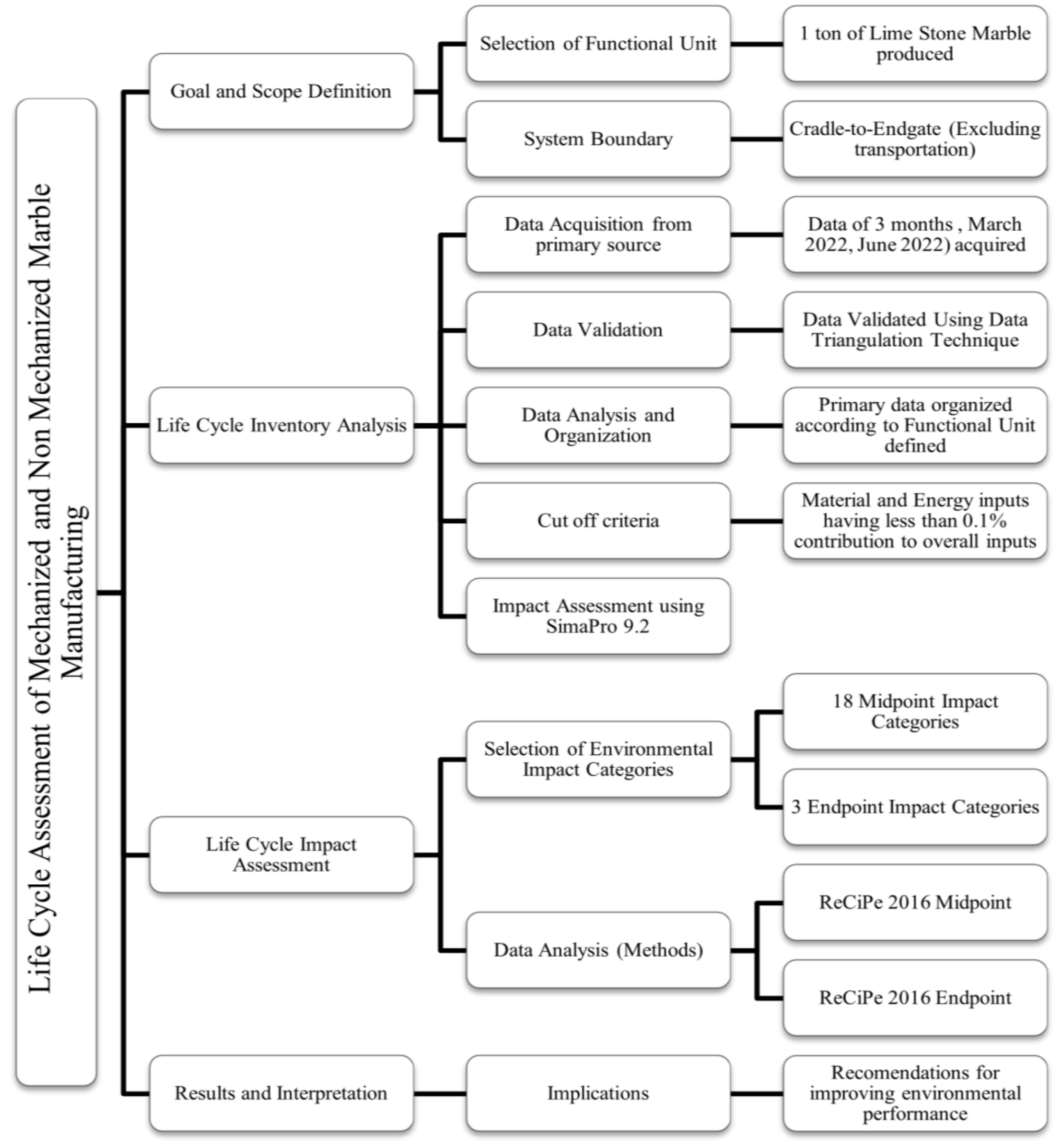

Figure 3-3: Complete methodology Flowchart

CHAPTER 4. DISCUSSION

This chapter presents a detailed analysis of the environmental impacts associated with the manufacturing process of the selected marble manufacturing industry. Initially, the impacts associated with the mechanized and non-mechanized marble manufacturing currently implemented in the industry are evaluated.

4.1 Baseline Scenario-Mechanized Marble Manufacturing

Table 4.1 depicts the impact scores of each impact category associated with each process of mechanized marble manufacturing in the selected manufacturing industry. Results showed that global warming and ecotoxicity were the most affected impact categories. For validation purposes, the data was also collected from all related industry studies that evaluated the environmental impacts. The finishing and polishing step of marble mechanized manufacturing is identified in this study as the primary environmental hotspot, with greater environmental implications than most other phases. For 1 ton of marble via mechanized way, the global warming value was calculated to be 64.2315554 g CO2 equivalent. It was 16.66725 kg CO2 equivalent for during the quarry extraction phases for 1 ton of marble. The effects of global warming were, however, far greater in our investigation, with 64.231 kg CO2 equivalent for 20.643631 kg were produced through quarry cutting. 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 technology.

The graphical representation of data presented in Table 4.1is 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 marble manufacturing. The Figure 4.1 clearly shows that the mechanized marble manufacturing 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. The main reason behind most of the mid point categories increase is diesel generator usage. The generator used for electricity generation during mechanized quarry extraction is (250 KVA) which consumes 10 liters per hour diesel consequently increasing mid-point categories. During operation generator is at 50% load with 0.8 Power factor.

Table 4.1: Results at the Midpoint level for the mechanized production system

Impact category	**Unit**	**Total**	**Quarry Extraction**	**Quarry Cutting**	**Polished Finish Marble**
Global warming	kg CO_2 eq	64.2315554	16.66725	20.643631	26.900054
Stratospheric ozone depletion	kg CFC11 eq	3.096E-9	5.8889178E-6	2.21027 E-7	3088516E-6
Ionizing radiation	kBq CO-60 eq	0.72617809	0.03339841	0.16685937	0.52592999
Ozone formation, Human health	kg NO_x eq	0.972122	0.060898245	0.07672868	0.083450126
Fine particulate matter formation	kg PM2.5 eq	0.2587888	0.011193463	0.0133999	0.01361920
Ozone formation Terrestrial ecosystems	kg NO_xeq	1.02766	0.06406491	0.080699336	0.08828961
Terrestrial acidification	kg SO_2eq	0.129529	0.03608155	0.044465851	0.048858044
Freshwater eutrophication	kg P eq	0.0025517	0.00052809	0.000867272	0.00119171
Marine Eutrophication	kg N eq	0.00053289	0.00012628	0.000177637	0.000236521
Terrestrial ecotoxicity	kg 1,4-CB	170.44L	30.22717	68.401358	71.813051
Ecotoxicity	kg 1,4-DCB	0.456564	0.098741246	0.17693911	0.18998392

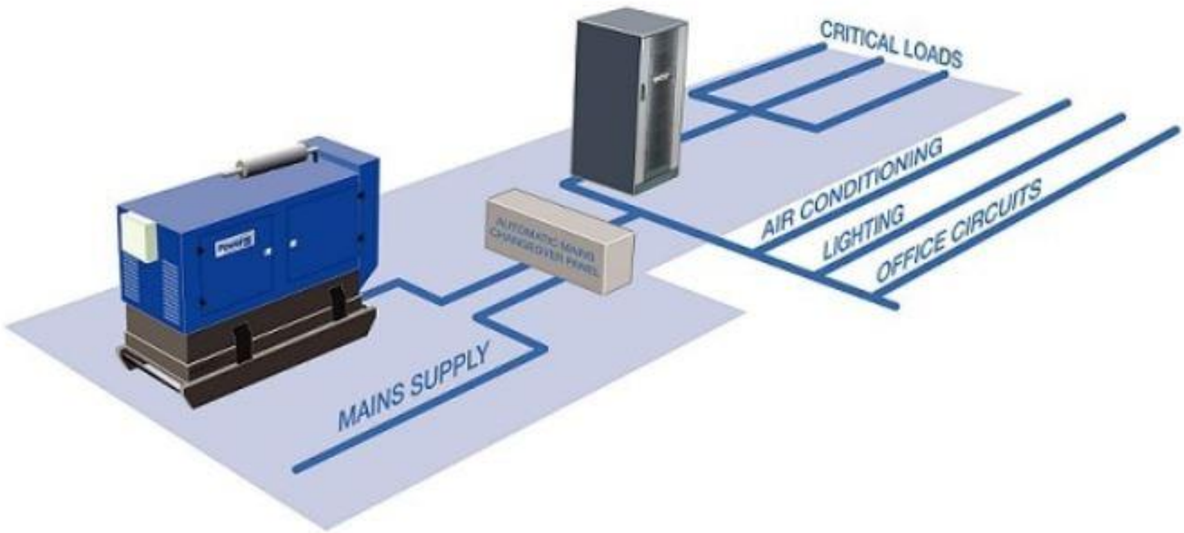

Figure 4-1: Diesel Power Generation and Distribution (Caterpillar D250 GC)

Figure 4.1 and Table 4.1 clearly shows that marble manufacturing comes out to be the most energy extensive process among all the processes presents in manufacturing phase . By all this discussion, graphs and table, it can easily be said that mechanized marble manufacturing as the most energy extensive process contributes most to environmental impacts due to this high energy consumption and the nature of manufacturing process. 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.

