DOKUZ EYLÜL UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

LIFE CYCLE ASSESSMENT FOR QUARTZ SURFACE PRODUCTION

by
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October, 2019
İZMİR

LIFE CYCLE ASSESSMENT FOR QUARTZ SURFACE PRODUCTION

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In Partial Fulfillment of the Requirements for the Degree of Master of Science in Environmental Engineering

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M.Sc THESIS EXAMINATION RESULT FORM

We have read the thesis entitled **"LIFE CYCLE ASSESSMENT FOR QUARTZ SURFACE PRODUCTION"** completed by **İPEK GÜRBÜZ** under supervision of **PROF. DR. NURDAN BÜYÜKKAMACI** and we certify that in our opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Science.

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I want to dedicate this thesis to the memory of my father, Mustafa SÖZKESEN, who always believed in my ability to be successful in my life. You are gone, but your belief in me has made this journey possible. This accomplishment would not have been possible without my family and husband. Thank you.

İpek GÜRBÜZ

LIFE CYCLE ASSESSMENT FOR QUARTZ SURFACE PRODUCTION

ABSTRACT

One of the most prevalent minerals in the Earth's crust is quartz, which is consisted of silicon dioxide. It is one of the hardest natural material and, it is scratch and stain resistant, and non-porous. Bacteria and mold do not grow easily on quartz counters; therefore, it is widely used for kitchen and bathroom counters. In quartz surface production, quartz, mirror and glass fracture, seashell, silicon carbide, resin, pigment, some catalysts, and cobalt is used as raw materials. Natural gas, electricity, and water is used in the production processes. Water is mainly consumed in polishing step and wastewater is produced during this process. In addition to wastewater, solid wastes including rubbles, sludge, packing material, and air emissions are produced in this sector. In the scope this thesis, determination of environmental impacts of quartz surface manufacturing was aimed. A pilot plant, which production capacity is one million m^2 of quartz surface per year, was chosen for this aim. To evaluate the environmental effects of the plant, the Life Cycle Assessment (LCA) approach was used. Functional unit was selected to be m^2 of surface production. Raw material transportation, quartz surface production, and wastewater treatment phases were taken into consideration in the LCA analysis. All input and output of each phases was determined for the pilot plant. The LCA studies were carried out using the GaBi Software (Thinkstep, Germany). CML 2001 (Institute of Environmental Sciences, Leiden University) impact assessment method was used to evaluate the environmental impacts.

Keywords: LCA, quartz surface, sustainability, wastewater

KUARTZ YÜZEY ÜRETİMİ İÇİN YAŞAM DÖNGÜSÜ ANALİZİ

ÖZ

Yerkabuğundaki en yaygın minerallerden biri olan kuvars, silikon dioksitten oluşmaktadır. En sert doğal malzemelerden biridir, çizilmeye ve lekeye dayanıklıdır ve gözeneksizdir. Bakteriler ve küf, kuvars tezgahlarında kolayca üremediğinden bu malzeme mutfak ve banyo tezgahlarında yaygın olarak kullanılmaktadır. Kuvars yüzey üretiminde, kuvars, ayna ve cam kırığı, deniz kabuğu, silisyum karbür, reçine, pigment, bazı katalizörler ve kobalt hammadde olarak kullanılmaktadır. Üretim için doğal gaz, elektrik ve suya ihtiyaç vardır. Su esas olarak parlatma aşamasında tüketilmekte ve bu işlem sırasında atıksu üretilmektedir. Atıksuya ek olarak, bu sektörde moloz, çamur, paketleme malzemesi gibi katı atıklar ve hava emisyonları oluşmaktadır. Bu tez çalışması kapsamında, kuvars yüzey üretiminin çevresel etkilerinin belirlenmesi amaçlanmıştır. Bu amaçla, üretim kapasitesi yılda bir milyon m^2 kuvars yüzey olan bir pilot tesis seçilmiştir. Tesisin çevresel etkilerini değerlendirmek için Yaşam Döngüsü Analizi (YDA) aracı kullanılmıştır. Fonksiyonel birim olarak m^2 yüzey üretimi seçilmiştir. Yaşam döngüsü analizinde hammadde nakliyesi, kuvars yüzey üretimi ve atıksu arıtma aşamaları dikkate alınmıştır. Pilot tesis için her bir aşamaya ait tüm girdi ve çıktılar belirlenmiştir. YDA çalışmaları, GaBi Yazılımı (Thinkstep, Almanya) kullanılarak yapılmıştır. Çevresel etkilerin değerlendirilmesinde CML 2001 (Leiden Üniversitesi Çevre Bilimleri Enstitüsü) etki değerlendirme yöntemi kullanılmıştır.

Anahtar Kelimeler: YDA, kuartz yüzey, sürdürülebilirlik, atıksu

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CHAPTER ONE

INTRODUCTION

1.1 Introduction

Quartz is a chemical combination consisting of one part of silicon and two parts of oxygen. The most prevalent form of crystalline silicon dioxide (SiO_2) is quartz. Besides being one of the most useful natural materials, quartz is the most abundant mineral on the surface of the world. It is orijinal properties make it one of the most beneficial natural ingredients.

Quartz has a hardness of seven times on the Mohs scale, which increases its durability. It is usable for electrical properties and heat resistance, for this reason this make it functional in electronic manufacturing. It is very popular in the make of glass, because of its brightness, color and transparency (Turkish Minerals, n.d).

Quartz has an annual growth rate of 15.7% between 1999 and 2014. Quartz's popularity is due to its combination of durableness, low marked price, and configuration (Eisenberg, 2017). Global countertop demands and countertop demand by material is given in Figure 1.1.

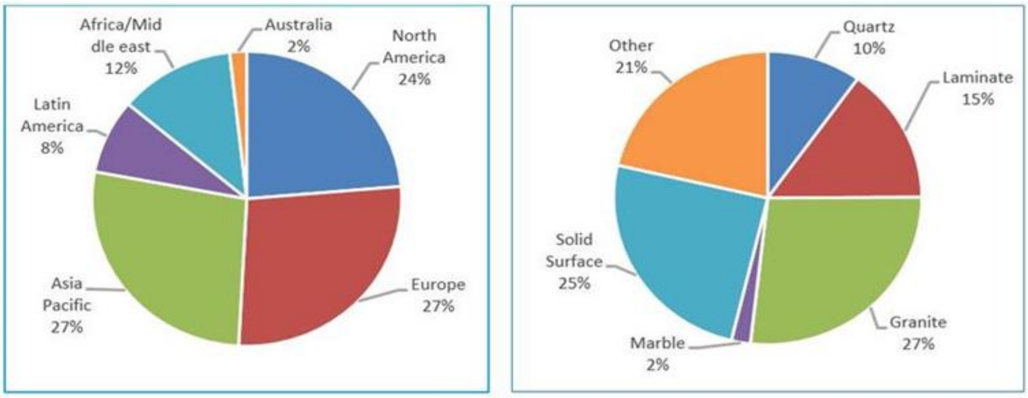


Figure 1.1 Global countertop demand and countertop demand by material (Eisenberg, 2017)

It is expected that a compound annual growth rate (CAGR) of quartz market be over 5% during the forecast period for 2019 to 2024 (Figure 1.2). The most important factors driving the market are studied by Mordor Intelligence, n.d.

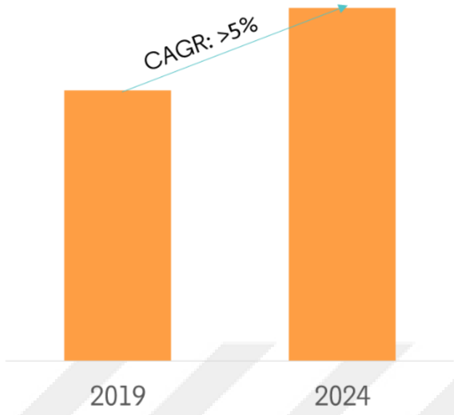


Figure 1.2 CAGR of quartz market (Mordor Intelligence, n.d.)

Some of major factors, which increase the compound annual growth rate of quartz market, are:

- Electronics and Semi conductive Industry: The increasing in production and usage of electronic devices for instances mobile phones, LCD/LED TV, tablets, laptops, etc.
- Heavy investments in the electronics industry.
- Competitive Landscape: There are several main quartz producers in global scale.
- The end-user industries *(Such as building and construction, medical sector etc.):* The support to improve production, product quality of medical equipment. The increasing demand of the end-user industries.

Major factors of increases in the compound annual growth rate of quartz market in 2018 and quartz market growth rate by region, the period of 2019-2024 is given in Figure 1.3 and 1.4, respectively (Mordor Intelligence, n.d.).

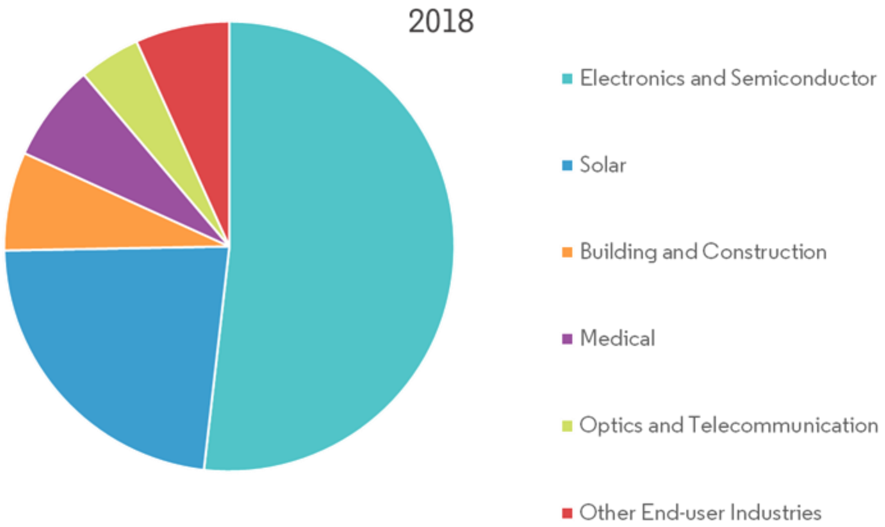


Figure 1.3 Major factors of increases in thecompound annual growth rate of quartz market, global, 2018 (Mordor Intelligence, n.d.)

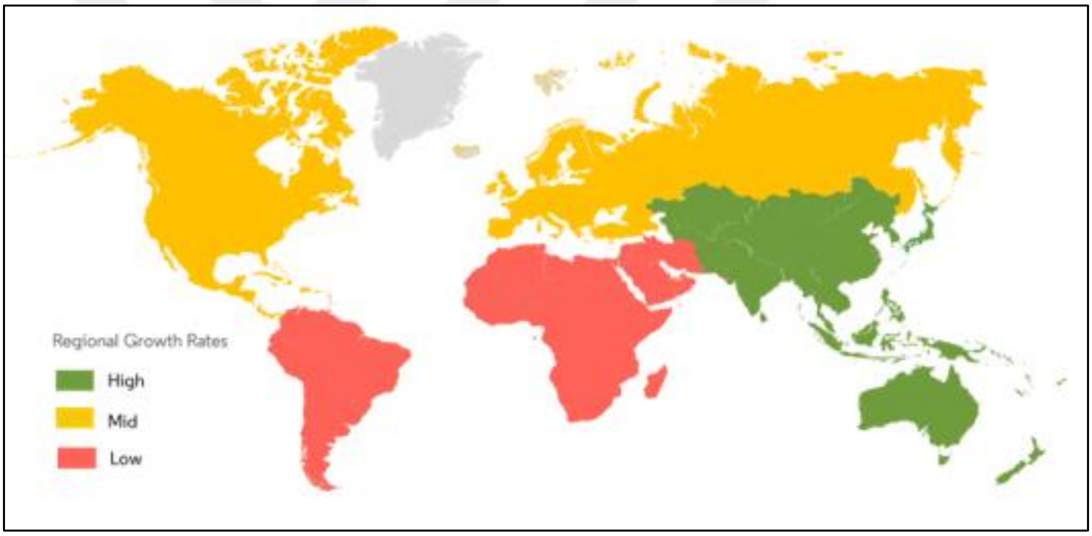


Figure 1.4 Growth rate of quartz market as regionally, 2019-2024 (Mordor Intelligence, n.d.)

The usage increase of the quartz surface at last periods are very attention grabbing. Quartz surfaces are used in floors, walls and facade claddings, kitchen and bathroom countertops and in various special application areas.

Engineered quartz stone is produced with a mixture of quartarts, resin, pigment and additives and is accessible in a multifarious of colors and patterns. It can be combined with reflective materials such as glass to obtain glossy surfaces. For product range, seashells can also be used as additives according to market demand. As in almost all productions, quartz surface production gives some environmental damage by consuming material sources, water, energy, and by generating some wastes including wastewater, emissions, and solid wastes. The environmental impacts of quartz surface production can be calculated using LCA approach.

LCA is used to evaluate the environmental effects of an output or material, from its origin through to disposal across its entire lifecycle. During a product life cycle, all activities or processes have environmental impacts, such as resource consumption and emissions.

LCA is useful to measure the environmental effects of the production process, but LCA implementation is often a retrospective environmental measure of production. The procedures of the LCA studies are given in ISO 14040 and standart is the international benchmarking of LCAs (ISO 14040, 2007).

1.2 Aim and Scope of the Thesis

There are two basic requirements for Europe and Turkey for the production of building materials. One of them is the use of sustainable natural resources, and the second is the protection of the environment in the manufacturing process of building materials. The ecological criteria for the award of the European Union Community ecolabel to hard coverings including quartz material, is given in 2009/607/EC. In Europe, construction products should have European Conformity (CE) and Environmental Product Declaration (EPD) certificate according to European Standard EN 15804. For an EPD certificate, LCA study may be carried out and according to LCA study results, improvement actions can be defined (Günkaya et al., 2018). Similar studies are needed for Turkish companies to compete in the international market.

This thesis is about on the determination of the environmental effects of the quartz surface product, which is produced with resin, quartz and recycled glass, by using LCA approach. LCA studies were carried out for one of the building material productors of Turkey.

CHAPTER TWO
QUARTZ SURFACE PRODUCTION

2.1 Introduction to Quartz Materials

Quartz is a natural silicate mineral composed of silicon dioxide (SiO_2). One of the most prevalent and available mineral is quartz. According to MOH (Measurement of Hardness), Diamond is 10 on the scale, Topaz is 8, behind Quartz is 7 and Granite is 6.

Quartz surfaces are produced from a mixture of quartz aggregate chips, a resin binder, pigments and additives. While processed stone slabs and workbenches are available in a wide range of colors, patterns, textures, they can be combined with glass or other ornamental materials upon request. Granite is becoming increasingly popular due to its durability and non-porous quartz structure (BCA-Building and Construction Authority, n.d.).

