# COMPARISON OF SUB-PROCESSES AND FINAL PRODUCTS OF IRON AND STEEL PRODUCTION WITH LIFE CYCLE ASSESSMENT

A THESIS SUBMITTED TO
THE GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES
OF
MIDDLE EAST TECHNICAL UNIVERSITY

BY

GÜLNUR ÖLMEZ

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR
THE DEGREE OF MASTER OF SCIENCE
IN
ENVIRONMENTAL ENGINEERING

NOVEMBER 2011

Approval of the thesis:

**COMPARISON OF SUB-PROCESSES AND FINAL PRODUCTS OF IRON AND STEEL PRODUCTION WITH LIFE CYCLE ASSESSMENT**

submitted by **GÜLNUR ÖLMEZ** in partial fulfillment of the requirements for the degree of **Master of Science in Environmental Engineering Department, Middle East Technical University** by,

Prof. Dr. Canan Özgen _________________
Dean, Graduate School of **Natural and Applied Sciences**

Prof. Dr. Göksel N. Demirer _________________
Head of Department, **Environmental Engineering**

Prof. Dr. Ülkü Yetiş _________________
Supervisor, **Environmental Engineering Dept., METU**

Prof. Dr. Filiz B. Dilek _________________
Co-Supervisor, **Environmental Engineering Dept., METU**

**Examining Committee Members:**

Prof. Dr. Kahraman Ünlü _________________
Environmental Engineering Dept., METU

Prof. Dr. Ülkü Yetiş _________________
Environmental Engineering Dept., METU

Prof. Dr. Tanju Karanfil _________________
Environmental Engineering Dept., Clemson University

Asst. Prof. Dr. Emre Alp _________________
Environmental Engineering Dept., METU

Dr. Elif Asuman Korkusuz Ülgen _________________
Optima Engineering

**Date:** _________________

**I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.**

Name, Last name : Gülnur Ölmez

Signature :

# ABSTRACT

COMPARISON OF SUB-PROCESSES AND FINAL PRODUCTS OF IRON AND STEEL PRODUCTION WITH LIFE CYCLE ASSESSMENT

Ölmez, Gülnur
M.Sc., Department of Environmental Engineering
Supervisor: Prof. Dr. Ülkü Yetiş
Co-Supervisor: Prof. Dr. Filiz B. Dilek

November 2011, 191 pages

Iron and steel production is one of the most resource and energy demanding industries around the world. Throughout the life cycle of iron and steel products, the intensive use of raw materials and energy results in contributions to a wide range of environmental impacts. This study conducts a life cycle assessment (LCA) for iron and steel production in Turkey using SimaPro software and IMPACT 2002+ impact assessment method with the purpose of comparing the impacts of life cycle stage (coke making, sintering, iron making, steel making) and final products (billet, slab, hot rolled wire rod, hot rolled coil). The system boundary was set as cradle-to-gate, the functional unit was selected as 1 ton of product, and the study was conducted using the inventory data collected from one of the three integrated iron and steel facilities representing the majority of the industry in Turkey. Different production scenarios for the final products were also evaluated to see the variation in the total impacts. The results indicated that, liquid steel production process exhibited the highest total environmental impact, which was followed by sinter production. Coke production process showed the highest impact on depletion of non-renewable energy sources. The comparison of the impacts for different final products revealed that hot rolled coil causes the highest total environmental impact. Moreover, the environmental impact of mechanical workshop of the facility was found negligible when compared to the production processes.