If we consider other processes, quarry extraction, cutting and finishing processes have prime impacts on all 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. If quarry extraction, cutting and finishing and polishing are concerned, the impacts associated are Global warming, Terrestrial ecotoxicity and Fossil resourcescarcity. Now if we consider the process of marble manufacturing, this process comes out to be dominant in only 3 categories which are global warming, Terrestrial ecotoxicity, Fossil resource scarcity. The one of the major reasons behind this is the migration nature of limestone. In the meantime, marble in category 1 of the carcinogenic chemicals by IARC experts contribute mainly towards human carcinogenic toxicity. After discussing the processes individually, to get a better understanding of impacts, it is necessary to have an insightful discussion on overall impacts of the whole processes. As depicted in Table 4.1 global warming, terrestrial ecotoxicity and Fossil resource scarcity dominate adverse environmental impacts with the values of 64.2315554 kg Co2 eq and 170.44 kg 1,4-DCB and 19.2570737 kg oil eq respectively. If global warming is concerned it is evident from Table 4.1 that all three processes such as quarry extraction, cutting and finish and polished mechanized manufacturing process are 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. Meanwhile, if we consider the impact category of terrestrial ecotoxicity, cutting and finishing along with polishing processes are the main contributors to this impact category. The usage of electricity and the energy sources mentioned above are substantial contributors to the negative effects on the environment. Therefore, the quarry cutting and finishing and polishing process has less value in the impact category of global warming as compared to terrestrial ecotoxicity. The reason is due to the significant requirements of land and soil for quarry extraction which leads to losses in terms of biodiversity and ecosystem destruction leads to terrestrial ecotoxicity. These findings can be validated by a study carried by National Ready Mixed Concrete Association and Indian Bureau of mines. The results revealed that marble plate production contribution towards terrestrial ecotoxicity is higher as compared to global warming and all other categories as shown in Table 4.1 and Figure 4.1.

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 quarry extraction, cutting and finish and polishing 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

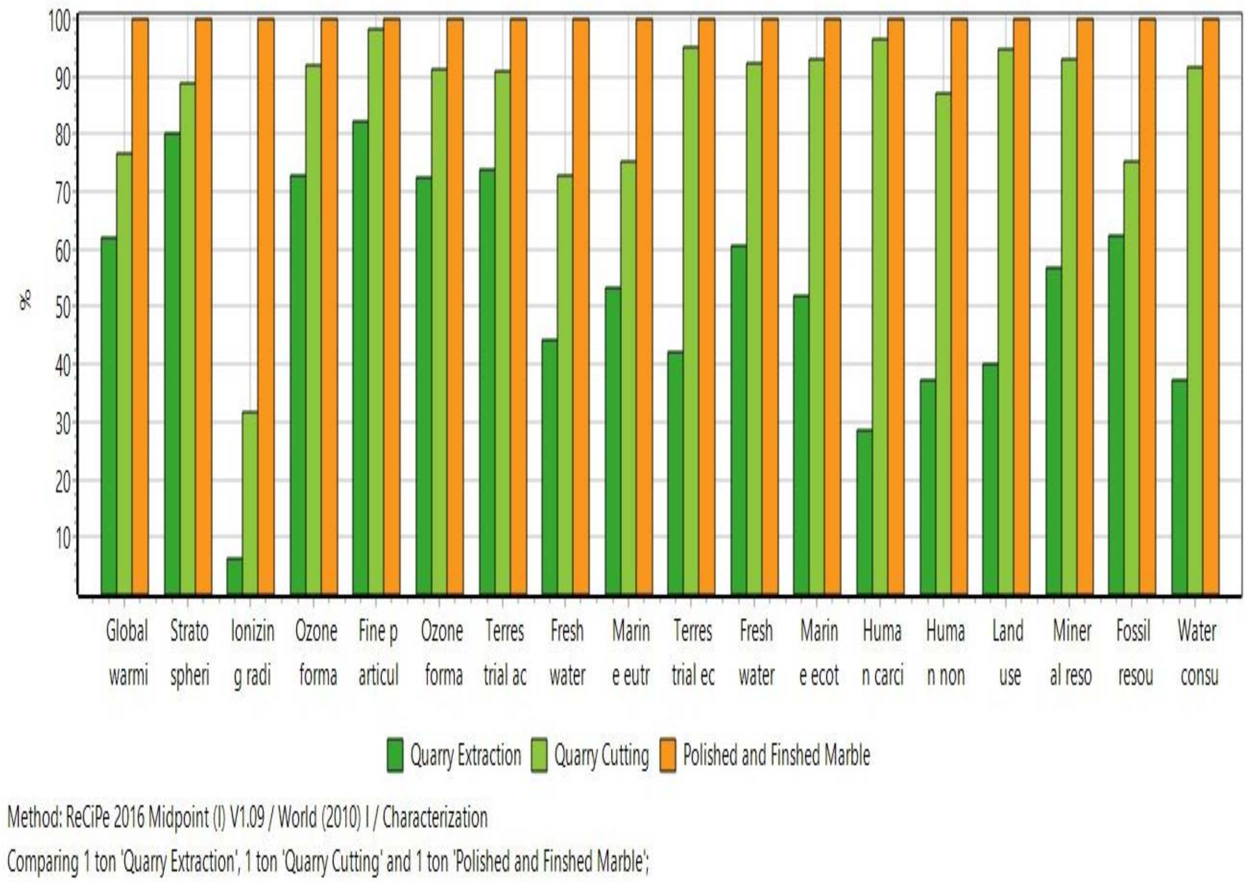

Figure 4-2: Graphical representation of Mechanized Marble (midpoint results).

discussed above. The normalization chart presented in Figure 4.3 is considered as an extra step in LCA which helps to evaluate the relative importance of various impact categories. At midpoint level, the normalization step reveals that human health is the most affected category during our processes. The wastewater causes huge environmental issues especially aquatic and agricultural, furthermore, there is material waste which causes huge landfill or dumps imagine 70% of the material is going to waste at each extraction despite the authorities warning they are using the same blasting technique, while mechanized block extraction has a total of 25% waste which is way less than the non-mechanized block extraction.

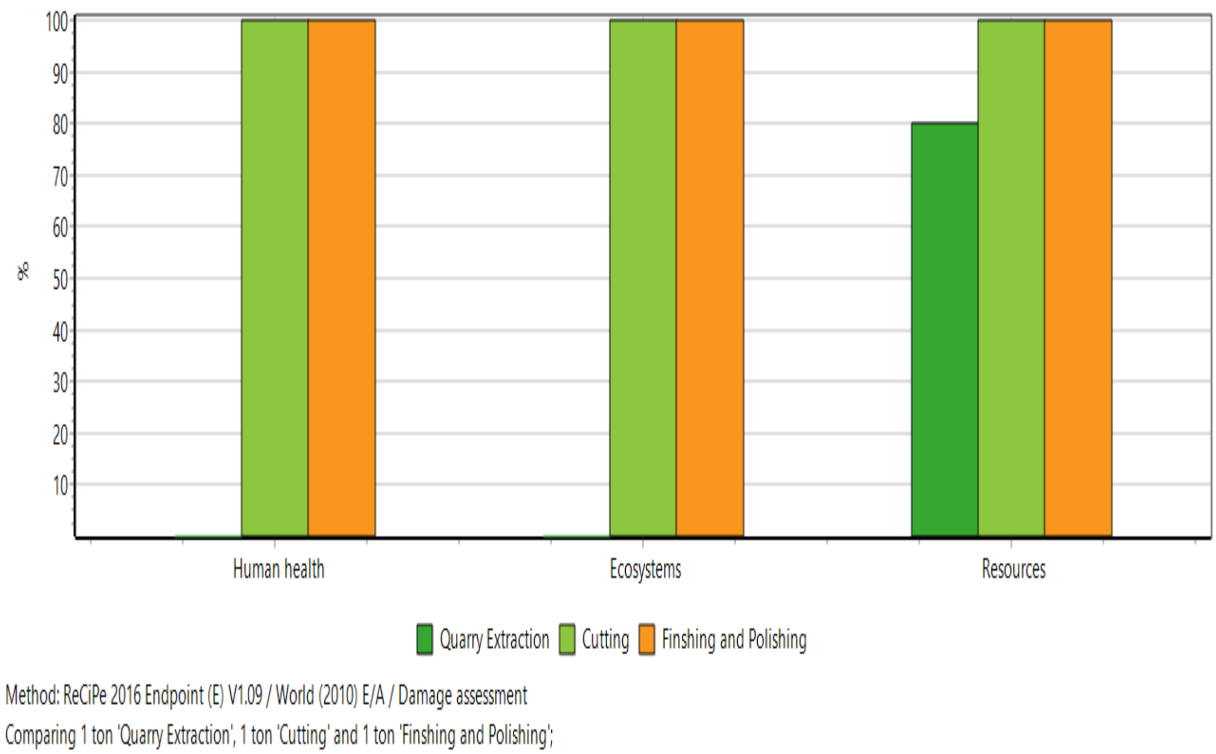

Figure 4-3: Graphical representation of endpoint results.