2.2 Quartz Materials Production

In general, the production process starts with the selection of raw materials. A homogeneous mixture is obtained by mixing quartz with resin and other additives. With the vacuum and vibration process, the mixture is compressed into slabs and this process takes nearly 100 seconds under a pressure of 100 tons. This production step minimizes surface roughness and reduces water absorption. The slabs are hardened at a temperature of 85 ^{o}C degrees in the curing oven for 30 minutes after the press process. This process step is increasing the resistance of products to impacts and stains. The curing process can be accelerated by using ovens or steam and the slabs are measured when curing is completed. After that, they are calibrated and polished and prepared for packaging and shipping. (BCA-Building and Construction Authority, n.d.).

In Figure 2.1, the general flow schema of quartz surface production is shown.

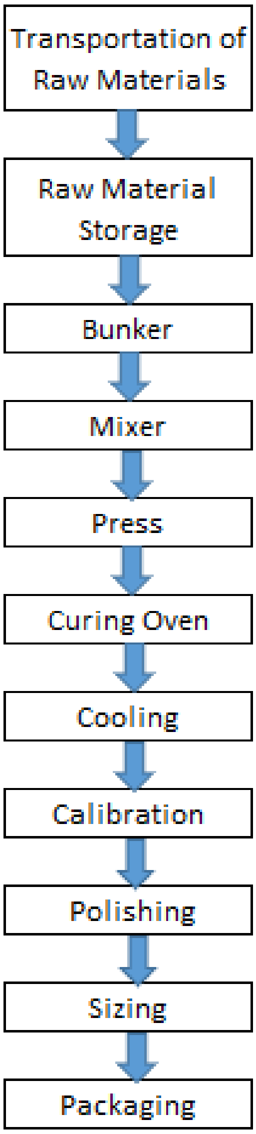


Figure 2.1 General flow schema of quartz surface production (BCA-Building and Construction Authority, n.d.)

2.3 Quartz Materials Production in the World and in Turkey

Ceramic production in Turkey began in the 1950’s and improved with rapid increasing from 1980's. Due to new technologies and modern machines, Turkey has risen from ninth to fourth place in worldwide tile production in 2014. In 2015, the produced ceramic tile amount was 320,000,000 m^2, the established capacity of ceramic tile is 411,000,000 m^2, and the exported amount is 77,000,000 m^2 (Ceramic Turkey, 2016).

Ceramic tile and sanitary ware are some of the raw materials demans in the Turkish Ceramic Industry.Quartz, quartz sand, pegmatite, clay, aplite and feldspars are mainly raw materials, which that used in ceramic tile production. In 2015, the clay production amound was 1,792,000 tons/year, kaolin production was 768,000 tons/year and quartz/quartz sand production amound was 512,000 tons/year. Clay, feldspar, quartz sand, quartz and kaolin are mainly raw materials, which that used in sanitary ware industry. In 2015, the clay production amound was 96,000 tons/year, Quartz/quartz sand production amound was 39,000 tons/year, feldspar production was 90,000 tons/year, and kaolin production was 75,000 tons/year (Seramik Türkiye, 2016).

Ceramic, chemistry, concrete plant and iron casting industries are used silica sand (quartz sand) as a raw material. Quartz sand is refined by washing, enriching and grading and it is produced over 4,000,000 tons/year from Şile region in Turkey. As a raw material, quartz and quartz sand are extensive in Turkey. In last 20 years, 3,100,000 tons and 5,900,000 tons of quartz-silica sand has been exported and imported, respectively (Seramik Türkiye, 2016).

Because of its strong feeling and strength for a long time, Quartz surface products are construction materials that frequently referred in the world. Quartz deposits located in Brazil are the world's largest. Several quartz deposits are located in USA, Namibia, Angola, Madagascar, China, and India. But these reserves do not show invariability (Tecnodieci, n.d.).

2.4 Waste Management in Quartz Surface Production

Proper waste management is a key factor for the sustainable production in industrial facilities. All sub-process of the production must be taken into consideration during the determination of waste management strategies. All waste should be managed to prevent adverse effects on human health and the environment.

Waste management is one of the most important issue for sustainable production. The important point in waste management is to collect and reduce waste at its produced source and to evaluate the reuse of the waste. Priority to prevention of waste generation should be given at source.

In all conditions and applications, practices that will have minimum impact on environment, ecosystem and human health should be studied. In order to form the waste management strategy of a factory, it is necessary to determine the waste types (liquid, solid, emission, etc.) of the factory correctly.

Generally, some non-hazardous/hazardous solid wastes, air emissions and liquid wastes are comprised of quartz surface production process. The type and definition of all wastes are shown in Table 2.1.

Table 2.1 Wastes types in production process

Types of waste		Definition of waste
Solid Waste	Non-Hazardous	Wastewater Treatment Sludge
Solid Waste	Non-Hazardous	Wastepaper
Solid Waste	Non-Hazardous	Waste Plastic
Solid Waste	Non-Hazardous	Waste Wooden Pallet
Solid Waste	Non-Hazardous	Demolition Waste
Liquid Waste	Hazardous	Waste Organic Material
Solid Waste	Hazardous	Contaminated Packaging Waste
Solid Waste	Hazardous	Contaminated PPE
Liquid Waste	Hazardous	Wastewater
Emissions	Hazardous	Air Emissions (Dust)

CHAPTER THREE
LIFE CYCLE ASSESSMENT

3.1 General Structure of LCA

As some researches show, the industrial working area have gone over the boundary a long time ago. The capacity of to safely keep the nature is not possible. We need immediate action for sustainability (Takata, 2007). With these necessities the notion of LCA was found out.

LCA is a method to analyze the environmental effects to process/operation (transportation of raw materials, production, handling, shipping, incineration, recycling etc.) (Charters, 2010). Cradle to grave LCA approach phases are given in Figure 3.1.

LCA provides significant data at decision making and improving the environmental performance of aimed products.

Figure 3.1 Cradle to grave life cycle assessment phases (Innovation Services, 2015)

The LCA steps are goal and scope definition, inventory analysis, impact assessment, and interpretation. The detailed methodology of each steps are defined in ISO 14040 and ISO 14044 guidelines (Günkaya et al., 2018). Four steps of LCA are shown in Figure 3.2.

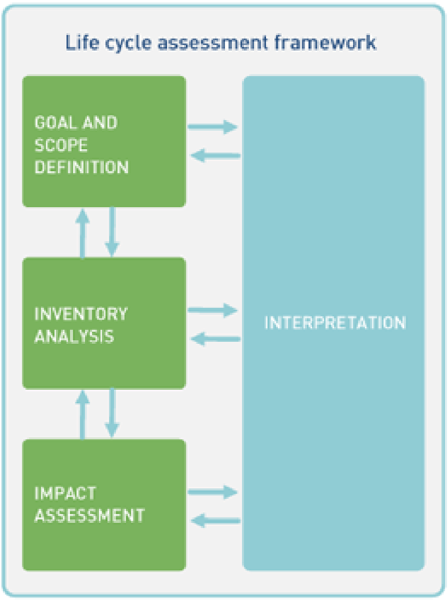


Figure 3.2 LCA framework (Sustainable Mind, n.d)

LCA studies might play significant roles of establishing the most proper environment and wastewater management strategy.

LCA analysis can be turned over into generically appointed steps. As an example, LCA can be done for only refer to materials improvement from cradle to gate approach. There are mainly four types of LCA approach methods (Fındıkçı, 2016):

- Sources extraction ('cradle') and disposal stage ('grave') are termed as "cradle-to-grave".
- An evaluation of a fractional product life cycle from source extraction (cradle) to the factory gate is termed as "cradle-to-gate" (i.e., before it is transported to the end user).
- The end-of-life annihilation step for the output is a recycling process is termed as "cradle-to-cradle". It is a method used to minimize the environmental impact of sustainable production and output.

- To consider one value-added process in the all production series is termed as "gate-to-gate".

Where necessary, the results of LCA can be used as an input in another LCA step (Sadaba et al., 2017). LCA boundary terms were shown in Figure 3.3.

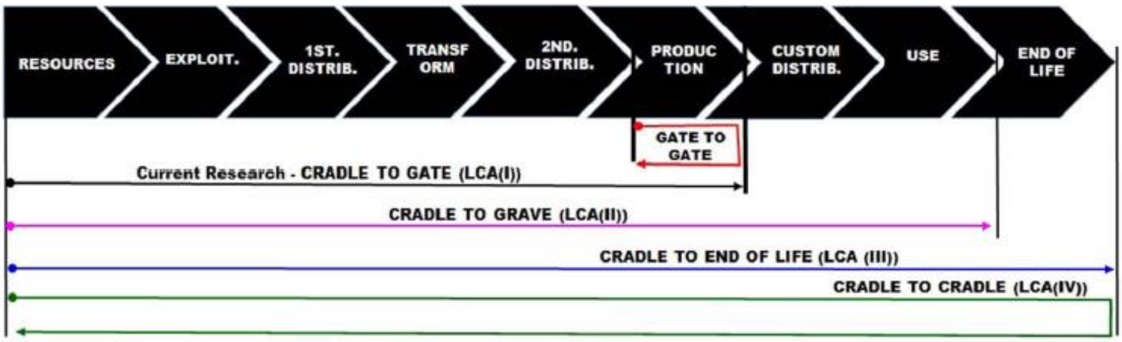


Figure 3.3 LCA boundary terms (Sadaba et al., 2017)

According to the Figure 3.3:

- The “cradle to gate” approach was indicated by LCA (I).
- The “cradle to grave” approach was indicated by LCA (II).
- The “cradle to end of life” approach was indicated by LCA (III).
- The “cradle to cradlee” approach was indicated by LCA (IV).

3.2 LCA Applications in the Production of Quartz and Similar Materials

The life cycle of quartz surfaces begins with the extraction of the natural materials, which are non-renewable sources, used in its production. To make an environmentally friendly production, quartz extraction impacts must be reduced. The quartz surface production is an energy consuming process, therefore less energy consuming applications should be performed. Less packing material usage is another important issue for the sustainable production of quartz surface material. These matters are also criteria for EU ecolabel hard covering products (EU Ecolabel Coverings / Hard Covering, n.d.).

In a study, environmental impacts of natural stone, engineered quartz, and porcelain, which are used in countertop and floor, were compared. They reported that, lifespan of the engineered quartz is 25 – 30 years and most of the materials used for the engineered quartz production are non-renewable resources. They have negative impacts on health and the environment such as nitrates, dioxin, arsenic, lead, and mercury (Use Natural Stone, n.d.).

There are limited studies on LCA applications for the quartz and similar materials production. One of these studies is about the marble plate production. Günkaya et al., (2018) defined the implementation of life cycle assessment to analyze the environmental effect of marble plate production. Environmental effects are defined and calculated with the CML-IA method.

The goal of this study is to define the environmental impact of marble production and to compare with ceramic tile by using methodology. Figure 3.4 shows the system boundaries for this study, and the production data of one m^2 of marbel plate is given in Table 3.1.

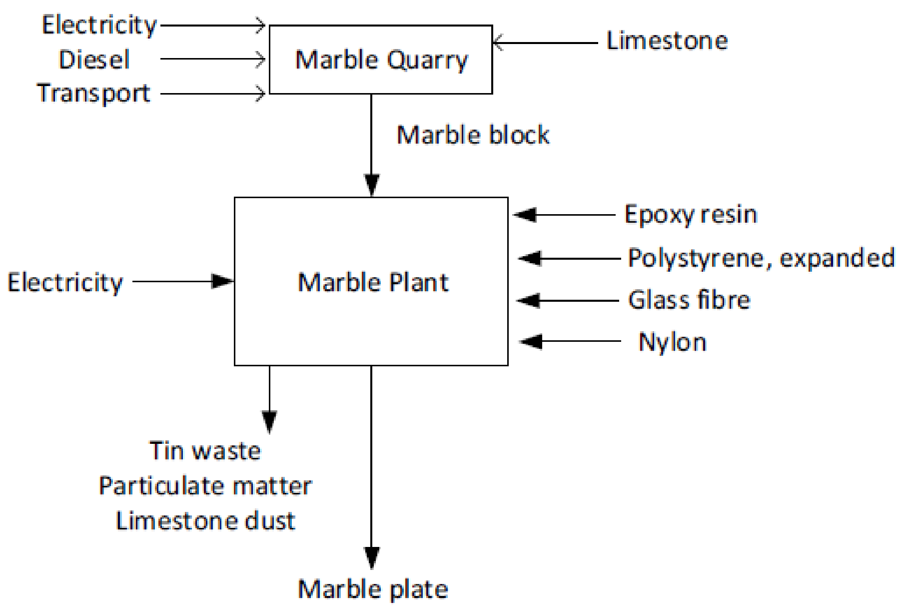


Figure 3.4 System boundaries of LCA study on marble plate production (Günkaya et al., 2018)

Table 3.1 Production data for one m^2 of marble plate product (Günkaya et al., 2018)

Data component	Amount
Inputs	
Marble block (kg/m^2)	85.54
Epoxy resin (g/m^2)	25.27
Glass fiber (g/m^2)	111.29
Polystyrene, expanded (g/m^2)	55.89
Nylon (g/m^2)	3.89
Electricity consumption (kWh/m^2)	2.04
Outputs	
Product marble (m^2)	48.6
Limestone dust (g/m^2)	36.94
Tin waste (from epoxy resins packaging) (g/ m^2)	0.425
Particulate matter (PM) (g/m^2)	0.160

Assumptions used in this study are:

- Functional unit was selected to be m^2 of marble and ceramic products.

- A "cradle to gate" approach was considered, end of life phases was not considered in this study.

- All production data were obtained from a marble production which was organized and existed in a quarry.

- The particulate matter (PM) data was given by the air emissions report of the quarry.

- The recycled water (100%) are using in marble production. It is supposed that there is no wastewater produced in the manifacture. Almost all of marble quarry are located in rugged terrain and the marble mills need very high amount of water. Due to this reason, water is expensive input in manufacturing.

- In ceramic production, wastewater quantity was calculated by taking into consideration as cubic meter of wastewater and the discharge limits given by Turkish Regulation about Water Pollution Discharge Control.

Environmental impacts of the marble plate production, which were found in Günkaya and his friends' research, are given in Table 3.2.