**Keywords:** Iron and steel production, life cycle assessment, SimaPro software

# ÖZ

## DEMİR VE ÇELİK ÜRETİMİ ALT SÜREÇLERi VE NİHAİ ÜRÜNLERİNİN YAŞAM DÖNGÜSÜ DEĞERLENDİRMESİ İLE KARŞILAŞTIRILMASI

Ölmez, Gülnur
Yüksek Lisans, Çevre Mühendisliği Bölümü
Tez Yöneticisi: Prof. Dr. Ülkü Yetiş
Ortak Tez Yöneticisi: Prof. Dr. Filiz B. Dilek

Kasım 2011, 191 sayfa

Demir ve çelik üretimi, dünyanın en büyük kaynak ve enerji gerektiren endüstrilerden biridir. Demir ve çelik ürünlerinin yaşam döngüsü boyunca, hammadde ve enerjinin yoğun kullanımı çok çeşitli çevresel etkilere sebep olur. Bu çalışma, SimaPro yazılımı ve IMPACT 2002+ değerlendirme metodu kullanılarak yaşam döngüsü aşamalarının (kok yapımı, sinterleme, demir üretimi, çelik üretimi) ve nihai ürünlerin (kütük, slab, sıcak haddelenmiş kangal, sıcak haddelenmiş bobin) etkilerini karşılaştırma amacı ile, Türkiye'de demir ve çelik üretimi için bir Yaşam Döngüsü Değerlendirmesi'ni (YDD) ortaya koymaktadır. Sistem sınırı beşikten kapıya olarak belirlenmiş, işlevsel birim 1 ton ürün olarak seçilmiş ve çalışma Türkiye'de sektörün çoğunluğunu temsil eden üç entegre demir ve çelik tesisinden biri olan tesisten elde edilen envanter verileri kullanılarak yapılmıştır. Nihai ürünler için farklı üretim senaryoları toplam etki üzerindeki değişiklikleri görmek için değerlendirilmiştir. Elde edilen sonuçlara göre, sıvı çelik toplam çevresel etkiler açısından en büyük etkiye sahip olduğu ve bunu sinterin takip ettiği bulunmuştur. Kok üretim prosesi yenilenemeyen enerji kaynaklarının tüketimine en büyük etkiyi göstermiştir. Farklı nihai ürünlerin etkilerinin karşılaştırılması, sıcak haddelenmiş bobinin en yüksek toplam çevresel etkiye sahip olduğunu ortaya koymaktadır. Ayrıca, üretim süreçleri ile karşılaştırıldığında, tesisin mekanik atölyesinin çevresel etkisi göz ardı edilebilir bulunmuştur.

**Anahtar Kelimeler:** Demir çelik üretimi, yaşam döngüsü değerlendirmesi, SimaPro yazılımı

*To My Family*

## ACKNOWLEDGMENTS

I would like to express my deepest gratitude to my supervisor Prof. Dr. Ülkü Yetiş and my co-supervisor Prof. Dr. Filiz B. Dilek for their invaluable support, encouragement, guidance and insights throughout my study.

I would like to express my gratitude to Supervising Committee Members for their valuable appreciations and contributions to my study.

This study was supported by a project of the Scientific and Technological Research Council of Turkey (TUBITAK – 107G126); I also want to thank them for the support. And, I want to thank the authorities of the facility that provide the opportunity for me to conduct my study and the technical staff that allocate time for me.

I would like to express my gratitude to my friends Çisem Yiğit and Nur Çakır for their friendship, understanding, positive energy and valuable support throughout my study. And I also want to thank my cousin Ceren Bora for her guidance and moral support.

I wish to express my gratitude to my mother Necla Maden, my father Rıdvan Maden and my sister Ayşegül Maden for their confidence and belief in me. I appreciate their support and love throughout my life. And lastly, I would like to express my warmest thanks and love to my dearie husband Harun Deniz Ölmez for his endless support and encouragement. I could never complete this thesis without him. So I glad I have you.

**TABLE OF CONTENTS**

# LIST OF TABLES

## TABLES

# LIST OF FIGURES

## FIGURES

# CHAPTER 1

# INTRODUCTION

## 1.1. General

Steel is one of the most attractive, most robust and sustainable basic materials for a sustainable development of modern industrialized societies around the world. Thousands of different types of steel products facilitate and improve our daily life in innumerable applications [1]. With the increase in worldwide total economic activities and the growth of economy reflecting the demand for more housing, car, and white goods and for other iron and steel products/structures, and therefore production has been increasing rapidly [2]. The global production of crude steel reached 1.417.264 thousand tons in 2010 [3].