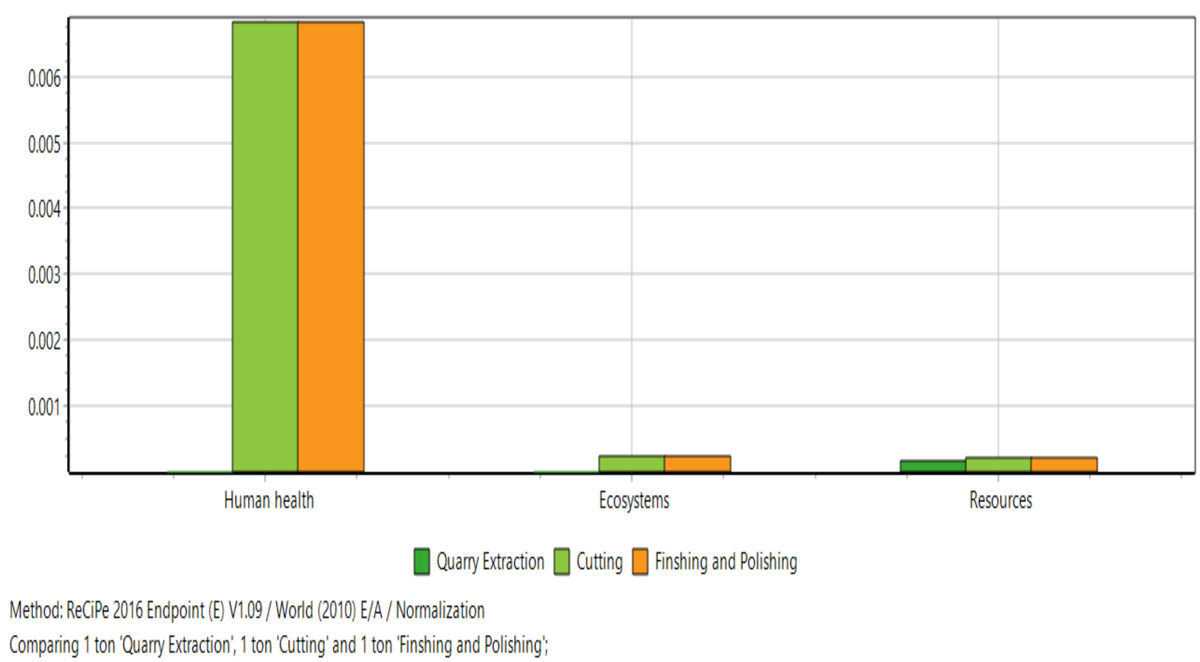

Figure 4-4: Characterization Chart of endpoint results.

Table 4.2: Results at the ReCiPe 2016 Midpoint level for the mechanized production system

Impact category	**Unit**	**Total**	**Quarry Extraction**	**Quarry Cutting**	**Polished Finish Marble**
Global warming	kg CO_2 eq	49.947828	16.66725	14.4505	18.83008
Stratospheric ozone depletion	kg CFC11 eq	3.096E-9	5.8889178E-6	2.21057E-7	30886E-6
Ionizing radiation	kBq CO-60 eq	0.72617809	0.03339841	0.16685937	0.52592999
Ozone formation, Human health	kg NO_x eq	0.972122408	0.060898245	0.07672868	0.083450126
Fine particulate matter formation	kg PM2.5 eq	0.258788885473	0.011193463	0.0133999	0.01361920
Ozone formation, Terrestrial ecosystems	kg NO_x eq	1.027660955	0.064064919	0.08069933	0.08828961
Terrestrial acidification	kg SO_2 eq	0.129529104	0.036081555	0.0444658	0.048858044
Freshwater eutrophication	kg P eq	0.002551770	0.0005280915	0.000867272	0.0011917134
Marine Eutrophication	kg N eq	0.000532891	0.0001262843	0.00017763	0.0002365216

Terrestrial ecotoxicity	kg 1,4-CB	128.369481	30.22717	47.880951	50.269136
Marine ecotoxicity	kg 1,4-DCB	0.45656429	0.098741246	0.17693911	0.18998392
Human carcinogenic toxicity	kg 1,4-DCB	0.00659671293	0.0008358009	0.00282827	0.0029326
Human non-carcinogenic toxicity	kg 1,4-DCB kg 1,4-B	0.538013954	0.89037447	0.20398474	0.23445576
Land use	m^2 a cropeq	0.926296635	0.15755568	0.37423753	0.39450202
Mineral resource scarcity	kg Cu eq	0.0639177446	0.013297856	0.02172746	0.023392395
Fossil resource scarcity''	kg oil eq	14.9936816	5.0444871	4.2743526	5.6757638
Water consumption	m^3	0.290791037	0.0482220	0.118818	0.1297658

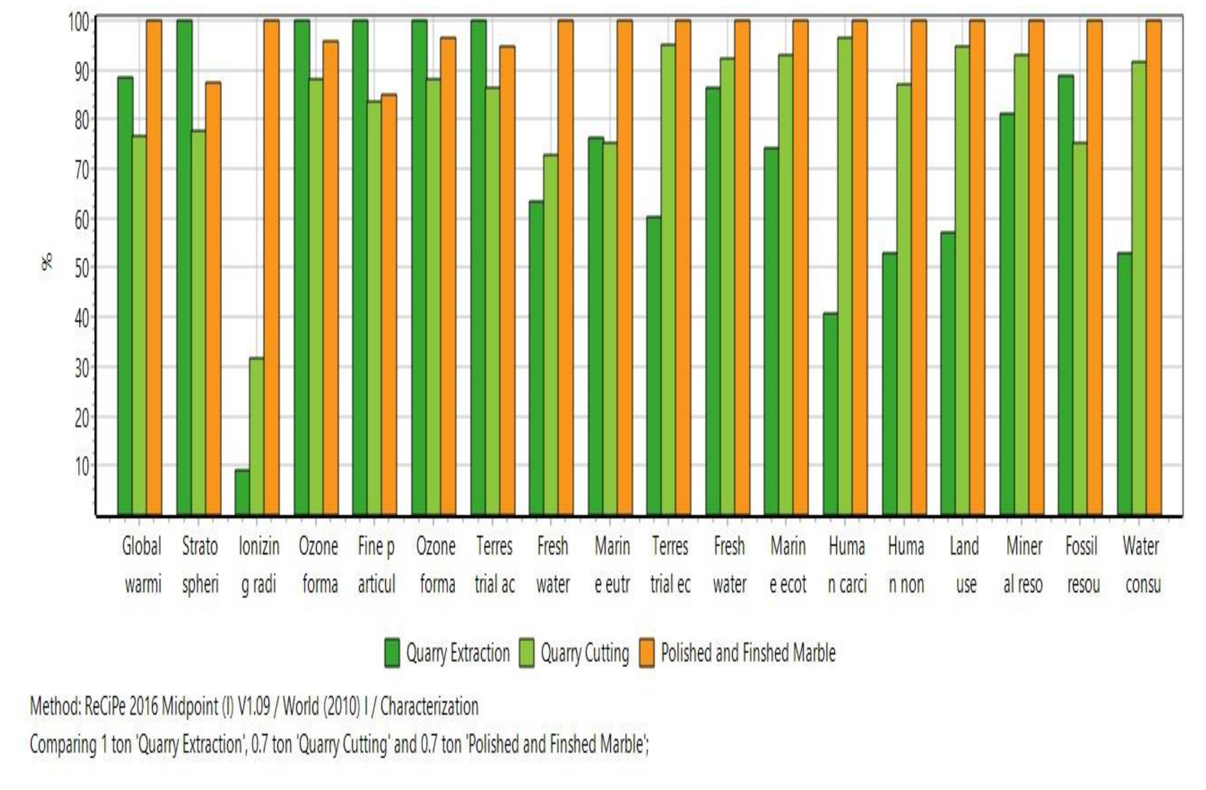

Figure 4-5: Graphical representation of Mechanized Marble midpoint results with 30% Waste