Table 3.2 Marble plate production environmental impact (Günkaya et al., 2018)

Impact category	Unit	Total
ADP_e	kg Sb eq./m^2	3.36E-06
ADP_{ff}	MJ/m^2	48.3
GWP	kg CO_2 eq./m^2	3.96
ODP	kg CFC-11 eq./m^2	1.46E-07
HTP	kg 1,4-DB eq./m^2	0.554
FAETP	kg 1,4-DB eq./m^2	2.76E-02
TEP	kg 1,4-DB eq./m^2	3.22E-03
POP	kg C_2H_4 eq./m^2	6.55E-03
AP	kg SO_2 eq./m^2	2.78E-02
EP	kg PO_4^{---}eq./m^2	2.47E-03

According to results of Günkaya et al., electricity and marble block are important for the marble plate production. On the other part, environmental impact of diesel and electricity are significant for marble block production.

The analyzed results revealed that; fossil fuel based abiotic depletion value of ceramic tile is lower than the marble plate. In addition to this, human toxicity (HT) and global warming (GW) values of marble plate are lesser than ceramic tile. In terms of the environmental concerns, fossil fuel consumption and global warming potential impacts are remarkable. Therefore, there is no precise result to make a choise to use of marble plate or ceramic tile.

Energy consumption must be reduced in Marble plate production industry. Use of the renewable energy sources is one of the ways to reduce of environmental effects. Use the solar energy panel is suggested in this thesis to aichieve this goal. Additionally, usage of the new tecnologies have advantages to reduce environmental effect.

In other respects, global warming potential must be reduced in ceramic tile production industry by improving new processes.

Moreover, the study shows that, Hydrogen Fluoride (HF) emissions cause environmental effects. So that, additional precautions are suggested to reduce HF emissions.

Bianco et al. (2017), reviewed the environmental impact related to the extraction and processing of ornamental stones (such as marbles and granites) (Bianco et al., 2017). Preindustrial period, ornamental stones were handled by manually and used regionally. Associated with the development of transportation ways and quarrying techniques, it caused to a more intensive handling of this resource.

Taking into consideration that production process, stone is one of the natural material and effects connected to the manufacturing are restricted, the time of life of ornamental stone can be much longer according to other construction materials, at the end of life, it can be reutilized in the original form; can be rcycled in other structures (e.g; aggregate). In this research, several LCA studies have been handled for several major stone producers in different countries.

The system boundaries are from-cradle-to-gate. Stone quarrying, cutting of blocks into slabs and tiles, and surface finishing process were taken into consideration in LCA analysis. For each of production steps, the most prevalent and sample techniques were investigated.

Functional units chosen for this study are the volume of one m^3 of stone block and the surface of one m^2 of tile. The data collected refer to the year of 2016, and the average values calculated on cutting of 99 blocks.

At the end of the life, steel blades can be recycled. Stone slurry can be used as a by-product for different implementations (e.g, environmental rehabilitation study). GaBi software (CML 2001) was used for calculating the environmental effects of the multi-blade cutting techniques and input-output chart of their study is shown in Figure 3.5. Water was continually recycled in a close loop, so that water has no impacts in LCA. The slurry wastes were stored in the landfill at the end of life. The inputs-outputs for multiblade cutting technique and the environmental effects of cutting one m^2 of slab with multi-blade technique are shown in Table 3.3 and 3.4, respectively.

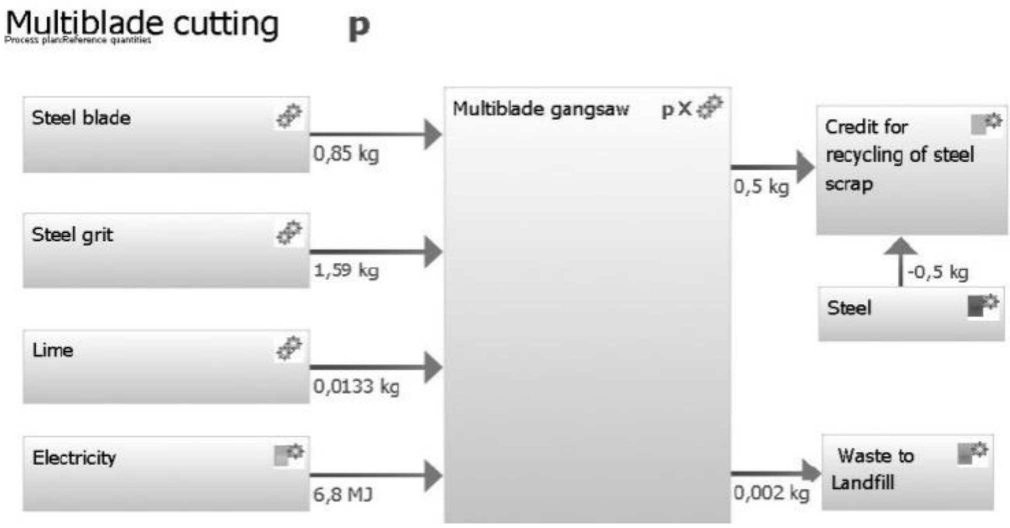


Figure 3.5 Input – output chart for multiblade cutting technique (Bianco et al., 2017)

Table 3.3 Inputs-outputs for multiblade cutting technique (Bianco et al., 2017)

Inputs	Quantity	Outputs	Quantity
Stone block	0.03 m^3	Stone slab	1 m^2
Electricity	6.8 MJ	Exhausted steel	0.5 kg
Steel blades	0.85 kg	Slurry waste	0.002 kg
Steel grit	1.59 kg		
Lime	0.013 kg		

Table 3.4 The environmental effects of cutting one m^2 of slab with multi-blade technique (CML2001 Method)

Impact category	Unit f Measure	Total
Abiotic Depletion (ADPe)	kg Sb-Equiv.	$3.02 \cdot 10^{-7}$
Abiotic Depletion (ADPf)	MJ	$5.81 \cdot 10$
Acidification Potential (AP)	kg SO2-Equiv.	$1.07 \cdot 10^{-2}$
Eutrophication Potential (EP)	kg Phosphate-Equiv.	$7.27 \cdot 10^{-4}$
Freshwater Aquatic Ecotoxicity Pot. (FAETP)	kg DCB-Equiv.	$6.57 \cdot 10^{-3}$
Global Warming Potential (GWP)	kg CO2-Equiv.	5.49
Human Toxicity Potential (HTP)	kg DCB-Equiv.	$4.92 \cdot 10^{-1}$
Marine Aquatic Ecotoxicity Pot. (MAETP)	kg DCB-Equiv.	$6.95 \cdot 10^{2}$
Ozone Layer Depletion Potential (ODP)	kg R11-Equiv.	$4.27 \cdot 10^{-8}$
Photochem. Ozone Creation Potential (POCP)	kg Ethene-Equiv.	$2.27 \cdot 10^{-3}$

The results of the study are shown in Figure 3.6. The whole production chain from the extraction of blocks till the finished stone product could be improved according to the environmental effects. Software databases were lacked about specific stone production processes. Due to the high number of assumptions, these studies were not always significant (Bianco et al., 2017).

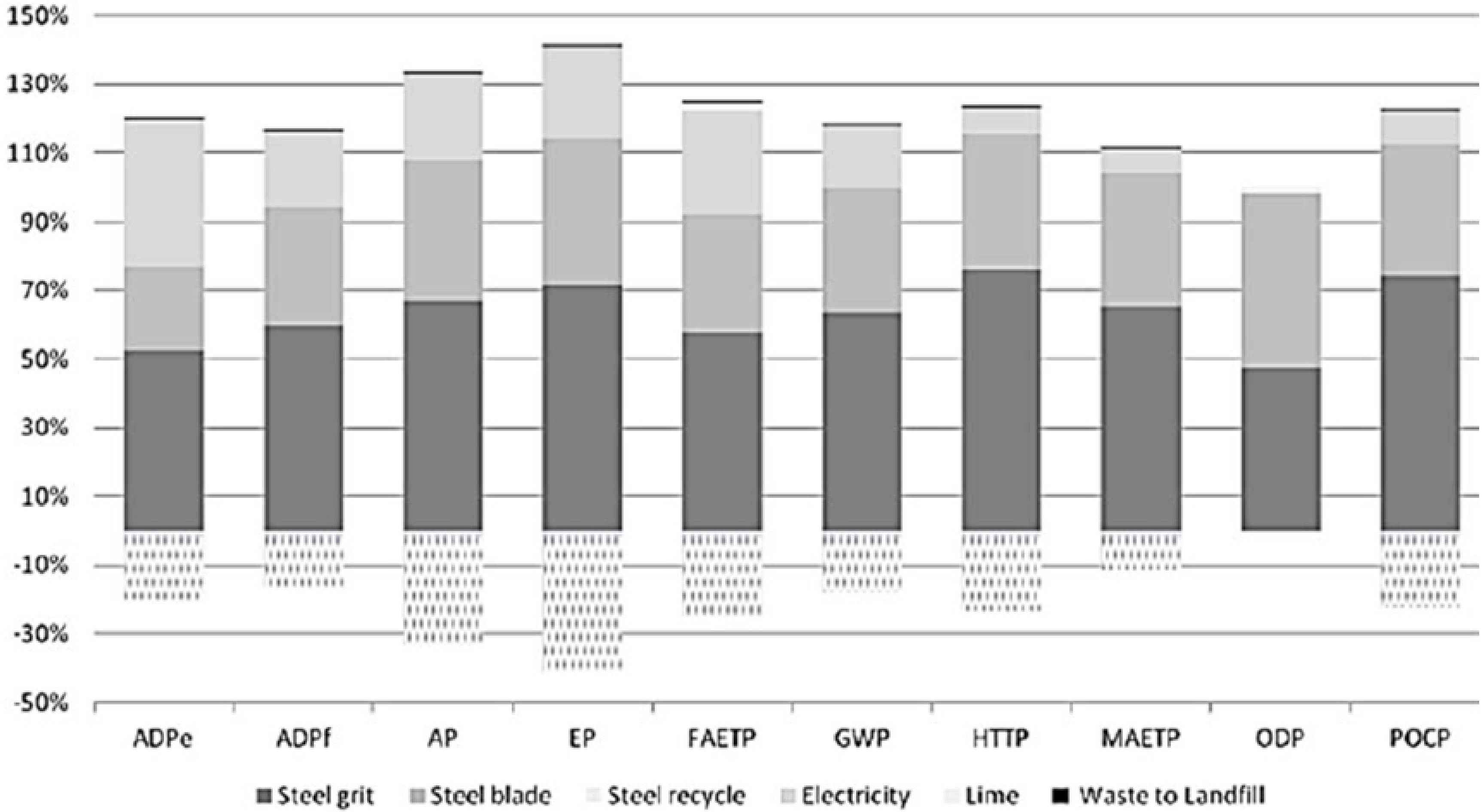


Figure 3.6 Percentage contribution of the environmental effects related to stone tile cut with multi-blde technique (CML2001 method) (for one m^2)

CHAPTER FOUR
MATERIAL AND METHODS

4.1 Description of the Pilot Plant

In the scope of this study, determination of environmental impacts of quartz surface manufacturing was aimed. A pilot plant, which production capacity is one million m^2 of quartz surface per year, was chosen for this aim. The plant manufactures natural composite stone and it is constructed on an approximately 10,000 m^2 indoor area. At the same time, facility has a license about glass waste recycling from Ministry of Environment and Urbanization.

Quartz, resin, catalyst, paint, and effect material are input of the production process. All materials are stored in the warehouse and transported by roadway.

Manufacturing process starts with material selection and quartz mixture and added resin, catalyst, paint and effect material (broken pieces of glass, see shell etc.) in a mixer. Mixture is molded and compressed with a press machine. This process minimizes surface roughness and reduces water absorption.

The pressed mixture is cured in the curing oven at a temperature of 95-100 ^oC degrees in the curing oven for 30-50 minutes. The purpose of this process is, to increase the product resistance to stain and impact. Chilled slabs are polished with water and abrasive stone. Polished slabs are trimmed to a defined size. The slabs are measured after curing is completed. And all slabs are calibrated polished and prepared for packing and shipping. Process flow schema is shown in Figure 4.1.

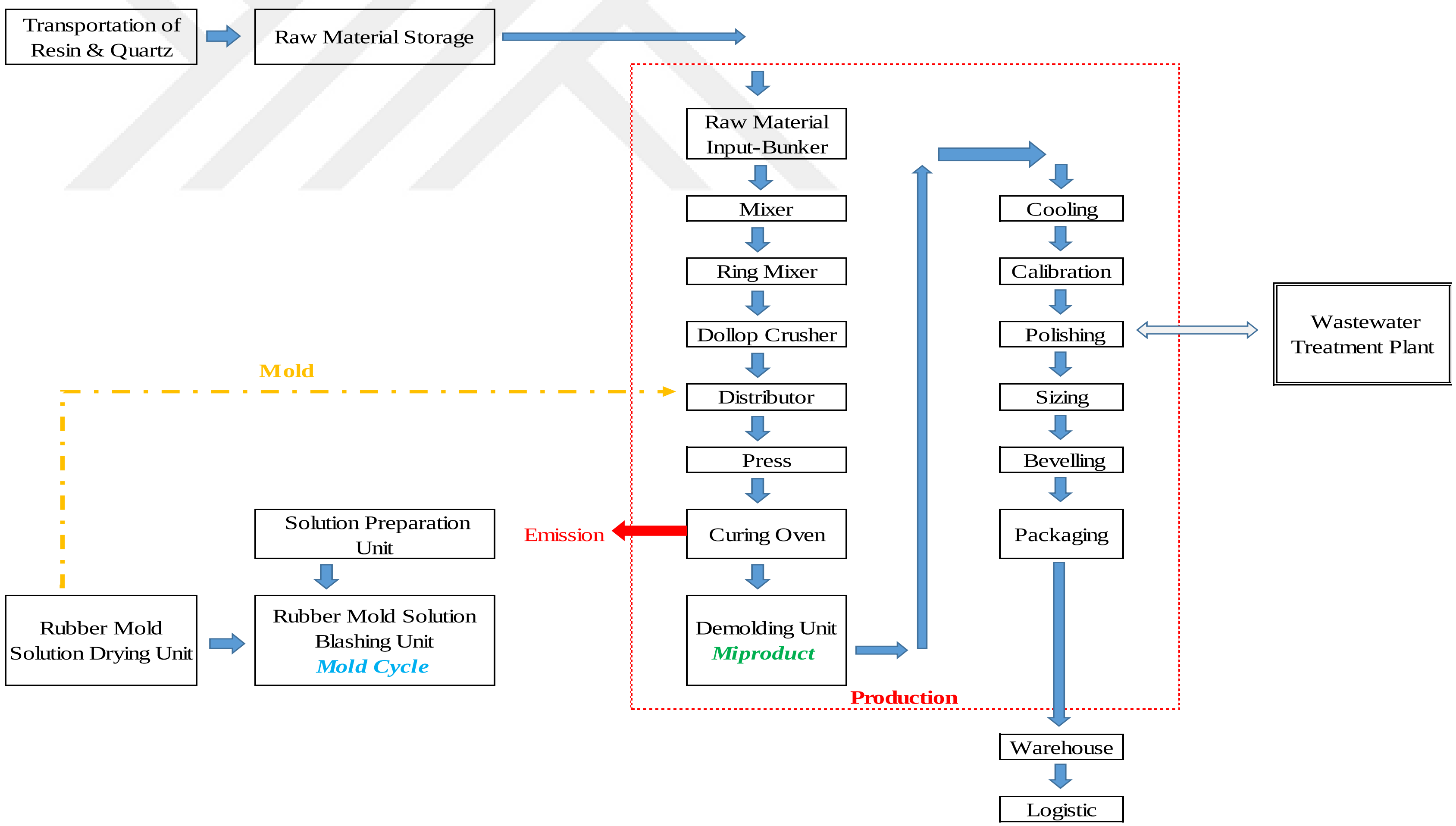


Figure 4.1 Quartz surface production process flow schema in the pilot plant

4.1.1 Water and Energy Uses in the Plant

In the pilot plant, the effluent of the treatment plant is recycled to the production process and reused in a closed loop. Water is used only in the polishing unit in the production process. Approximately 30 m^3/day of water is needed for production. Water consumption records are recorded on a monthly basis.