In the iron and steel production over world, China takes the first place, and Japan, Russian, and U.S. follow it. Turkey, with a 25.304.000 tons production had a share of 1.9% of the total world production in 2009 [3] and ranked number ten among the 64 steel-producing countries in the World. Meanwhile, in Europe, Turkey ranks number two after Germany [3]. So; iron and steel industry has a vital role in the economic development of Turkey [2].

Iron and steel production is highly energy intensive and therefore it is associated with significant $CO_2$ emissions. For instance, Japanese Steel Industry that accounts for over 10% of the world steel production is responsible for 14% of the total $CO_2$ emissions from Japan [5]. Similarly, the energy consumption by Turkish Iron and Steel Industry is also high corresponding to 10.3% of the total electricity, 5.6% of the total natural gas, 21,2% of the total hard coal and ultimately 6.4% of the total industrial energy utilization in 2009 [6]. This high energy consumption indicates that resource conservation, energy efficiency, and emissions reduction in iron and steel industry are important topics for Turkey. In this context, life cycle analysis (LCA) tool has been applied widely for the assessment of environmental impacts associated with process variants in the manufacture of many different industrial products.

LCA provides a method for assessment of all environmental impacts associated with a service or product. Through the LCA analysis, all possible environmental loads of a service are ultimately classified according to their contribution to a number of environmental impacts, including ozone depletion potential, global warming potential and human toxicity. While LCA can be applied to compare the environmental impact of different products (product-based LCA), it can be also applied to compare different production processes or to evaluate the sub-processes in a production process between each other (process-based LCA), Hence, LCA can be used to determine the hotspots in a life cycle, i.e. the stages causing greatest environmental harm, so that these can be targeted for improvements [7].

Within the framework of harmonization period between Turkey and the European Union (EU), various environmental EU directives have been transposed to national legislation. In this context, Waste Framework Directive (2006/12/EC) was transposed into national legislation and the Regulation on Hazardous Waste Control (Official Gazette No. 25755 dated 14.03.2005) has been revised, Regulation on the General Principles of Waste Management (Official Gazette No. 26927 dated 05.07.2008) was published. As of 11.12.2010, 2006/12/EC was repealed by the Directive 2008/98/EC (Directive on waste and repealing certain Directives) that defines the essential requirements for the management of wastes. This directive recommends a life cycle approach to strengthen the measures that must be taken in regard to waste prevention, taking into account the whole life-cycle of products and materials [8].

Several studies on LCA for iron and steel industry have been conducted around the world [8]. Some of these studies were conducted on a product basis and the environmental effects of various metal products [8] and of specifically steel products [12] were assessed accordingly. There are also other studies conducted on a process basis, in which environmental effects of iron and steel production sub-processes have been assessed [13]. However, as the studies used different approaches, system boundaries and inventory data, they all showed different results in terms of contributions to environmental impacts. For example, although the same impact assessment methods were used by Burchart-Korol [13] and Tongpool et al. [12], the results were not comparable since they have different basis. Tongpool et al. [12] compared the proportional impacts of different steel products (i.e. product-based LCA), while Burchart-Korol [13] assessed the impacts of production process (i.e. process-based LCA). Furthermore, the impact categories considered in these studies are not also comparable to each other. Tongpool et al [12] used mid-point impact category assessment and reported that the slab exhibited the lowest impact in all impact categories covered, while Burchart-Korol [13] compared different impact categories and reported that the highest impact on the environment occurs in the category of human health. So, it is hard to reach to a general conclusion out of these literature studies available. It is clear that there is a need for further investigation to clarify the situation regarding the life cycle assessment for iron and steel industry because there is not any study covering all production stages together, in literature. Moreover, the differences in the inventory data used could result in different results. In most of the studies, country specific inventory data were used; therefore, the results reported are somewhat specific to their country. In fact, conducting a LCA study specific to country is of vital importance in order to reach the realistic results representing country conditions.