The Figure depicted in schematic 4.4 shows that the same mechanized marble has been manufactured in real case scenarios with 30% waste during extraction of quarry through drilling or other machines such as wire cutting technique (technique initially three holes are drilled perpendicular to each other for wire installation). The impact categories associated with this case scenario are bit lower as compared to the ideal case with no waste products during quarry. The difference can be seen in Tables 4.1 and 4.2. The impact categories most affected are the same but show a bit lower value as compared to the ideal case. As depicted in Table 4.2 global warming terrestrial ecotoxicity and fossil resource scarcity dominate adverse environmental impacts with the values of 49.947828 kg Co2 eq, 128.369481 kg 1,4-DCB and 14.9936816 kg oil eq respectively. If global warming is concerned it is evident from Table 4.2 that quarry extraction, cutting and finish and polishing process are 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. Meanwhile if we consider the impact category of terrestrial ecotoxicity, Quarry extraction, cutting and finish and polishing process along with electricity 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, research done to evaluate the effects of different energy sources found that wind energy is very important for affecting the category of terrestrial ecotoxicity. As far as energy mix of Pakistan is concerned, wind resources are not a major contributor. Therefore, the quarry extraction, cutting and finishing along polish process has higher value in the impact category of terrestrial ecotoxicity as compared to global warming. These findings can be validated by a study carried by National Ready Mixed Concrete Association and Indian Bureau of mines. The results revealed that marble plate production contribution towards terrestrial ecotoxicity is higher as compared to global warming and all other categories as shown in Table 4.2 and Figure 4.4.

The contributions of processes to endpoint indicators are shown in Figure 4.5. The results are almost consistent as in the case of midpoint categories. The quarry extraction, cutting and finish and polishing 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 the process and energy mix as discussed above. If we consider the concerned industries and their manufacturing process, it was observed that one of the major issues associated with the manufacturing process of this facility is maybe the lack of resources or proper guidance. For instance, solar energy facilities can be used in the drilling and cutting along with polishing processes like many other facilities as they are cheaper than the energy mix provided by the local markets and help in production due to shortened lead times.

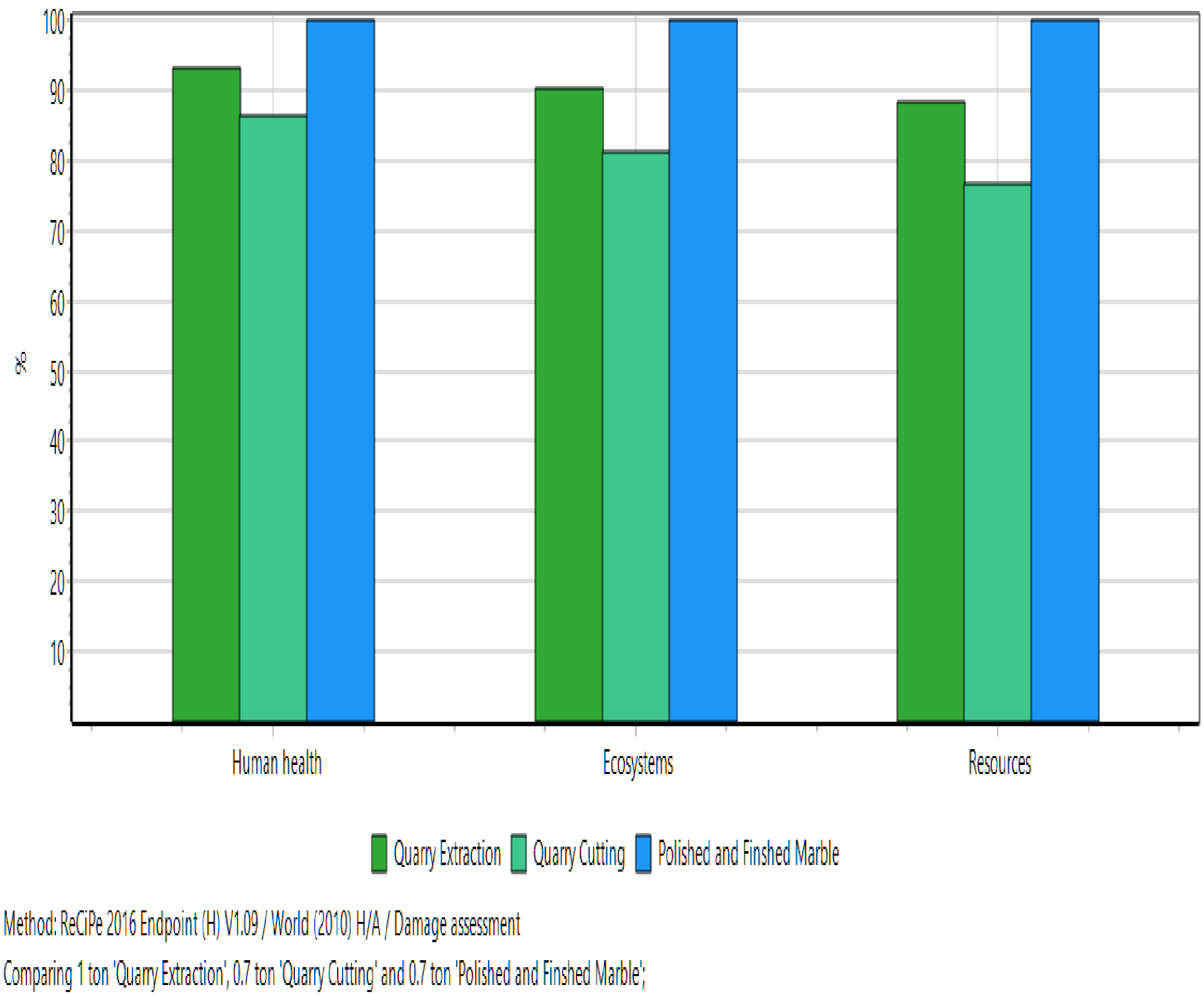

Figure 4-6: Graphical representation of endpoint results with 30% Waste

4.2 Environmental Impact Assessment

If we investigate the previous section, it is obvious that most of the environmental impacts are associated with all three processes 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 industries and their manufacturing process, it was observed that one of the major issues associated with the manufacturing process of this facility is maybe the lack of resources or proper guidance. For instance, solar energy facilities can be used in the drilling and cutting along with polishing processes like many other facilities as they are cheaper than the energy mix provided by the local markets and help in production due to shortened lead times. If solar energy is used, we can produce many marble tones in one manufacturing cycle with no extra energy consumption. However, there may be impacts related to production, but we are concerned with the processes inside the gate-to-gate boundary due to our scope definition.

4.3 Baseline Scenario-Non-Mechanized Marble Manufacturing

The results regarding the process of marble manufacturing through non-mechanized methods are shown in Table 4.3 and Figure 4.6. The general trend for the impact categories is the same as mechanized marble manufacturing in both ideal (no waste) and real with (70% waste) products. The impact categories shown in respective Figures can best predict and conclude the process steps and their contribution in each respective category. Table 4.3 shows almost the same contribution of each process as compared to mechanized with no waste. The values compared in both Table 4.1 & 4.2 show very little difference with no waste for Global warming, Terrestrial ecotoxicity, and Fossil resourcescarcity. The trend is the same for all the rest of the values as well as can be evident from the Figure and table of the respective mechanized marble manufacturing schematics.

Table 4.3: Results at Midpoint Level for Non-Mechanized Production System

Impact category	Unit	Total	Quarry Extraction	Quarry Cutting	Polished Finish Marble
Global warming	kg CO_2eq	60.234555	16.66720051	16.6672500	26.90005448
Stratospheric ozone depletion	kg CFC11 eq	3.096E-9	5.8889178E-6	2.210237 E-7	3088516E-6
Ionizing radiation	kBq CO-60 eq	0.72617809	0.03339841	0.16685937	0.52592999
Ozone formation	kg NO_xeq	0.972122408	0.060898245	0.07672868	0.083450126
Terrestrial ecosystems	kg NO_xeq	1.027660955	0.064064919	0.080699336	0.08828961
Terrestrial acidification	kg SO_2eq	0.129529104	0.036081555	0.044465851	0.048858044
Freshwater eutrophication	kg P eq	0.002551770777	0.00052809155	0.000867272	0.0011917134
Marine Eutrophication	kg N eq	0.000532891	0.00012628436	0.000177637 29	0.00023652168
Terrestrial ecotoxicity	kg 1,4-CB	132.2674	30.22716991	30.22716991	71.81305089
Marine ecotoxicity	kg 1,4-DCB	0.45656429	0.098741246	0.17693911	0.18998392
Human carcinogenic toxicity	kg 1,4-DCB	0.00659671293	0.00083580093	0.002828278	0.002932634

Human non-carcinogenic toxicity	kg 1,4-DCB kg 1,4-B	0.538013954	0.89037447	0.20398474	0.23445576
Land use	m^2 a crop eq	0.926296635	0.15755568	0.37423753	0.39450202
Mineral resource scarcity	kg Cu eq	0.0639177446	0.013297856	0.021727464	0.023392395
Fossil resource scarcity	kg oil eq	18.19721	5.044487078	5.044487078	8.10823404
Water consumption	m^3	0.290791037	0.048222071	0.11881804	0.12976589

Figure 4-7: Graphical representation of Non-Mechanized Marble midpoint.