The production process is working continuesly in a 24/7 period at the pilot plant. All machines, crane, heating and ventilation installation and also wastewater treatment plant is operated with electricity. Electricity consumption records are recorded on a monthly basis (Table 4.1) and totally 9.5 million kWh/year electricity is consumed.

Table 4.1 Energy consumption records of the pilot plant

Month	**Energy consumption, kWh**
January	853052
February	792998
March	867601
April	770512
May	775679
June	672631
July	809583
August	675471
September	736586
October	811923
November	794461
December	872480
Average	786081

4.1.2 Wastewater Management in the Plant

The continuity of the production process, depends on water usage, which is an expensive input, at the same time, water is a valuable natural source for life. Due to these reasons, it is been chosen to use recycled water in the production process of the pilot plant.

Domestic wastewater is generated from the water consumption at toilet, sink and bathrooms. The pilot plant has a permit from local municipality about discharge of domestic wastewater effluent to the sewage system.

Wastewater is produced during the polishing process and it is treated with a 30 m^3 capacity of the wastewater treatment plant. The effluent of the treatment plant is recycled to the production process and reused in a closed loop.

In the treatment plant, phycial and chemical treatment is applied. It contains equalization tank and chemical treatment units. As a result of the chemical treatment, 14000 tons/year of chemical sludge produces. There is a filter press, which is one of the mechanical dewatering equipment, for dewatering of the sludge. Supernatant of the filter press is recycled to the chemical treatment. Wastewater treatment plant flow scheme is shown in Figure 4.2.

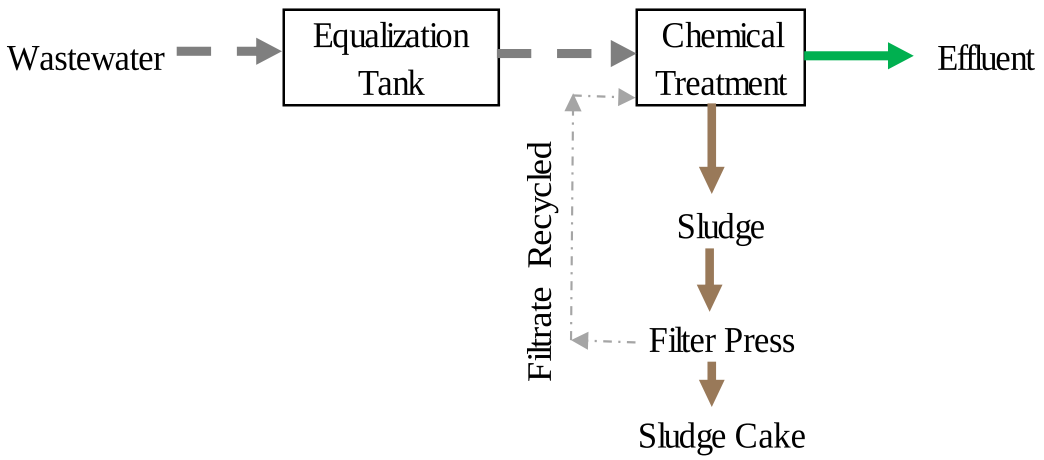


Figure 4.2 Wastewater treatment plant flow scheme in the pilot plant

4.2 LCA Application

4.2.1 Aim and Scope of the Study

To identify the environmental effects of quartz surface production is the goal of this study. With this thesis, environmental effects of the selected pilot plant were identified. The assessment includes all process stages and distribution of environmental impacts for process inputs were determined.

4.2.2 Functional Unit

Functional unit must be corelated with all data which ise used in the scenarios. Functional unit is important for mass balance. Functional unit was selected to be m^2 of production of quartz surface for two scenarios.

All parameters used to define quartz surface characterization express contamination in one m^2 of production.

4.2.3 System Boundaries

Determining the system boundaries is one of most important point of LCA study. The system boundary defines, the content of the inputs and outputs.

System boundaries were determined by using "gate to gate" approach. Raw materials transportation, quartz surface production, and wastewater treatment phases were taken into consideration in these scenarios. System boundaries of quartz surface production is given in Figure 4.3.

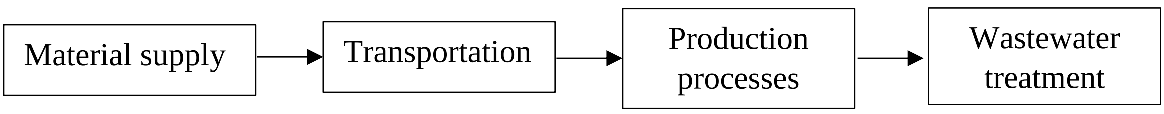


Figure 4.3 System boundaries of the LCA study

4.2.4 GaBi Software and Data Set Used

There are several LCA software package for determine the environmental impacts. A list of the best-known software packages for LCA is shown in Table 4.2. (Ormazabal, et al., 2014)

Table 4.2 The best-known software packages for LCA calculation (Ormazabal, et al., 2014)

Tool	Developer	*Approach*	Web
AIST-LCA 4	National Institute of Advanced Industrial Science and Technology (AIST), Japan	*Generic*	www.aist-riss.jp/main/
Athena	Athena Sustainable Materials Institute, Canada	*Building and construction*	www.athenasmi.org/
BEES 4.0	National Institute of Standards and Technology, USA	*Building materials*	www.nist.gov/el/economics/BEESSoftware.cfm
CMLCA 4.2	Leiden University, Institute of Environmental Sciences (CML), Holland	*Generic*	www.cml.leiden.edu/software/
E³DATABASE	Ludwig-Bölkow-Systemtechnik GmbH, Germany	*Generic*	www.e3database.com/
EARTHSTER 2 TURBO	GreenDelta GmbH	*Generic*	www.greendelta.com/
ECO-BAT 4.0	Haute Ecole d'Ingénierie et de Gestion du Canton de Vaud, Switzerland	*Building and construction*	www.eco-bat.ch/
GaBi	Pe-International	*Generic*	www.gabi-software.com/
GEMIS	Oeko Institut, Germany	*Generic*	www.gemis.de
LEGEP	LEGEP Software GmbH, Germany	*Generic and Building*	www.legep.de/?lang=en
OpenLCA	GreenDelta GmbH	*Generic*	www.openlca.org/
REGIS	Sinum AG - EcoPerformance Systems	Generic	www.sinum.com/
SABENTO	ifu Hamburg GmbH, Germany	Chemical	www.sabento.com
SIMAPRO	PRé-Consultants	Generic	www.pre-sustainability.com/
SULCA 4.2	VTT Technical Research Centre of Finland	*Generic and forest*	www.vtt.fi/index.jsp
TEAM	Ecobilan PricewaterhouseCoopers	*Generic*	www.ecobilan.pwc.fr/en/boite-a-outils/team.jhtml
TESPI	ENEA, Italy	*Generic*	www.elca.enea.it/
UMBERTO	ifu Hamburg GMBH	*Generic*	www.umberto.de/en/
USES-LCA 2.0	Netherlands Center For Environmental Modeling	*Terrestrial, freshwater, and marine ecosystems*	www.cem-nl.eu/useslca.html

SimaPro and GaBi are the most prevelant used for LCA software. Another widely known software tool is OpenLCA and it allows the user to calculate all the stages associated to LCA.

Three of the selected software packages (SimaPro, GaBi and OpenLCA) were analysed by Ormazabal, et al., 2014. The aspects analysed are as graphic interface, uncertainty analysis and, comparison of results. As a result of the analysis, it was found that the three methods provide the minimum requirements, which are the Life Cycle Inventory Analysis and the Life Cycle Inventory. In three methods, all results are presented in reports. The three software packages allow the results to be exported, both graphically and in tables to text editors such as Word or Excel. GaBi allow you to go one step further and add tables and graphs that are automatically changed when inventory changes.

In this study, GaBi Software (Thinkstep, Germany) was chosen because it provides flexible working possibilities. CML 2001 impact assessment method was used to evaluate the environmental impacts.

The needed data for the software was obtained from the literature, pilot plant and Eco-invent database, which are integrated into the GaBi 9.1. Production process mass balance is the most significant point while life cycle is created.

Data and production flow chart regarding to the quartz surface production process were taken from a quartz surface production plant, which is located in İzmir. The particulate matter (dust) results were taken from the legal air emission analysis report of the plant.

All input and output of each phases is determined in Table 4.3. In material supply phase, required materials including quartz sand, pigments (titanium dioxide, iron hydroxide, etc.), resin, broken glass, acetone, and catalyzer is taken from the related facilities. The environmental effects of the production phase of these materials was neglected.

Table 4.3 Input and output values for one m^2 product

		Flows	Amount	Units
Quartz Surface Production	INPUT	Acetone	0.05	kg
		Electricity from natural gas	34.2	MJ
		Gasoline	0.0906	kg
		Internal recycled water	1.50E+03	kg
		Natural gas Turkey	0.159	kg
		Resin	4	kg
		Quartz	84	kg
		Broken Glass	1.2	kg
		Titanium dioxide	0.27	kg
	OUTPUT	Demolition waste	1.3	kg
		Carbon monoxide	0.0024	kg
		Quartz slabs	1	sqm
		Dust	0.0175	kg
		Exhaust	0.0035	kg
		Nitrogen dixide	0.007	kg
		Nitrogen monoxide	0.004	kg
		Sulphur dioxide	0.000527	kg
		VOC	0.16	kg
		Wastewater	1.50E+03	kg

The quartz surface production process comprises some non-hazardous and hazardous waste. The type and amount of all wastes are shown in Table 4.4. Since the amount of other wastes are very low, only the amount of wastewater treatment plant sludge and demolition waste was considered in the LCA study.

Table 4.4 Types of wastes in production process

Types of Waste	Definition of Waste	Total Amount of Waste (kg waste / m^2 product)
Non-Hazardous	Waste Water Treatment Sludge	14
Non-Hazardous	Waste Paper	0.035
Non-Hazardous	Waste Plastic	0.15
Non-Hazardous	Waste Wooden Pallet	0.06
Non-Hazardous	Demolition Waste	1.3
Non-Hazardous	Metal Waste	0.01
Hazardous	Waste Organic Material	0.022
Hazardous	Contaminated Packacing Waste	0.015
Hazardous	Contaminated PPE	0.01

In transportation phase, arrival routes of quartz and resin raw materials have been determined. Then, exhaust emission values were determined by taking into consideration the values given in Table 4.5, the fuel type, vehicle type and distance used in L/km basis.

Table 4.5 Average value of emissions for diesel liquid in L/km (Ötken et al., 2009)

Type of Emissions Resources	Average Value
CO_2	3.900512 g/s
CO	0.012988 g/s
NO_x	0.030507 g/s
HC	0.009035 g/s

In the production process, electricity, natural gas, and water is consumed in addition to raw and auxiliary materials transported from the related facilities. The treated water in the treatment plant is recycled to the production process and reused in a closed loop. Very small amount of fresh water is consumed due to the loss of water during treatment stage and this was neglected in the LCA study. Therefore, only recycled water was used as input of the production process. Emission values of the production phase was determined from the pilot plant operational data.

In wastewater treatment plant phase, the amount of wastewater, coagulant, and energy was taken into consideration as input; the amount of treated water and sludge was considered as output.

All required data was achieved from the pilot plant and all data was calculated for an annual basis depending on the functional unit, which is m^2 of production of quartz surface. Inventory table of raw and supplementary materials for production of one m^2 quartz surface is given in Table 4.6.

Table 4.6 Life cycle inventory data for one m^2 quartz surface

Material	Material amount
Quartz sand	84 kg
Resin	4 kg
Acetone	0.05 kg
Broken glass	1.2 kg
Titanium dioxide	0.27 kg

Input of the system is shown in Figure 4.4 and screenshot examples from the input and output values, which is used in GaBi program are given in Figure 4.5 – 4.7.