In Turkey, as being one of the leading countries of the world's steel production, the concept of LCA has become widespread by the day. In this regard, Turkey participated in a study conducted by the International Iron and Steel Institute (IISI) throughout the world in 2000 to communicate sustainable development activities of the world steel industry [8]. In this study, the industries participated in are enabled to compare their raw material, energy consumptions and emission levels with the levels determined by IISI. In addition, there is another study conducted by Ertem et al. [21] in an attempt to compare the specific energy consumptions of three integrated iron and steel producers in Turkey. However, there is no any LCA study specifically conducted on iron and steel industry in Turkey, which would put forward the environmental impact issues. Therefore, within the context of this study, it is aimed to fulfill this gap by assessing the environmental impacts of integrated iron and steel industry in Turkey via conducting country specific LCA study.

### 1.2. The objective and scope of the study

The main objective of the study is to conduct a country specific LCA study for integrated iron and steel industry in Turkey and to add to the understanding of environmental impacts associated with steel production at an integrated plant and discover the best opportunities for future impact reduction. In the context of this main objective, the following tasks were undertaken:

- Sub-process based environmental impacts were assessed in order to detect the most polluting sub-process(es) during liquid steel production. The assessment was performed for the selected product of the corresponding sub-process and to determine the contributions of each sub-process to various environmental impact categories. Sub-processes of liquid steel production cover coke making, sintering, iron making and steel making processes.

- Product based environmental impacts were assessed. Evaluation was performed for the semi-finished products, namely billet and slab, and for the finished products, namely wire rod and coil.

- In the light of the findings of the above-mentioned tasks, three different production scenarios were evaluated for a given facility in order to see their effects on the total environmental impact exerted. These scenarios comprise of different production percentages for final products. First scenario was the real production percentages of the facility where field studies conducted. The second scenario was the case if all products are only semi-finished products from casting, and the third scenario was the case that all products are only finished products form hot-rolling.

The data required to achieve these objectives were gathered from one of the three integrated iron and steel production facilities in Turkey. The plant was considered as representative of the sector since it has features to reveal the average values of integrated iron and steel industry in Turkey, having the share of about 35% in steel production via integrated means, and also its manufacturing technology was common to others in Turkey. The whole production processes in the facility were evaluated in terms of raw materials utilized, products, by-products, wastes and emissions generated and the production data of 2009 were used.

Then, the whole life cycle analysis was conducted using SimaPro version 7.2.4. The life cycle boundaries were chosen as 'cradle-to-gate' covering upstream processes, transportation, production processes and utility services. The functional units for the first task were selected as 1 ton of product from sub-processes. The functional units for the second task were selected as 1 ton of final steel product. The final products are semi-finished products; slab and billet, and finished products; coil and wire rod. Impact 2002+ was selected as the impact assessment method. Mass allocation was made to allocate the environmental impacts of the process to products and co-products. Normalization and single score results were used to interpret the data.

### 1.3. Thesis overview

This thesis includes seven chapters. Chapter 1, Introduction, covers the importance of iron and steel industry in Turkey, the legislation basis of LCA and mainly the objective and the scope of the study. In Chapter 2, LCA concept is introduced covering the aim and the steps. In Chapter 3, basic iron and steel production methods and the sub-processes are described. In Chapter 4, the literature review on previously conducted studies is presented. Chapter 5 gives the methodology of the study. This chapter also covers the details of inventory and use of the software. In Chapter 6, LCA results are presented, interpreted and then discussed. Chapter 7 covers the summary and conclusion of the study results and finally Chapter 8 covers the recommendations.

# CHAPTER 2

# LIFE CYCLE ASSESSMENT

Society has become concerned about environmental problems such as climate change, stratospheric ozone depletion, tropospheric ozone creation, eutrophication, acidification, eco-toxicological and human-toxicological pollutants, depletion of resources, water use, land use, and noise. The increased awareness of environmental protection, and the possible impacts associated with products or service has increased interest in the development of methods to better understand and address these impacts. The life cycle concept provides the most comprehensive environmental profile of product or services [25]. LCA is a technique for analyzing the environmental aspects and potential impacts associated with a product at all stages in their life cycle [26].