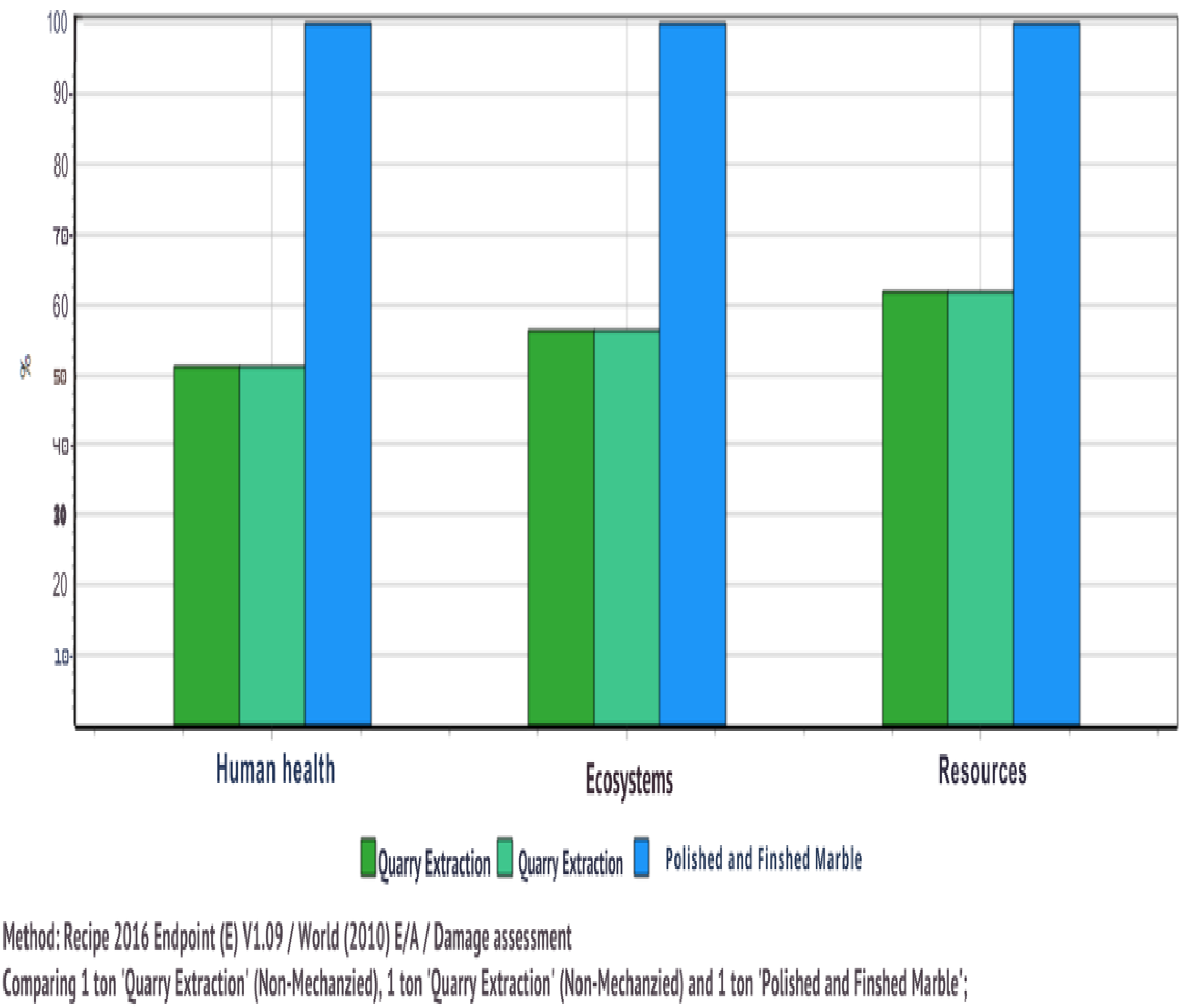

Figure 4-8: Graphical representation of endpoint results.

The contributions of processes to endpoint indicators are shown in Figure 4.7. The results are almost consistent as in the case of midpoint categories. The finish and polishing 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 other two process are also contributed to half of the amount to human health, ecosystem and resources as shown in Figure 4.7

Table 4.4: Results at the ReCiPe 2016 Midpoint level for the non-mechanized production system

Impact category	Unit	Total	Quarry Extraction	Quarry Cutting	Polished Finish Marble
Global warming	kg CO_2 eq	26.15254862	14.09111139	5.242106263	6.819330969
Stratospheric ozone depletion	kg CFC11 eq	3.096E-9	5.8889178E-6	2.2102357E-7	3088516E-6
Ionizing radiation	kBq CO-60 eq	0.72617809	0.03339841	0.16685937	0.52592999
Ozone formation, Human health	kg NO_x eq	0.972122408	0.060898245	0.07672868	0.083450126
Fine particulate matter formation	kg PM2.5 eq	0.258788885473	0.011193463	0.0133999	0.01361920
Ozone formation, Terrestrial ecosystems	kg NO_x eq	1.027660955	0.064064919	0.080699336	0.08828961
Terrestrial acidification	kg SO_2eq	0.129529104	0.036081555	0.044465851	0.048858044
Freshwater eutrophication	kg P eq	0.00255177077755	0.00052809155	0.000867272	0.0011917134
Marine Eutrophication	kg N eq	0.000532891	0.00012628436	0.00017763729	0.00023652168
Terrestrial ecotoxicity	kg 1,4-CB	166.814646	47.880951	68.66269431	49.91558

Marine ecotoxicity	kg 1,4-DCB	0.45656429	0.098741246	0.17693911	0.18998392
Human carcinogenic toxicity	kg 1,4-DCB	0.00659671293	0.00083580093	0.002828278	0.002932634
Human non-carcinogenic toxicity	kg 1,4-DCB kg 1,4-B	0.538013954	0.89037447	0.20398474	0.23445576
Mineral resource scarcity	kg Cu eq	0.0639177446	0.013297856	0.021727464	0.023392395
Fossil resource scarcity	kg oil eq	19.2570737	5.0444871	6.1043526	8.108234
Water consumption	m^3	0.290791037	0.0482271	0.118814	0.12976589

Table 4.4 shows the non-mechanized method of marble manufacturing with 70% of waste data recorded and taken from the respective industries in the selected regions. Table 4.4 shows a prominent decrease in the three respective impact categories such as global warming, Terrestrial ecotoxicity, and fossil resources scarcity due to 70% waste during quarry extraction through blasting. The respective values for the three most affected impact categories such as global warming, terrestrial ecotoxicity, and Fossil resource scarcity 26.15254862 kg CO2eq, 170.814646 kg 1,4- -DC, and 9.30826 kg oil eq respectively. It is observed that quarry extraction is the main contributing factor to global warming while in terrestrial ecotoxicity all three processes contribute to equal amounts due to 70% waste such as limestone chemical and other conversion organic products. The process most contributing in the fossil resources scarcity is also the quarry extraction. All others process has negligible effects on the impact categories as shown in Figure 4.8 and Table 4.4.