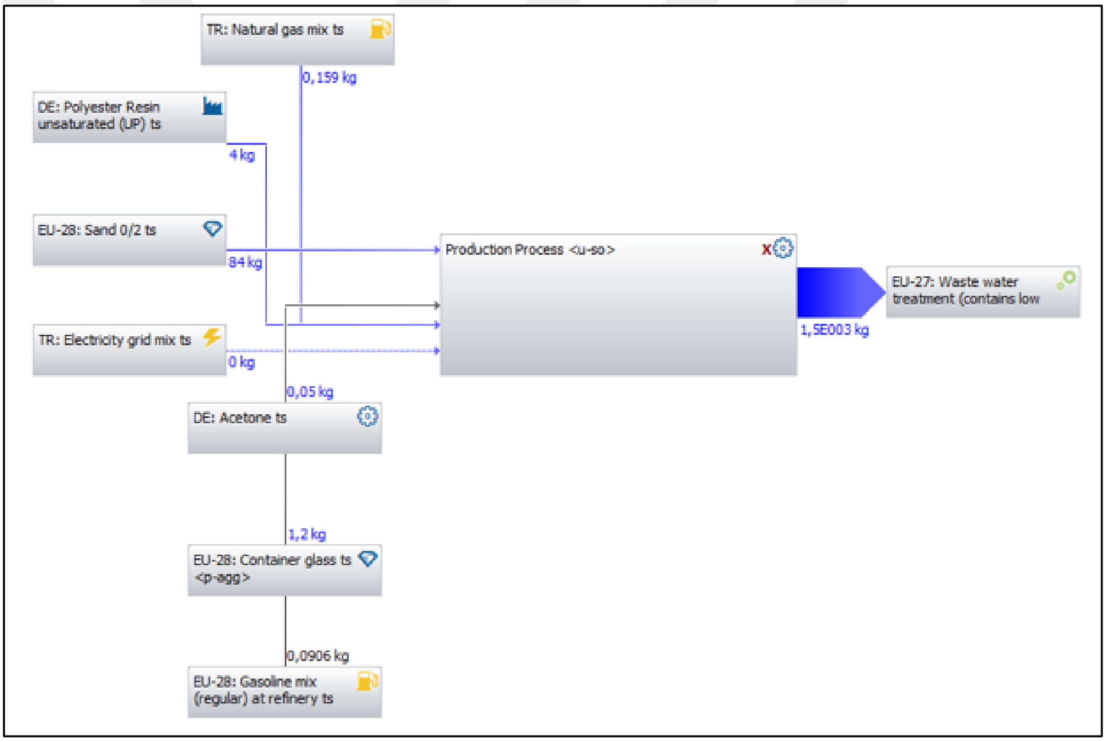


Figure 4.4 Input of the system

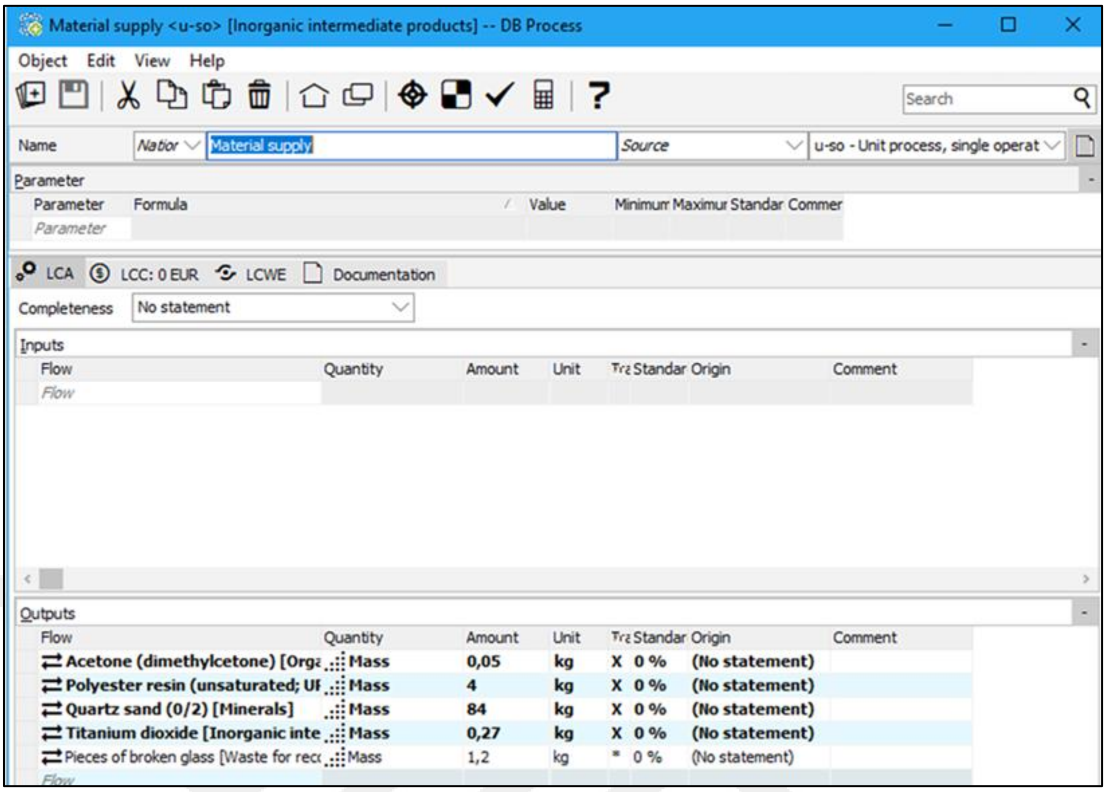


Figure 4.5 Screenshot example from the input-output values of material supply phase

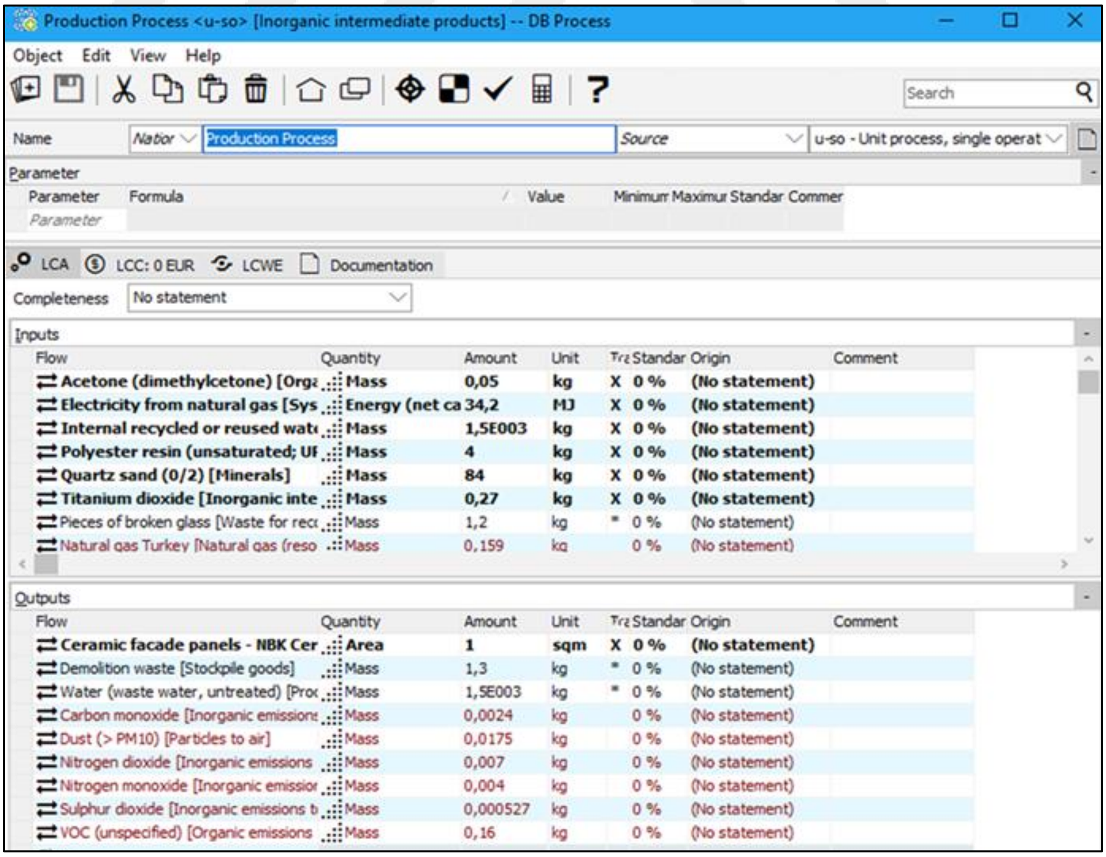


Figure 4.6 Screenshot example from the input-output values of production process phase

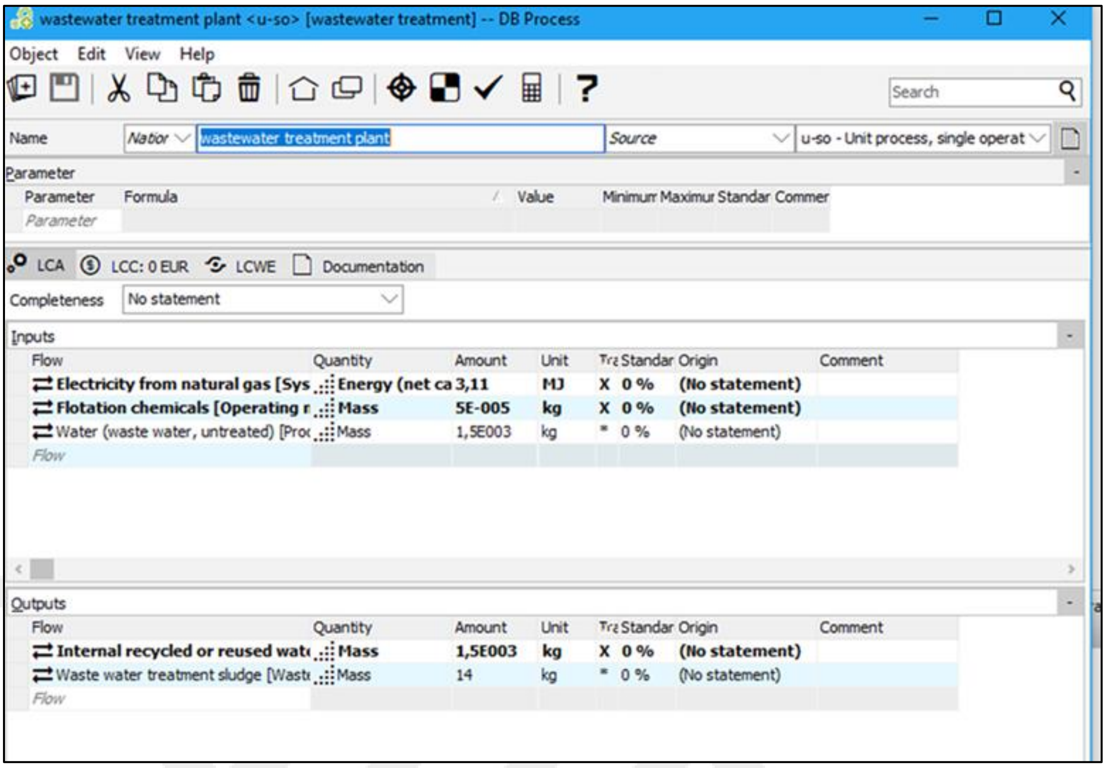


Figure 4.7 Screenshot example from the input-output values of wastewater treatment phase

4.2.5 *Assumptions*

Assumptions are given below:

- A “gate to gate” approach was considered.
- Raw materials transportation, quartz surface production, and wastewater treatment phases were taken into consideration in LCA analysis.
- Functional unit was selected to be m^2 of production of quartz surface for two scenarios.
- Waste disposal process were excluded from assessment.
- Production energy consumption data was taken from bills.
- Wastewater treatment plant energy consumption data was calculated based on energy consumption of installed wastewater plant capacity.
- Transportation emissions data was calcutaled based on the literature.

CHAPTER FIVE
RESULTS AND DISCUSSION

5.1 Environmental Impacts of the Pilot Plant

GaBi software -CML 2001- was used to determine environmental effects of this thesis. By Gabi, the environmental impacts of each process or activity are calculated separately and the results are presented in separate graphs for the impact categories.

Eleven environmental impact categories were taken into consideration: global warming potential, acidification potential, eutrophication potential, ozone layer depletion potential, abiotic depletion elements, abiotic depletion fossil, fresh water aquatic ecotoxicity potential, human toxicity potential, marine aquatic ecotoxicity potential, terrestic ecotoxicity potential, and photochemical ozone creation potential.

5.1.1 Global Warming Potential

Radiation (short-wave) reaches the earth from the sun and is partially absorbed by the earth's crust. Short wavelengths that are not absorbed by the Earth are reflected. Some of the reflected waves are absorbed by the greenhouse gases in the troposphere and propagated in all directions. This propagation causes warming around the world. This event is termed as global warming.

The greenhouse effect can be detected on a small and global scale. In addition to natural occurrences, human activities have an impact on the greenhouse effect. Long-term global impacts should be considered in the greenhouse effect analysis (GaBi Database & Modelling Principles Handbook, 2019).

GWP (Global Warming Potential) is articulated in CO_2, calculated in terms of carbon dioxide equivalent (CO_2 -Equivalent) and shows the effects of greenhouse gases on global warming for different periods, such as 20 years, 100 years, and 500 years. In this study, calculations were made for 100 years.

The different contributors to the GWP of the quartz surface production process are shown in Figure 5.1.

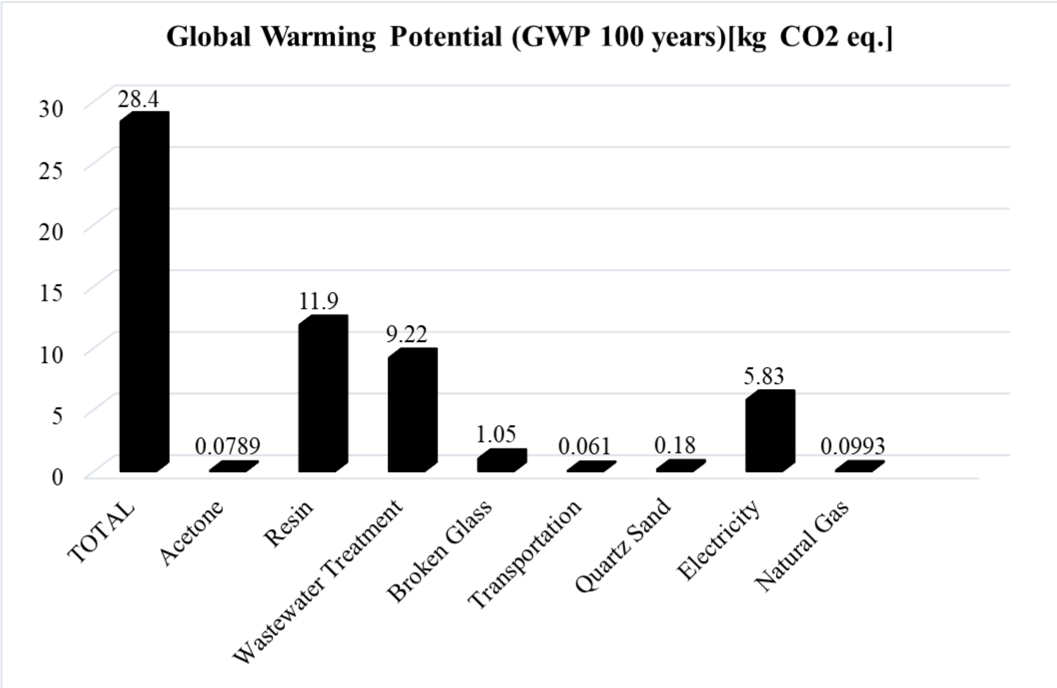


Figure 5.1 Global warming potential

28.4 kg CO_2-Eq of total GWP was calculated for producing one m^2 of quartz surface production. 42%, 32.5%, and 20.5% of GWP arises from resin usage, wastewater treatment, and electricity consumption, respectively.

5.1.2 Acidification Potential

Acidification occurs when air pollutants convert to acids in the air and it causes the pH of the rainwater and fog to drop from 5.6 to 4 and below.

Acidification potential occurs as a result of acids that are spread to the atmosphere and then accumulate in surface soils and waters. AP is expressed in SO_2 and calculated in terms of carbon dioxide equivalent (SO_2-Eq.). The sulphur dioxide is a reference substance.

There are two effects of acidification; Direct and indirect damaging effects. Trees, animals, humans, buildings, materials can be damaged because of acidification. Although acidification is a global problem, it should be evaluated that regional effects may occur.

The different contributors to the AP of the quartz surface production process are shown in Figure 5.2.

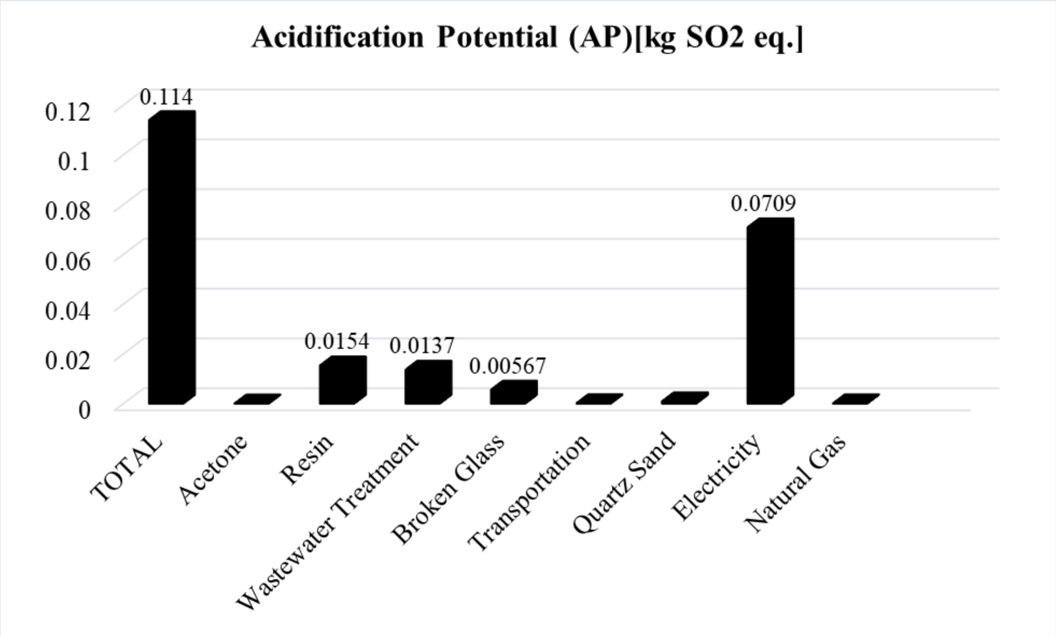


Figure 5.2 Acidification potential

0.114 kg SO_2-Eq of total AP was calculated for producing one m^2 of quartz slab production. 62.2 % of AP arises from electricity consumption.

5.1.3 Eutrophication Potential

Eutrophication is the excessive proliferation of plankton and algae in the large water ecosystem as a result of the substantial increase in nutrients for various reasons. Fertilization in agriculture, wastewater and air pollutants are some of the factors contributing to eutrophication. It can be terrestrial or aquatic. Eutrophication is a global problem and it should be evaluated that regional effects may occur.

EP is expressed in PO_4 and calculated in terms of phosphate equivalent (PO_4-Eq.). The sulphur dioxide is a reference substance.

The different contributors to the EP of the quartz surface production process are shown in Figure 5.3.

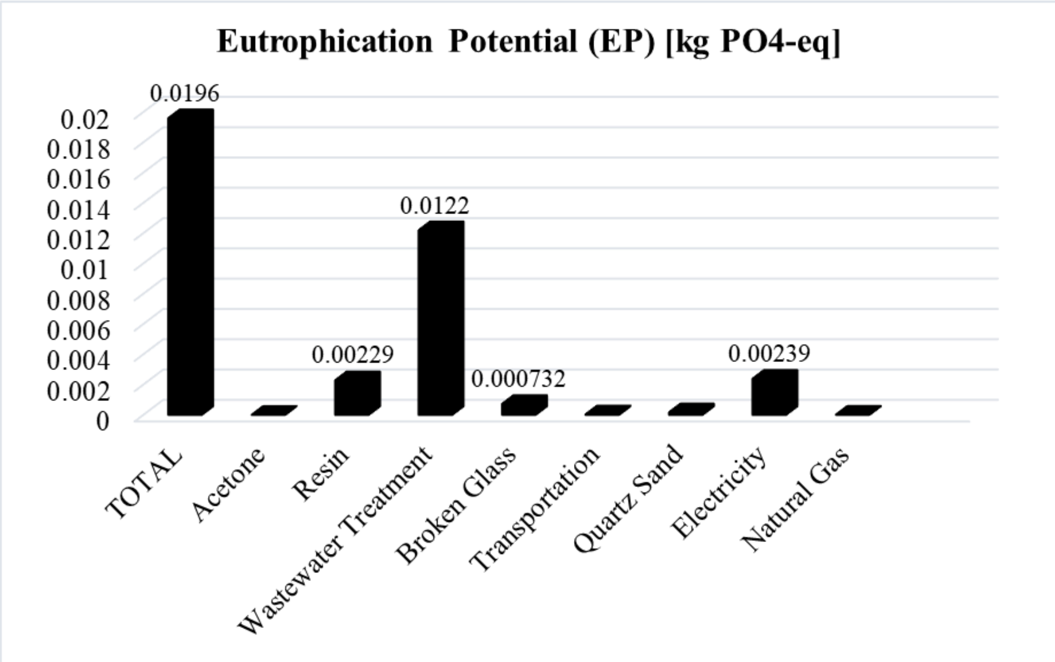


Figure 5.3 Eutrophication potential

0.0196 kg PO_4-Eq of total EP was calculated for producing one m^2 of quartz slab production. 62.2%, 12.2% and 11.7% of EP arises from wastewater treatment, electricity consumption, and resin usage, respectively.

5.1.4 Ozone Layer Depletion Potential

Ozone is formed by decomposition of oxygen atoms exposed to UV light. This leads to the formation of an ozone layer 15 to 50 km high in the stratosphere. Approximately 10% of this formed ozone layer reaches the troposphere.

Ozone layer is required for the continuation of life on Earth. The ozone layer releases UV lights of long wavelengths and absorbs shorter UV lights. Thus, only a small quantity of the UV radiation can reach to the Earth.

One of the activities that cause depletion of ozone is human (anthropogenic) emissions. This consumption is seen in published reports on the ozone layer.

Today, the hole is limited to the region above Antarctica. However, although not at the same latitude as Antarctica, ozone depletion may be detected on medium latitudes (eg, Europe).

Chlorofluorocarbons (CFC_s) and nitrogen oxides (NO_x) are the main substances having a thinning effect on the ozone layer. The heating of the earth's crust is an effect on the thinning of the ozone layer.

Animals, plants and humans are susceptible to UV-B and UV-A radiation and this issue is important for the continuousness of life. The probable effects of ozone depletion can be listed as follows; symptoms of cancer (skin cancer, etc.), Reduction in harvest crops (deterioration of photosynthesis), reduction of sea plankton and negative impact on human, animal and plant life conditions.

Actually, ozone layer depletion potential is a global problem, so that reasons the partly irreversible and long-term effects must be considered in the Ozone depletion potential assessment.

The Ozone Layer Depletion Potential is calculated in in CFC reference (CFC 11) eq. (R11-Eq.). The sulphur dioxide is a reference substance.

The different contributors to the ozone layer depletion potential of the quartz surface production process are shown in Figure 5.4.

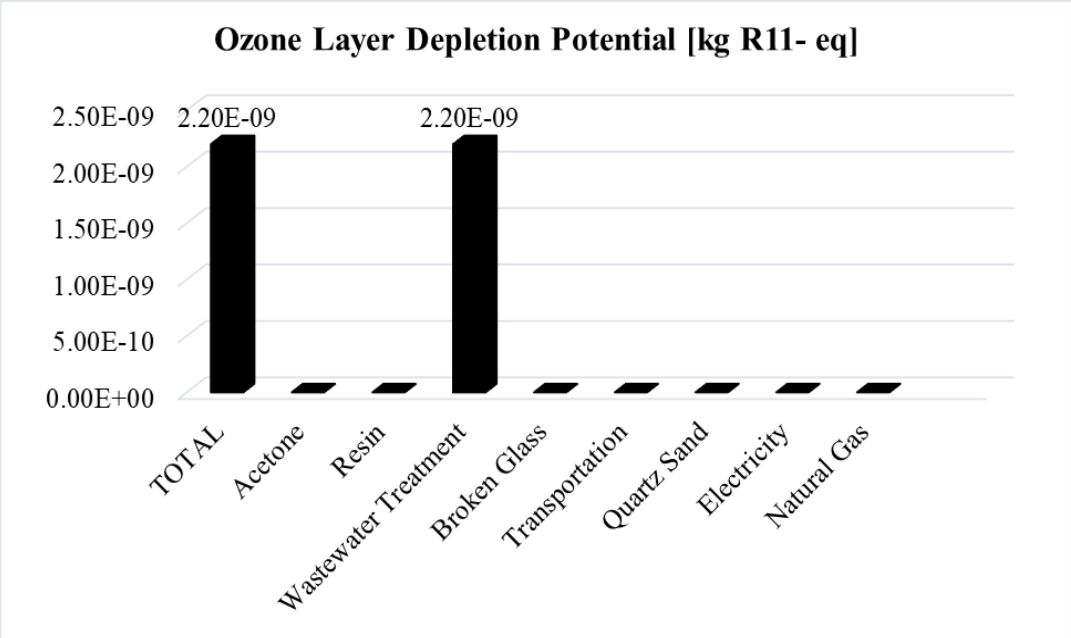


Figure 5.4 Ozone layer depletion potential

5.1.5 Abiotic Depletion (Elements and Fossils)

The potential for abiotic depletion is divided into two sub-categories, as element and fossil, and includes the assessment of the presence of natural elements (minerals and ores).

The crude oil, natural gas, and coal resources effect to Abiotic Depletion Potential (Fossil). The Oils, mineral raw materials, and metal-containing ores effect to Abiotic Depletion Potential (Element). Abiotic resources include raw materials obtained from non-renewable resources.

AP of fossil is expressed in MJ per kg or m^3 of fossil fuel and related to the Lower Heating Value (LHV) (Burchart-Korol, 2016). AP of element is indicated relative to antimony as expressed in kg Sb-eq (Schneider, 2011)

The different contributors to the AP (Element and Fossil) of the quartz surface production process are given in Figure 5.5 and Figure 5.6.

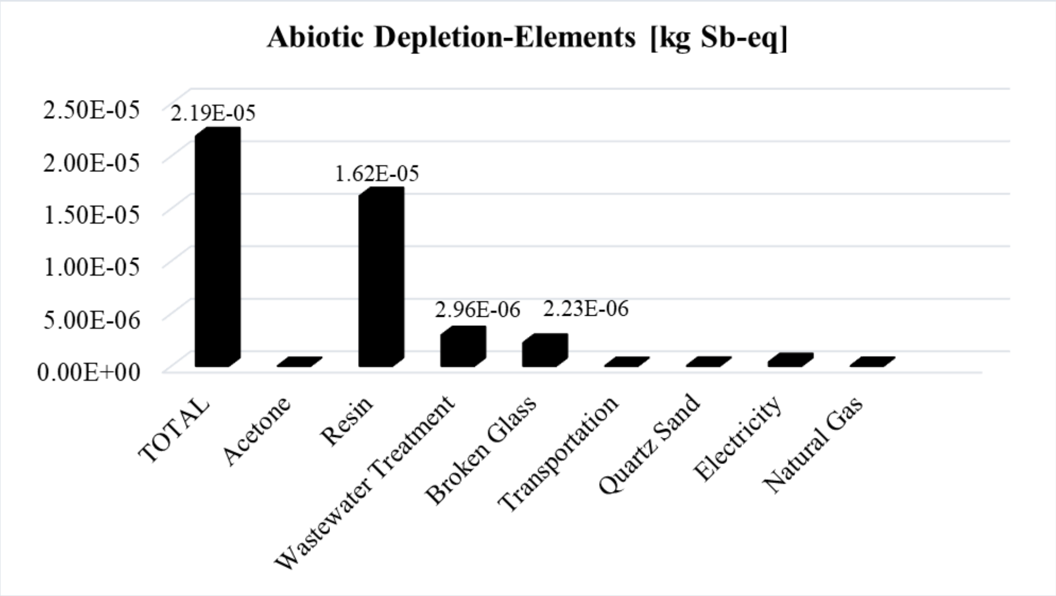


Figure 5.5 Abiotic depletion of elements

2.19E-05 kg Sb-Eq of total AD (Elements) was calculated for producing one m^2 of quartz slab production. 74%, 13.5% and 10.2% of AD arises from resin usage, wastewater treatment, and usage of broken glass, respectively.

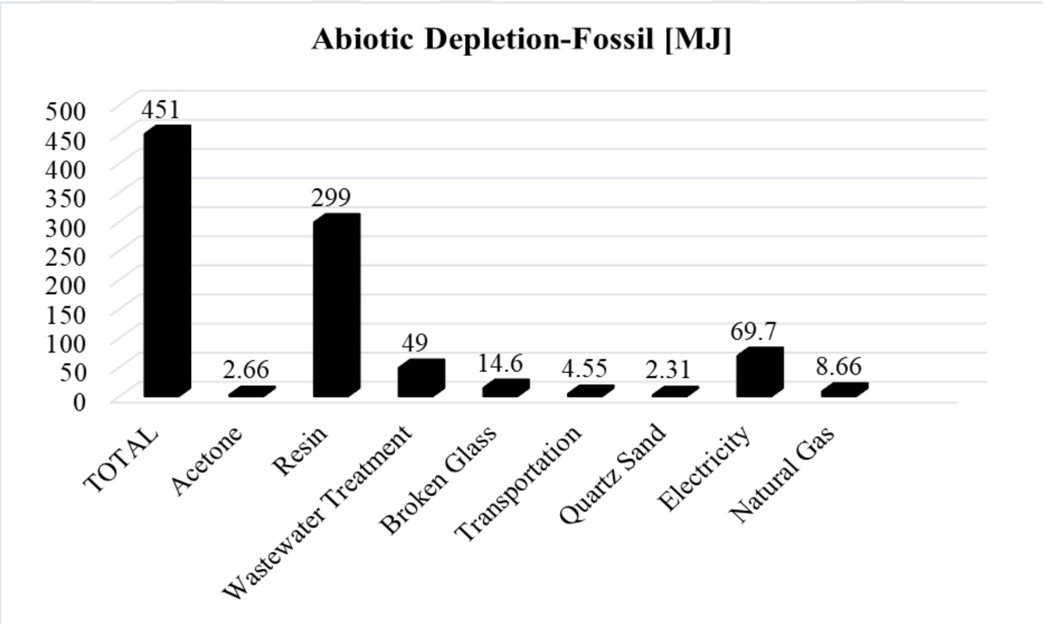


Figure 5.6 Abiotic depletion of fossils

451 MJ of total AD (Fossils) was calculated for producing one m^2 of quartz slab production. 66.3%, 10.8% and 15.4% of AD arises from resin usage, wastewater treatment, and electricity, respectively.