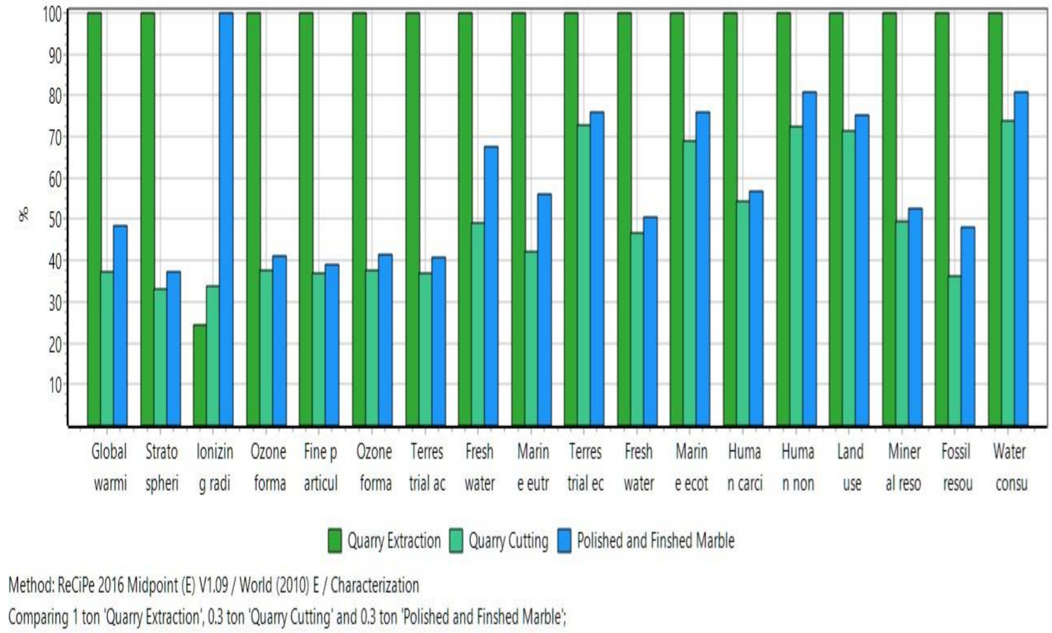

Figure 4-9: Graphical representation of Mechanized Marble midpoint with 70% Waste

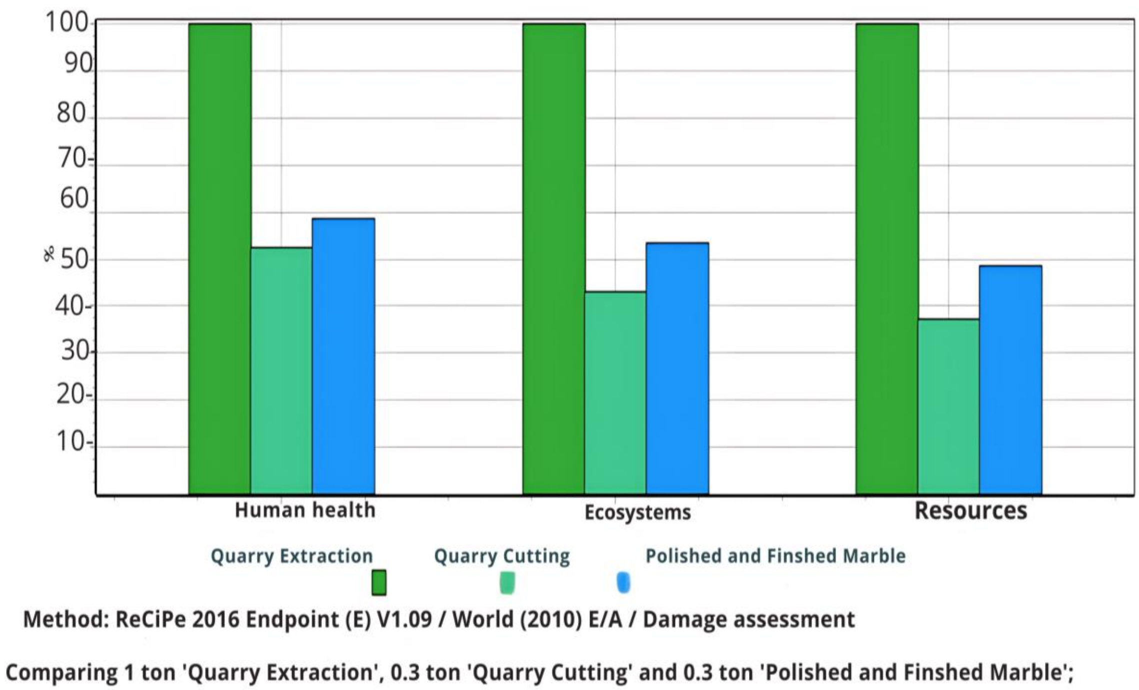

Figure 4-10: Graphical representation of endpoint results with 70% Waste

The contributions of non-mechanized marble manufacturing with 70% waste processes to endpoint indicators are shown in Figure 4.9. The results are almost consistent as in the case of midpoint categories. The quarry extraction processes come 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 other two processes are also contributed in half of the amount to human health, ecosystem, and resources as shown in Figure 4.9.

Table 8 shows the data statistics and the output of the solar-powered mechanized marble extraction phase. It has been shown that the values of the factors affecting the environment are greatly changed due to the transition from conventional fuel powering to clean solar energy. These factors in turn indicate positive environmental effects as well as economic concerns.

4.4 Comparative Analysis

The comparative analysis of both mechanized and non-mechanized marble manufacturing is depicted in Table 4.4 and Figure 4.10 as shown. The most three affected categories are the common among all the previously discussed categories and combinations are global warming, Terrestrial ecotoxicity and Fossil resource scarcity along with land use in the non-mechanized process of manufacturing due to blasting.

Table 4.5: Results at midpoint level for mechanized with solar power.

Impact category	Unit	Total	Quarry Extraction	Quarry Cutting	Polished Finish Marble
Global warming	kg CO_2 eq	38.5389	10.0002	12.38616	16.14003
Stratospheric ozone depletion	kg CFC11 eq	1.86E-09	3.53E-06	1.33E-07	1.854
Ionizing radiation''	kBq CO-60 eq	0.43566	0.02004	0.100116	0.315558
Ozone formation, Human health''	kg NO_x eq	0.583272	0.03654	0.046038	0.05007
Fine particulate matter formation''	kg PM2.5 eq	0.155273	0.006714	0.00804	0.008171
Ozone formation, Terrestrial ecosystems''	kg NO_xeq	0.616597	0.038436	0.04842	0.052974
Terrestrial acidification''	kg SO_2eq	0.077712	0.021648	0.026682	0.029315
Freshwater eutrophication''	kg P eq	0.001531	0.000318	0.000522	0.000715
Marine Eutrophication	kg N eq	0.00032	0.000078	0.000107	0.000142
Terrestrial ecotoxicity,	kg 1,4-CB	102.264	18.132	41.04	43.086
Ecotoxicity	kg 1,4-DCB	0.273939	0.059244	0.10614	0.11394

Table 4.6: Comparison of Mechanized and Non-Mechanized Marble Manufacturing

Impact category	Unit	Mech-Marble Mfg	Non-Mechanized Mfg	Difference
Global warming	kg CO_2 eq	64.2315554	60.23455	3.997005
Stratospheric-ozone depletion	kg CFC11 eq	3.98644E-06	9.64116E-06	-5.7E-06
Ionizing radiation	kBq CO-60 eq	0.015336514	0.029164636	-0.01383
Ozone formation, Human health	kg NO_x eq	0.04751429	0.093980748	-0.04647
Fine particulate matter formation	kg PM2.5 eq	0.017281112	0.026043789	-0.00876
Ozone formation Terrestrial ecosystems	kg NO_x eq	0.048597473	0.095970428	-0.04737
Terrestrial acidification	kg SO_2 eq	0.028084982	0.061985609	-0.0339
Freshwater eutrophication''	kg P eq	0.000188608	0.00066296	-0.00047
''Marine eutrophication	kg N eq	3.73726E-05	9.12395E-05	-5.4E-05
Terrestrial ecotoxicity	kg 1,4-DCB	170.44	132.2674	38.1726
Freshwater ecotoxicity	kg 1,4-DCB	0.041802427	0.08631294	-0.04451
Marine ecotoxicity	kg 1,4-DCB	0.077510053	0.144495109	-0.06699
Human carcinogenic toxicity	kg 1,4-DCB	0.370357094	0.572942848	-0.20259
Human non-carcinogenic toxicity	kg 1,4-DCB	0.670612475	1.651621145	-0.98101

Land use	m^2 a crop eq	0.102281367	17.13802678	-17.0357
Fossil resource scarcity	kg oil eq	19.2570737	18.19721	1.059864

This comparison depicts for both the process when there is no waste in the process with an ideal situation. The difference between the respective categories is very little but the land use has been impacted in greater amount in non-mechanized way due to blasting or other non-mechanical procedures. The difference between can be more evident when there is consideration of the percent waste in each process during each process and its extraction. Table 4.2 shows the extraction of marble quarry with a mechanized way with 30% marbles goes into waste reported by the selected industries. It is evident from the results shown in Table 4.2 and table 4.4 that global warming, Terrestrial ecotoxicity and Fossil resource scarcity values clearly deviated from the trend as shown. It shown in table 4.2 that global warming is mainly due to all the threes process such as quarry extraction, marble cutting and finishing and polishing with 30% marble goes to waste in consequences while Table 4.4 shows that the same global warming impact category is mainly affected due to quarry extraction.