5.1.6 Toxicity Potential

The toxicity potential (TP) is split into four sub-categories, human, freshwater, marine, and terrestic. The human toxicity potential (HTP) is a value that reflects the potential damage of the substance released into the receiving environment. The marine aquatic ecotoxicity is calculated as the same method and approach-wise as freshwater aquatic ecotoxicity. Terrestric ecotoxicity is caused by sulfuric acid and steam used in the conversion process as well as pesticide emissions applied to agricultural soil.

The unit of all types of toxicities (human, freshwater, marine, and terrestic) are given as 1.4-Dichlorbenzol ($C_6H_4C_{l2}$) and it is abbreviated as kg DCB-Eq.

The different contributors to the TP of the quartz surface production process for all sub-categories are shown in Figure 5.7 to Figure 5.10.

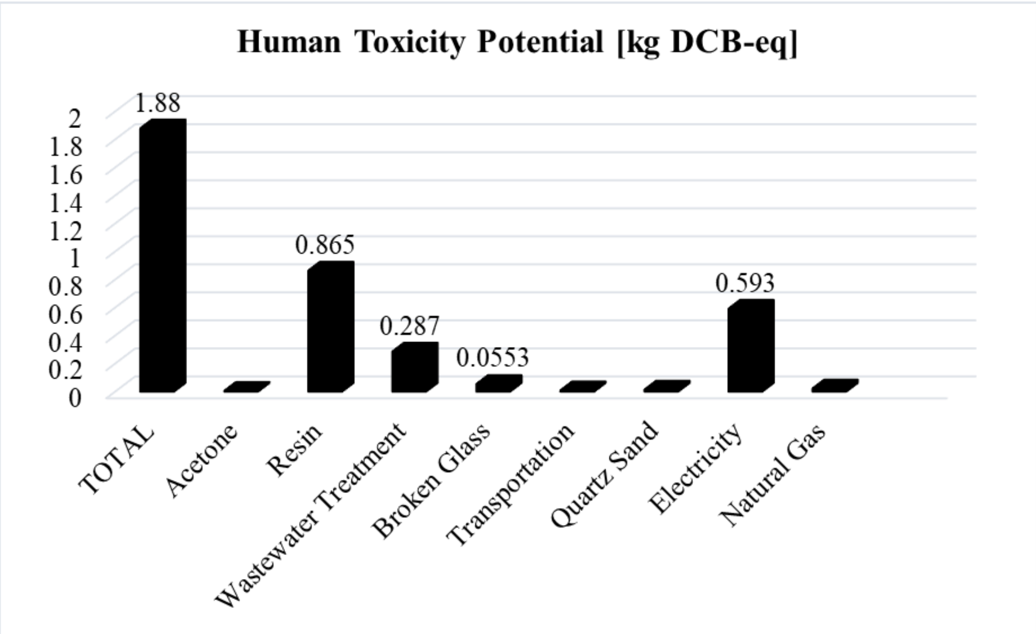


Figure 5.7 Human toxicity potential

1.88 kg DCB-Eq of total HTP was calculated for producing one m^2 of quartz surface production. 46%, 15.3%, 2.94% and 31.5% of HTP arises from resin usage, wastewater treatment, usage of broken glass, and electricity consumption, respectively.

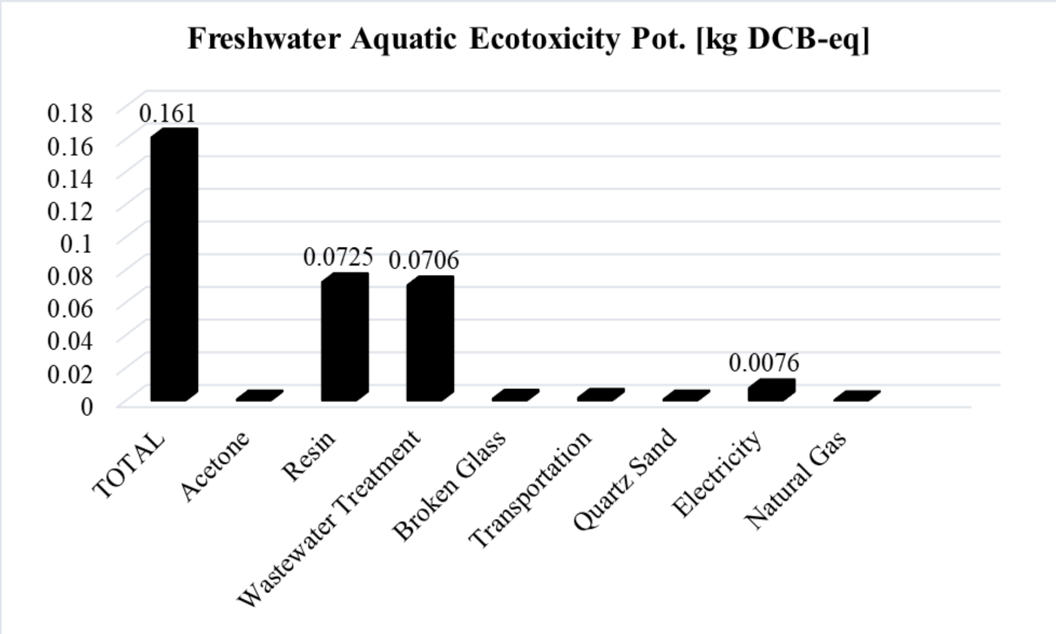


Figure 5.8 Freshwater aquatic ecotoxicity

0.161 kg DCB-Eq of total FAEP was calculated for producing one m^2 of quartz surface production. 45%, 43.9%, and 4.7% of FAEP arises from resin usage, wastewater treatment, and electricity consumption, respectively.

3.05E+03 kg DCB-Eq of total MAEP was calculated for producing one m^2 of quartz surface production. 13.39%, 61.3%, and 23.8% of FAEP arises from resin usage, wastewater treatment, and electricity consumption, respectively.

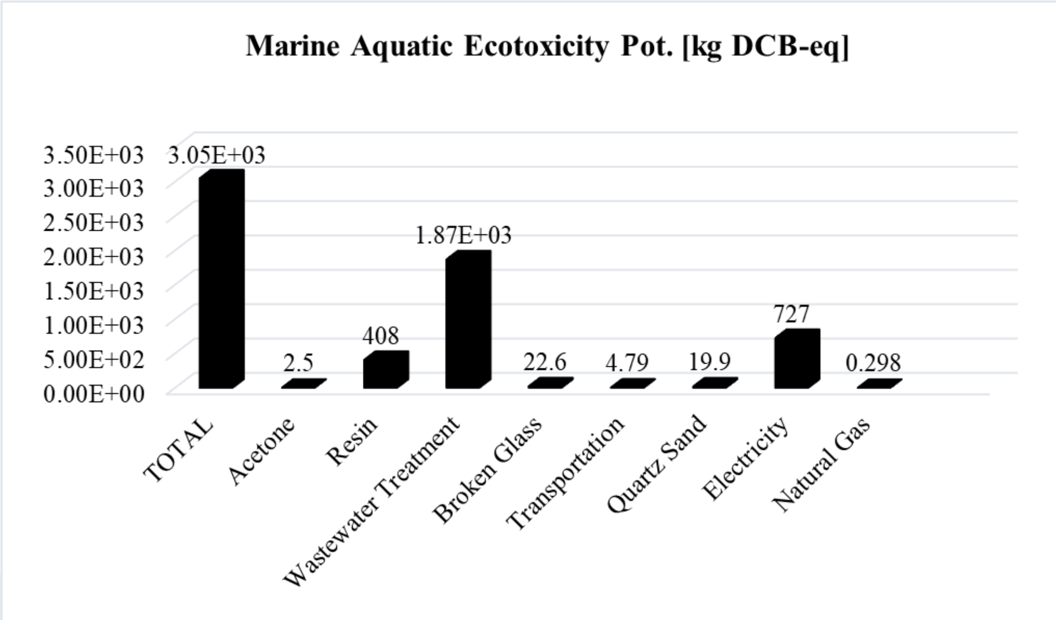


Figure 5.9 Marine aquatic ecotoxicity potential

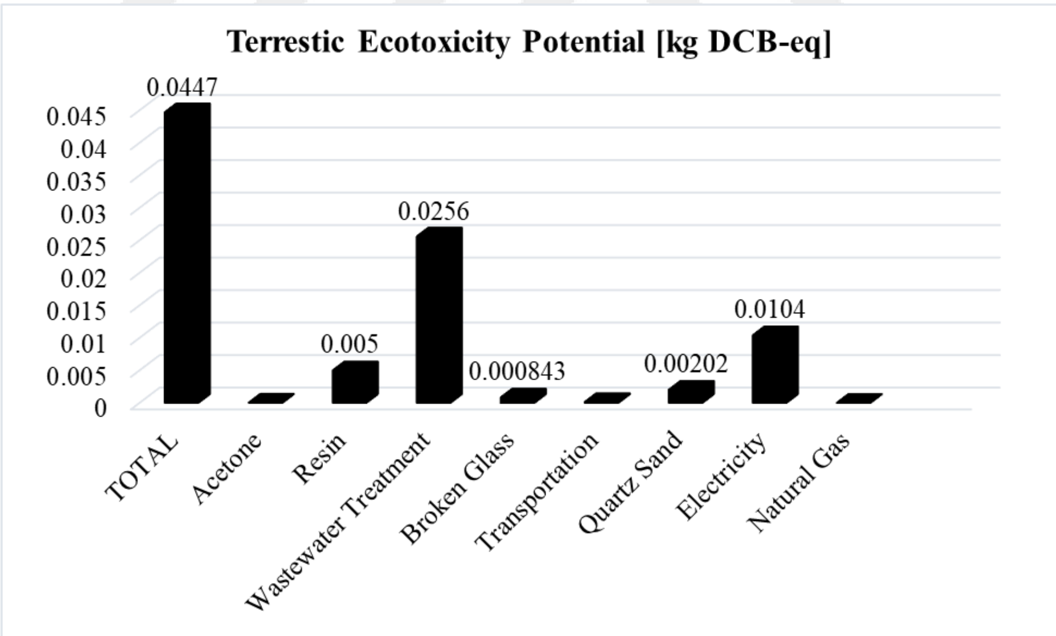


Figure 5.10 Terrestric ecotoxicity potential

0.0447 kg DCB-Eq of total TEP was calculated for producing one m^2 of quartz surface production. 11.2%, 57.3%, and 23.2% of TEP arises from resin usage, wastewater treatment, and electricity consumption, respectively.

5.1.7 Photochemical Ozone Creation Potential (POCP)

Photochemical ozone creation potential it is expressed in kg ethylene (C_2H_4) equivalents and it is suspected of damaging vegetation and material. POCO is also known as summer smog. Although ozone plays a guarding role in the stratosphere, it is classified as a harmful trace gas at Earth Crust. High ozone concentrations are toxic to human life.

The different contributors to the POCP of the quartz surface production process are given in Figure 5.11.

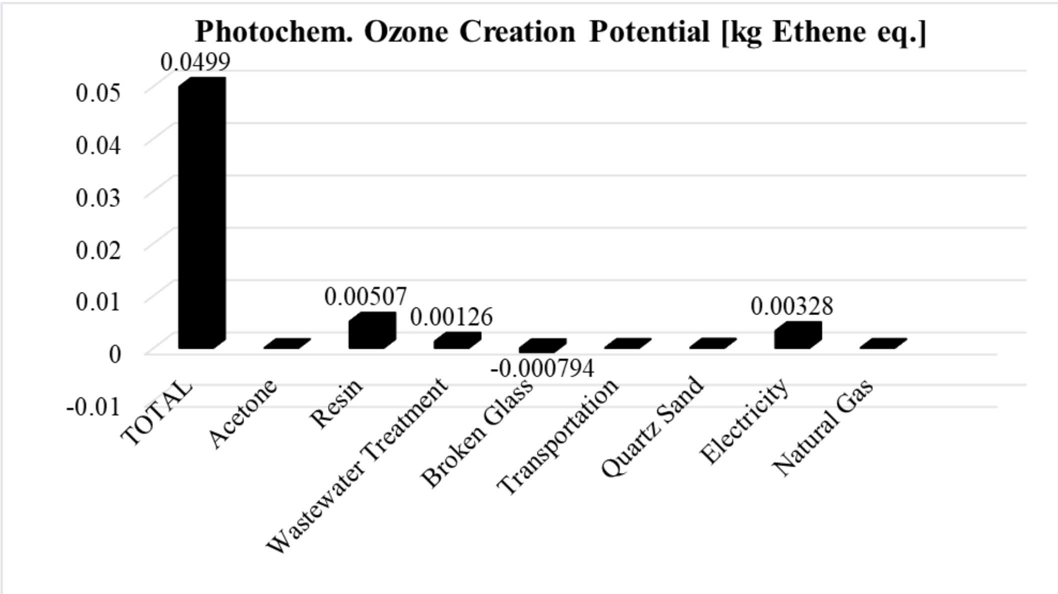


Figure 5.11 Photochemical ozone creation potential

0.0499 kg Ethane-Eq of total POCP was calculated for producing one m^2 of quartz surface production. 10.16%, 2.5%, and 6.57% of POCP arises from resin usage, wastewater treatment, and electricity consumption, respectively.

As is seen from the graph, 0.000794 kg Eten-Eq. gain is obtained due to the use of broken glass in the process. This gain is a positive effect the use of broken glass.