Table 4.7: Comparison of Mechanized (with solar power) and Non-Mechanized Marble Manufacturing

Impact category	**Unit**	**Mech-Marble Mfg**	**Non-Mechanized Mfg**	**Total**
Global warming	kg CO_2 eq	38.5389	60.23455	-21.6956
Stratospheric-ozone depletion	kg CFC11 eq	1.86E-09	9.64116E-06	-7.2E-06
Ionizing radiation	kBq CO-60 eq	0.43566	0.029164636	-0.01996
Ozone formation, Human healt	kg NO_x eq	0.583272	0.093980748	-0.06547
Fine particulate matter formation	kg PM2.5 eq	0.155273	0.026043789	-0.01568

Ozone formation Terrestrial ecosystems	kg NO_x eq	0.616597	0.095970428	-0.06681
Terrestrial acidification	kg SO_2 eq	0.077712	0.061985609	-0.04513
Freshwater eutrophication	kg P eq	0.001531	0.00066296	-0.00055
Marine eutrophication	kg N eq	0.00032	9.12395E-05	-6.9E-05
Terrestrial ecotoxicity	kg 1,4-DCB	102.264	132.2674	-30.0034
Freshwater ecotoxicity	kg 1,4-DCB	0.273939	0.08631294	-0.06123
Marine ecotoxicity	kg 1,4-DCB	38.5389	0.144495109	-0.09799
Human carcinogenic toxicity	kg 1,4-DCB	1.86E-09	0.572942848	-0.35073
Human non-carcinogenic toxicity	kg 1,4-DCB	0.43566	1.651621145	-1.24925
Land use	m^2 a crop eq	0.0613688	17.13802678	-17.0767
Fossil resource scarcity	kg oil eq	11.5542	18.19721	-6.64297

Table 10 shows that deploying a solar-powered system for marble extraction has shown a great impact in terms of the pollutants to the environment. In contrast, to Table 4.1 data statistics there is a clear decreasing trend in concentrations of the factors affecting the environment. The variables like greenhouse gas emissions, NO_x, CO_2, and SO_2 due to which the midpoint categories like global warming, ozone depletion, particulate materials in the air, marine toxicity, and the whole ecotoxicity is greatly reduced by almost 40% mitigation in overall manner.

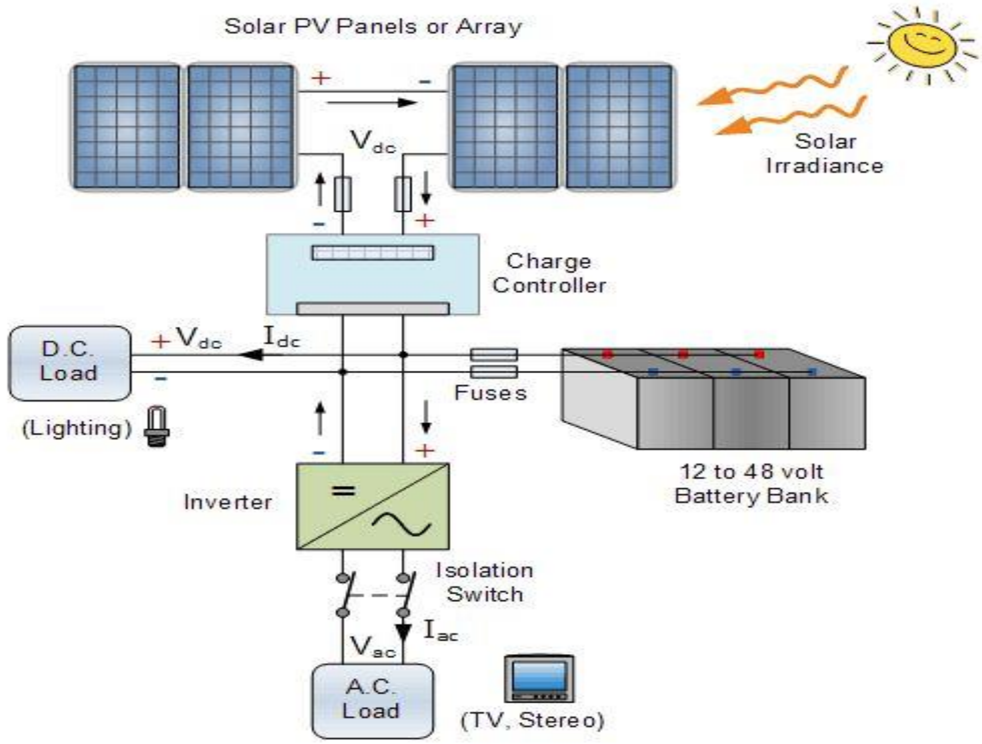

Figure 4-11: Stand-alone PV Power for Mechanized Marble Manufacturing

4.5 Replacement of Diesel Generator by Solar Panel for Mechanized Marble Extraction

It is evident from Table 4.1that most of the mid-point categories of mechanized marble extraction negatively impact the environment due to diesel power generation. Considering that diesel power generation is replaced by installing solar panels. The total power requirement for extracting mechanized block is 15500 watts therefore requiring 40 panels each having 580 watts power considering 30% power loss Figure 4.11. After installing solar panels, the power consumption during the extraction phase for mechanized marble is totally from renewable sources consequently reducing mid-point impact categories shown in Table 11. Installation of solar panels shows drastic improvement in the environmental performance of mechanized marble extraction especially global warming, Terrestrial ecotoxicity, and Fossil resource scarcity.

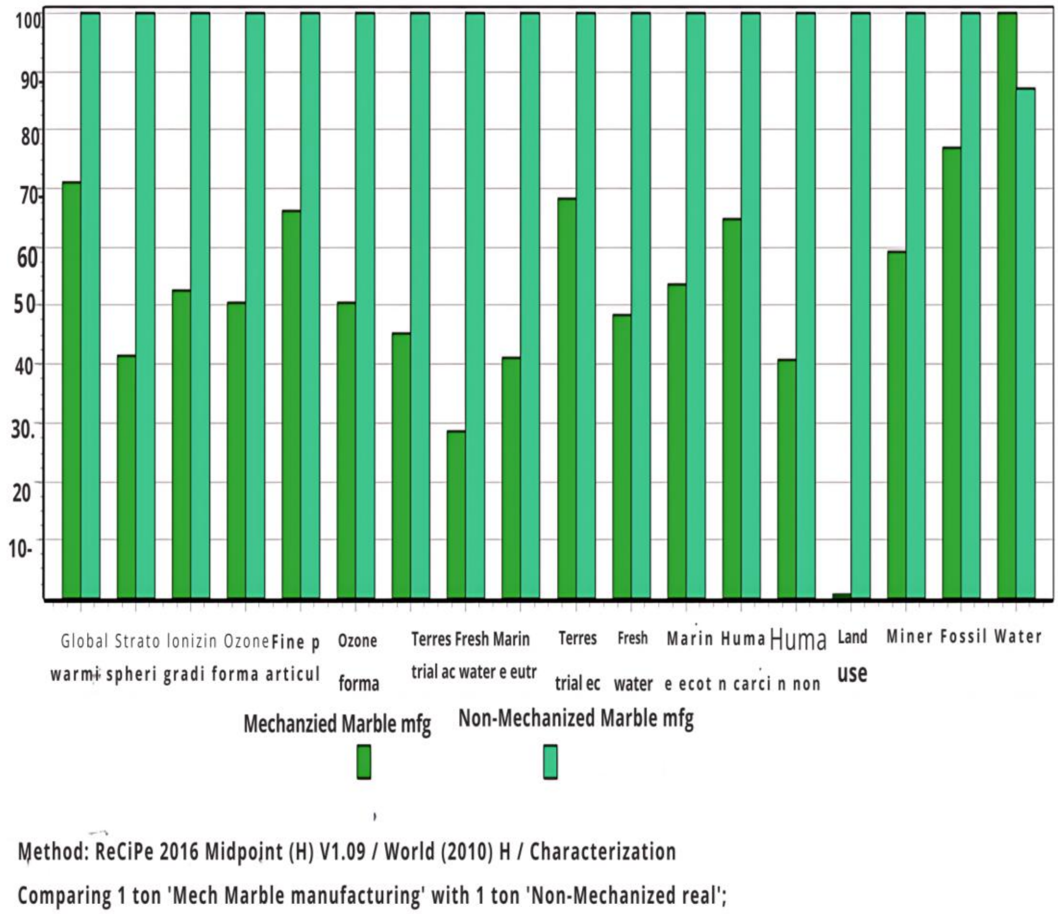

Figure 4-12: Comparison of Mechanized & Non-Mechanized Marble Manufacturing-Mid Point.

It is also evidence from table 4.2 that terrestrial ecotoxicity during mechanized marble manufacturing with 30% waste is mainly affected by the cutting and polishing and finishing processes while that of Table 4.4 shows for non-mechanized manufacturing that all the three process are comparably equally contributing to this category. The last and 3rd most affected category (Fossil resource scarcity) can also be compared from table 4.2 and table 4.4. It is shown that this category is equally affected by all the three process in the mechanized way of marble manufacturing while in case of non-mechanical method the Fossil resource scarcity is mainly affected by quarry extraction process.

The contributions of non-mechanized and mechanized marble manufacturing with 70% and 30% waste processes to endpoint indicators are shown in Figure 4.11 respectively. The results are

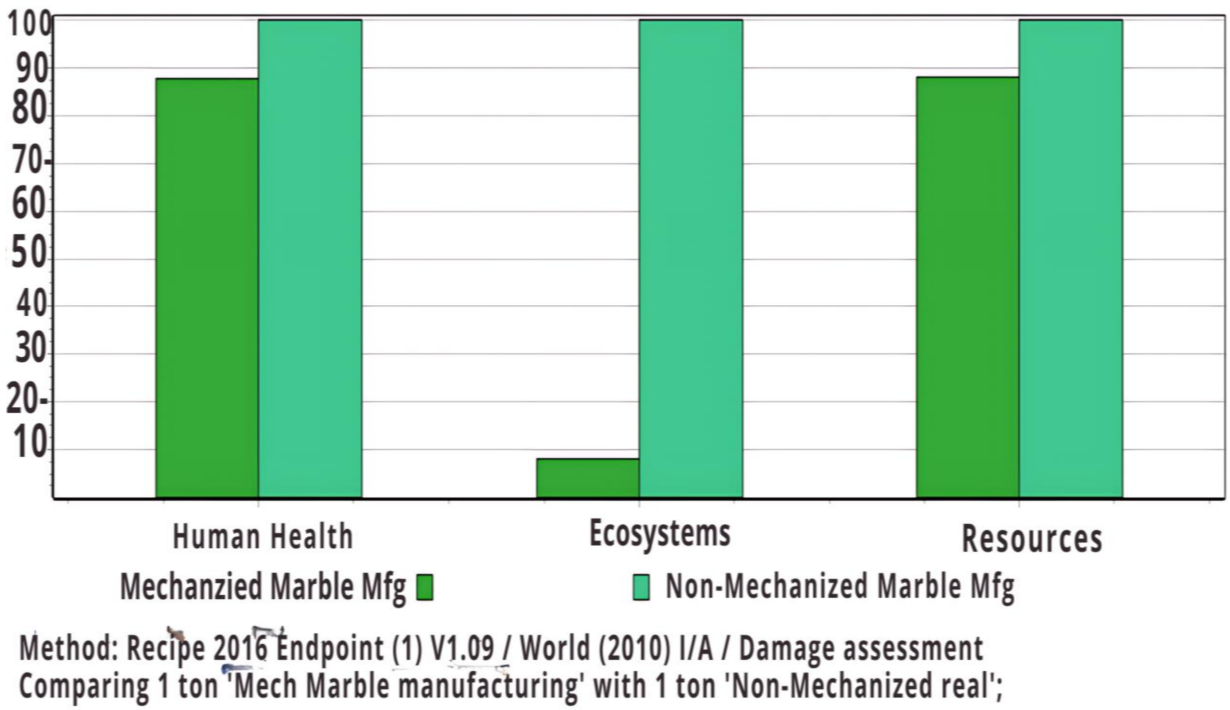

Figure 4-13: Comparison of Mechanized & Non-Mechanized Marble Manufacturing-End Point.

almost consistent as in the case of midpoint categories. The non-mechanized marble manufacturing with 70% waste come 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 mechanized manufacturing process are also contributing greatly to human health and resources as shown in Figure 4.11.

CHAPTER 5. CONCLUSIONS AND RECOMMENDATIONS

The manufacturing industries of developing nations are very crucial for their growth. For developing countries to grow, their industrial sectors are essential. But these sectors are linked to several things that have a negative effect on the environment. Due to a lack of awareness and appropriate norms, developing nations—Pakistan in particular—place very little emphasis on the industrial sector's environmental performance. This has a negative impact on the environment as well as lowering exports. To achieve this, appropriate steps must be taken to improve the environmental performance of various manufacturing businesses.

1. The study concludes to evaluate the performance of Pakistan's marble manufacturing sector. There are several ramifications of this study for decision-makers and stakeholders. The primary problems with this industry's overall and environmental performance are ignorance, inefficient use of resources, and the nation's energy composition.
2. Finishing and Polishing is shown to be the primary cause of environmental problems because of high energy-intensive need. In addition to the finish and polishing process, Pakistan's energy mix increases the susceptibility of electricity to these effects. In addition to non-renewable resources and coal-based (thermal) power plants, which have more negative environmental effects than other sources, it is the duty of stakeholders and government employees to investigate ways to produce more electricity through more efficient and renewable energy sources. In addition, the stakeholder should consider developing an appropriate system for tracking the quantity of limestone and the circumstances surrounding product usage.
3. This study included gate-to-gate scope with a functional unit of 1 ton marble manufacturing analyzed by and SimaPro 9 Recipe 2016 methods, analyzed the impacts of the manufacturing process on midpoint and endpoint levels. The primary focus of this study was to identify the major hotspots that contribute most to the environmental impacts associated with the marble manufacturing industry of Pakistan.
4. It can be concluded that mechanized Impact categories without waste results mid-Point recipe shows that the global warming and terrestrial ecotoxicity are due to the three-process involved in the marble manufacturing I.e. Quarry extraction, Cutting and Polishing. The most prominent process affecting these categories is finish and polishing. The quarry

extraction, cutting and finish and polishing process comes out to be the most dominant process causing most of the impacts to the human, ecosystem and resources depicted by endpoint method in SimaPro software.

5. It is also evident from table 4.2 and Figure 4.4 mechanized impact categories with 30 Percent Waste results Mid-Point recipe shows the same trend but exhibits smaller values of the global warming and terrestrial ecotoxicity. The reason is due to 30% marble goes into waste after quarry extractions. At the end, the product comes out to be 0.7 ton or less. The quarry extraction, cutting almost contribute equally but finish and polishing process almost comes out to be the most dominant process causing most of the impacts to the human, ecosystem and resources depicted by endpoint method in SimaPro software.
6. The trend for the impact categories for non-mechanized marble manufacturing without waste such as global warming and terrestrial ecotoxicity are the same. The most contributing process is the finish and polishing of the marble which is a highly intensive energy process. The values of these impact categories are smaller than mechanized due to lesser uses of electricity mix coming from market or general grid. The quarry extraction, cutting almost contribute equally but finish and polishing process almost comes out to be the most dominant process causing most of the impacts to the human, ecosystem and resources depicted by endpoint method in SimaPro software.
7. The value of global warming for the non-mechanized marble manufacturing with 70% marble goes into waste is very smaller with quarry extraction is the most contributing process while the terrestrial ecotoxicity value is highly greater than expected with equal contribution of all the three processes. The greatest contribution is due to the 70% chemical and limestone waste that goes into the soil. The cutting and finishing and polishing marble almost contribute equally but quarry extraction process almost comes out to be the most dominant process causing most of the impacts to the human, ecosystem and resources depicted by endpoint method in SimaPro software.
8. Most of the mid-point categories of mechanized marble extraction negatively impact the environment due to diesel power generation. Considering that diesel power generation is replaced by installing solar panels. After installing solar panels, the power consumption during the extraction phase for mechanized marble is totally from renewable sources

consequently reducing mid-point impact categories shown in Table 11. Installation of solar panels shows drastic improvement in the environmental performance of mechanized marble extraction especially global warming, Terrestrial ecotoxicity, and Fossil resource scarcity.

9. Data shows that deploying a solar-powered system for marble extraction has shown a great impact in terms of the pollutants to the environment. In contrast, to Table 4.1 data statistics there is a clear decreasing trend in concentrations of the factors affecting the environment. The variables like greenhouse gas emissions, NO_x, CO_2, and SO_2 due to which the midpoint categories like global warming, ozone depletion, particulate materials in the air, marine toxicity, and the whole ecotoxicity is greatly reduced by almost 40% mitigation in overall manner.

FUTURE RECOMMENDATIONS:

1. This investigation was conducted from Gradle to gate excluding the transport. Future research can undertake a full life cycle analysis of the marble manufacturing business to provide a more thorough picture of environmental implications.
2. Data was collected for this investigation from just one province of only three districts. For improved analysis, further research should be done in the future using data collected from more diverse geographic regions and multiple production sites.
3. It is also advised to conduct additional research to examine the environmental effects of other renewable energy sources, such as wind power.
4. For improved environmental performance, government employees and other stakeholders should also consider shifting Pakistan's energy mix more toward renewable and environmentally friendly resources.
5. Recently more mechanized quarries started working in the Mansehra district therefore it is recommended to compare mechanized (Pakistan) to mechanized (Develop Countries).
6. Industry waste can be reduced with cleaner production Techniques.

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