5.2 Evaluation of the Environmental Impacts

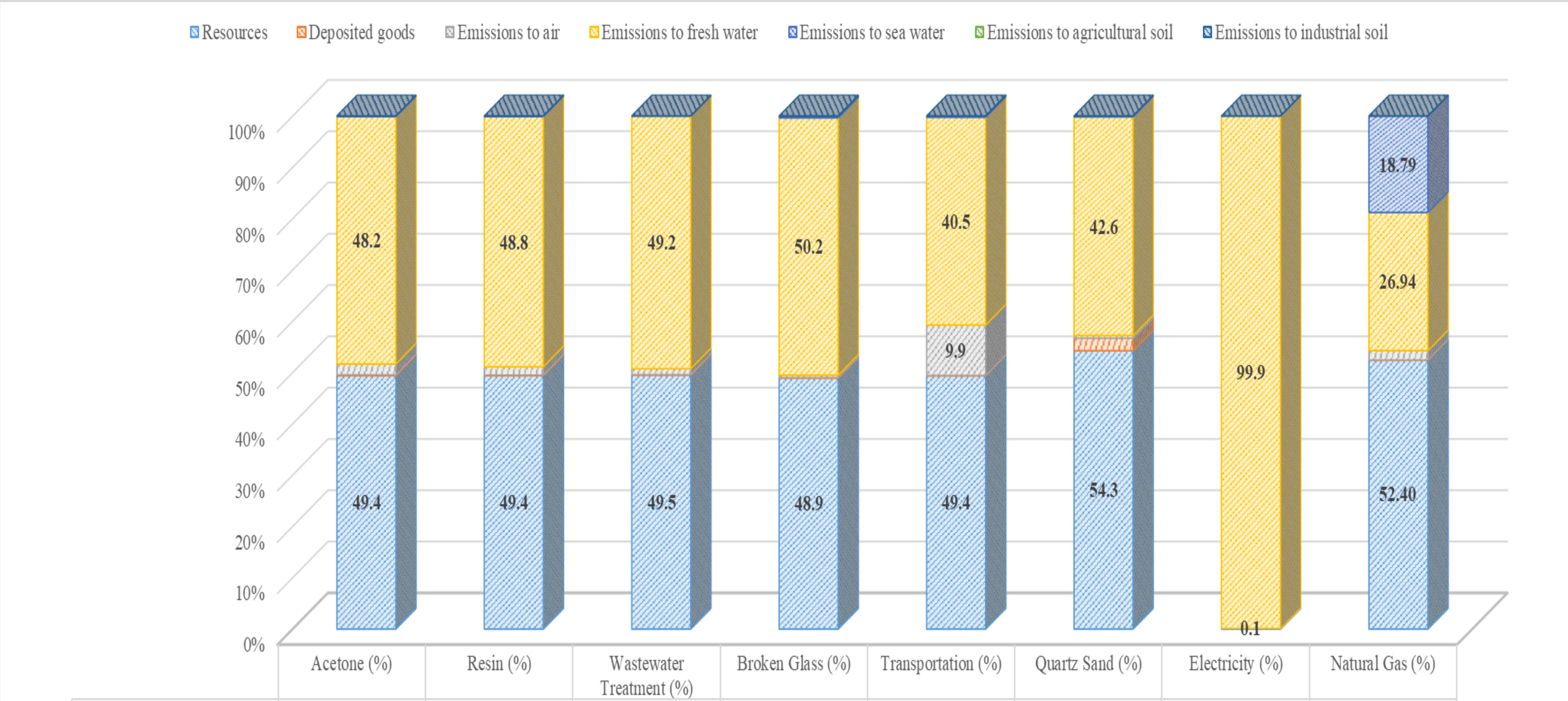
All results of environmental effects of quartz surface production are summarized in Table 5.1. The contribution of significant inputs, such as acetone, resin, broken glass, quartz sand, and electricity, and operations, such as wastewater treatment plant and transportation, to each impact category is seen in the table separately. In the table, the highest value for each environmental impact is remarked in bold.

As seen from Table 5.1, resin consumption is the one of the most significant responsible for the environmental impacts of the quartz surface production.

The distributions of environmental impacts are shown in Figure 5.12 and Figure 5.13. Depending on the results, it is seen that, almost 99.85% of the impacts are originated from emissions to fresh water, 0.148% of the impacts are from resources, and 0.002% from emissions to air.

Table 5.1 Results of the LCA study

Environmental Impacts	TOTAL	Acetone	Resin	Wastewater Treatment	Broken Glass	Transportation	Quartz Sand	Electricity	Natural Gas
Abiotic Depletion (ADP Elements) [kg Sb eq.]	2.19E-05	1.90E-08	**1.62E-05**	2.96E-06	2.23E-06	2.06E-08	4.53E-08	3.90E-07	2.74E-08
Abiotic Depletion (ADP Fossil) [MJ]	451	2.66	**299**	49	14.6	4.55	2.31	69.7	8.66
Acidification Potential (AP) [kg SO2 eq.]	0.114	0.000102	0.0154	0.0137	0.00567	0.000248	0.000985	**0.0709**	0.000182
Eutrophication Potential (EP) [kg Phosphate eq.]	0.0196	1.28E-05	0.00229	**0.0122**	0.000732	4.05E-05	0.000176	0.00239	2.05E-05
Freshwater Aquatic Ecotoxicity Pot. (FAETP inf.) [kg DCB eq.]	0.161	0.000704	**0.0725**	0.0706	0.00118	0.00168	0.00072	0.0076	0.000175
Global Warming Potential (GWP 100 years) [kg CO2 eq.]	28.4	0.0789	**11.9**	9.22	1.05	0.061	0.18	5.83	0.0993
Global Warming Potential (GWP 100 years), excl biogenic carbon [kg CO2 eq.]	22.8	0.0788	**11.8**	3.66	1.05	0.071	0.184	5.83	0.0994
Human Toxicity Potential (HTP inf.) [kg DCB eq.]	1.88	0.00656	**0.865**	0.287	0.0553	0.0102	0.0153	0.593	0.0234
Marine Aquatic Ecotoxicity Pot. (MAETP inf.) [kg DCB eq.]	3.05E+03	2.5	408	**1.87E+03**	22.6	4.79	19.9	727	0.298
Ozone Layer Depletion Potential (ODP, steady state) [kg R11 eq.]	2.20E-09	3.06E-16	8.71E-14	**2.20E-09**	4.23E-15	8.30E-17	2.15E-15	7.87E-15	1.23E-17
Photochem. Ozone Creation Potential (POCP) [kg Ethene eq.]	0.0499	1.94E-05	**0.00507**	0.00126	-0.000794	3.82E-05	8.86E-05	0.00328	3.62E-05
Terrestic Ecotoxicity Potential (TETP inf.) [kg DCB eq.]	0.0447	3.86E-05	0.005	**0.0256**	0.000843	0.000141	0.00202	0.0104	7.23E-06



	Acetone (%)	Resin (%)	Wastewater Treatment (%)	Broken Glass (%)	Transportation (%)	Quartz Sand (%)	Electricity (%)	Natural Gas (%)
Emissions to industrial soil	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00
Emissions to agricultural soil	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00
Emissions to sea water	0.1	0.1	0.0	0.3	0.2	0.2	0.0	18.79
Emissions to fresh water	48.2	48.8	49.2	50.2	40.5	42.6	99.9	26.94
Emissions to air	2.1	1.6	1.2	0.5	9.9	0.5	0.0	1.83
Deposited goods	0.1	0.1	0.1	0.1	0.0	2.4	0.0	0.03
Resources	49.4	49.4	49.5	48.9	49.4	54.3	0.1	52.40

Figure 5.12 Percentage distribution of environmental impacts for process inputs

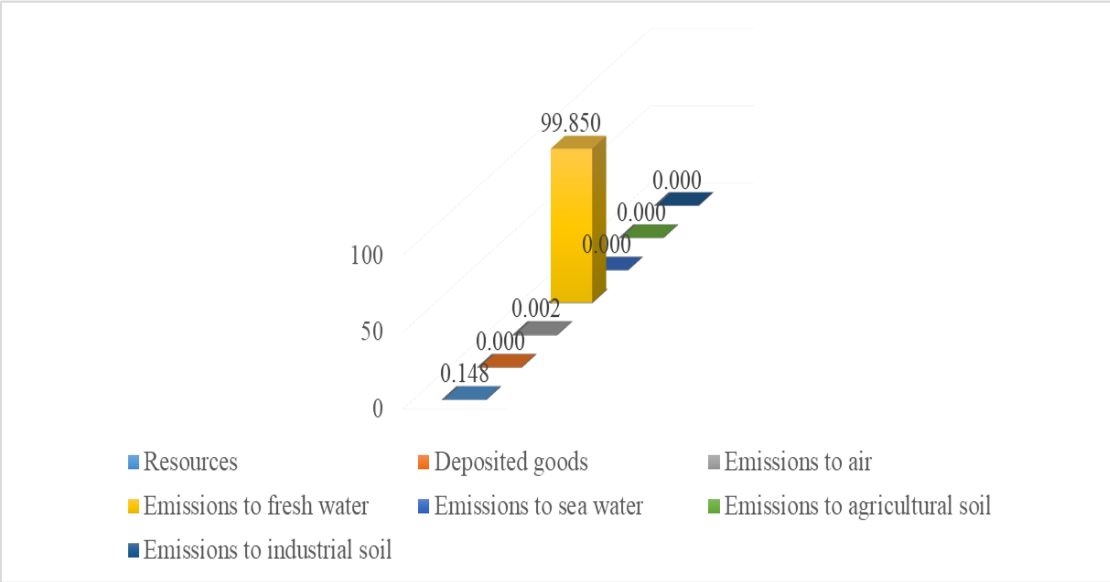


Figure 5.13 Percentage distribution of environmental impacts for total base

The environmental impact results of quartz surface production process are given in the Table 5.2 and Figure 5.14.

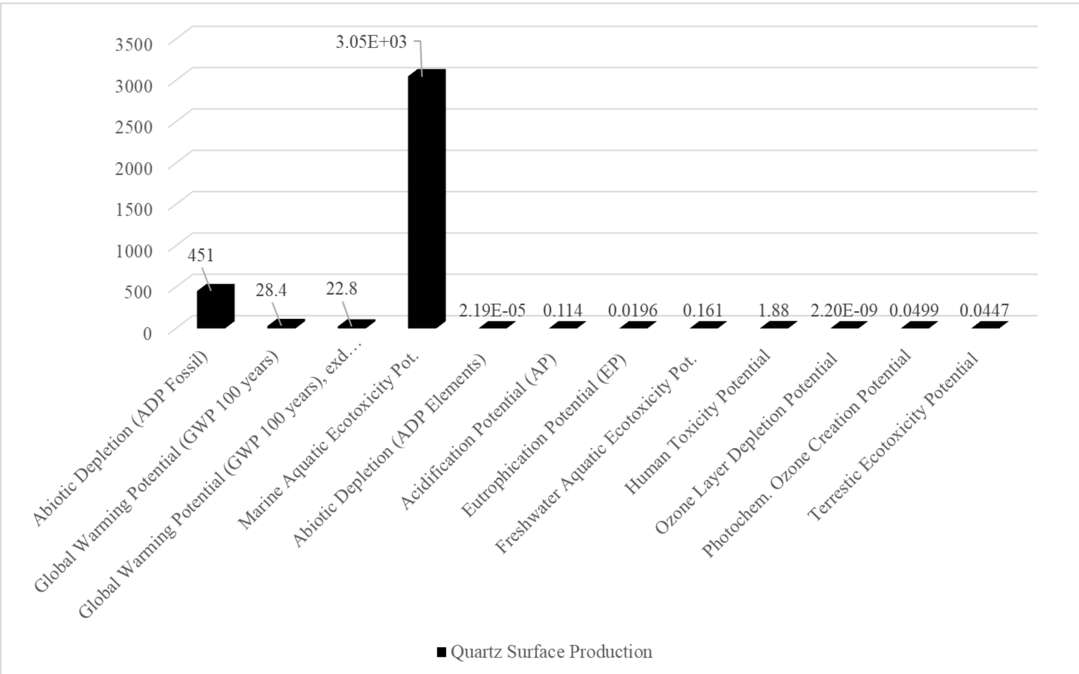


Figure 5.14 Environmental impacts of quartz surface production process

Table 5.2 Total environmental impacts of quartz surface production process

Environmental Impacts	TOTAL
Abiotic Depletion (ADP Elements) [kg Sb eq.]	2.19E-05
Abiotic Depletion (ADP Fossil) [MJ]	451
Acidification Potential (AP)[kg SO2 eq.]	0.114
Eutrophication Potential (EP) [kg Phosphate eq.]	0.0196
Freshwater Aquatic Ecotoxicity Pot. (FAETP inf.) [kg DCB eq.]	0.161
Global Warming Potential (GWP 100 years) [kg CO2 eq.]	28.4
Global Warming Potential (GWP 100 years), exd biogenic carbon [kg CO2 eq.]	22.8
Human Toxicity Potential (HTP inf.) [kg DCB eq.]	1.88
Marine Aquatic Ecotoxicity Pot. (MAETP inf.) [kg DCB eq.]	3.05E+03
Ozone Layer Depletion Potential (ODP, steady state) [kg R11 eq.]	2.20E-09
Photochem. Ozone Creation Potential (POCP) [kg Ethene eq.]	0.0499
Terrestic Ecotoxicity Potential (TETP inf.) [kg DCB eq.]	0.0447

CHAPTER SIX
CONCLUSIONS

6.1 Conclusions

In this study, quartz surface production was analyzed in terms of its environmental effects by using LCA approach. Enough quality and quantity data collection are very important phase of LCA studies. One of the most important achievements of this study is the provision of all inputs and outputs for the plant being examined. All required data was calculated for the pilot plant for an annual basis and the environmental impacts of the pilot plant was determined.

Quartz surface producers should revise global warming potential of their production by developing new projects. In the LCA of the use of resin and quartz as raw material in production, considerable attention could be paid to electricity consumption and the types of resin to ensure considerable gains in the environmental impact categories.

When the environmental impact categories of quartz surface production process are examined, it is seen that the most important effect is caused by using resin, which is one of the non-renewable natural sources. At the same time, it is seen that electricity consumption and wastewater treatment plant increase environmental impacts.

6.2 Recommendation

LCA calculation heavily depends on functional unit and the system boundaries. This study might be developed more with the help of extending the system boundaries further. In order to expand the limits of the study, assuming that wastewater is discharged without treatment, environmental impacts of wastewater discharged without treatment can be evaluated.

In order to reduce energy consumption in production processes, it is recommended to use new technologies and less energy consuming equipment.

In addition, it is recommended that improvement studies should be carried out to reduce the amount of sludge from the treatment plant. To reduce environmental impacts, it is recommended to minimize the chemicals used in the treatment plant and production and to select environmentally friendly products.

In this thesis, GaBi 9.1 Software and CML 2001 impact assessment methodology were used to determine the environmental impact. The GaBi Database is comprehensive; however, the database should be expanded considering the evolving and changing production processes.

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