LCA is a “cradle-to-grave” approach for assessing industrial systems. “Cradle-to-grave” begins with the extraction of raw materials continues through production, use, and ends at the point of end-of-life treatment, either by reuse, recycling or final disposal. LCA interprets all the stages of production independently from each other, which means that one operation leads to the next. LCA is a tool for the estimation of the accretive environmental impacts resulting from all the production stages in the life cycle. Meanwhile, impacts not considered in more conventional analyses are often included in LCA concept; such as, raw material extraction, transportation of materials, and ultimate product disposal. Hereby, LCA provides a comprehensive view of the environmental aspects of the product or process and a more accurate picture of the true environmental trade-offs in product and process selection [26].

As displayed in Figure 1, there are four phases while conducting a LCA study:

- Goal and scope definition,
- Inventory analysis,
- Impact assessment, and
- Interpretation.

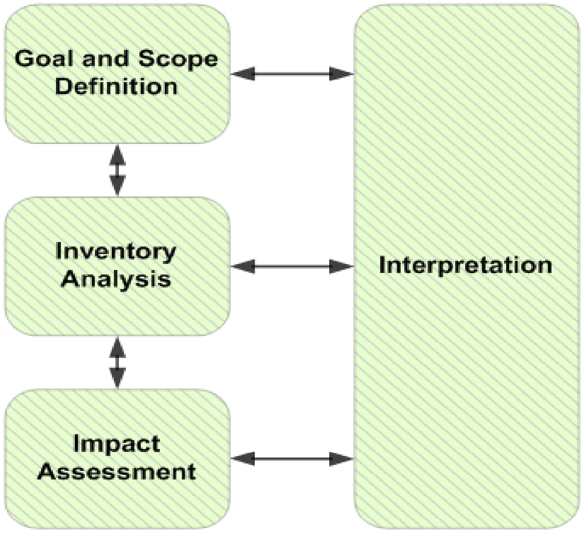



Figure 1. Phases of LCA [31]

The International Organization for Standardization (ISO) has published guidelines for each step of LCA which is named as "ISO 14040" series (Table 1). This series of 14040 describes the details of LCA. As noted in ISO Standards, LCA is a worldwide accepted procedure on the collection and evaluation of the inputs and outputs and the potential environmental impacts of a product system throughout its life cycle [29].

Table 1. ISO 14040 series [30]

| **Standart Number** | **Content** |
|---|---|
| ISO 14040 | Principles and framework (1997, 2006) |
| ISO 14041 | Goal and scope definition and inventory analysis (1998) |
| ISO 14042 | Life cycle impact assessment (2000) |
| ISO 14043 | Life cycle interpretation (2000) |

ISO 14040 provides general framework for LCA, ISO 14041 provides guidance for establishing the goal and scope of an LCA study and for conducting a life cycle Inventory (LCI). ISO 14042 provides statements for the life cycle impact assessment (LCIA) step and lastly ISO 14043 deals with the interpretation of the results produced by an LCA. Furthermore, the technical guidelines illustrate how to apply the standards [29].

### 2.1. Goal and scope definition

The first step in LCA is the goal and scope definition. It is important to define the main purpose at the beginning of the study, since it has a strong influence on further steps. If the objective of the study is to analyze the present status of a product or system and future status after improvements, LCA study must be organized by carefully dividing the process into sections or phases, to identify afterwards which parts of the process are responsible for each environmental effect [30]. When identification of the goal and scope definition is made, a description of the product system in terms of the system boundaries and functional unit is provided [27], and then comes the data quality requirements. System boundary defines the framework of the study. Functional unit is quantified performance of a product or system for use of a reference unit [14].

After the goal and scope definition of a LCA, it is important to define the system boundaries. The system boundaries define the unit processes to be included in the system to be modeled. It defines the extent of the system and determines the processes included. In this sub step, the inputs and outputs to be taken into account during the LCA study must be established. The product system should be modeled in such a manner that inputs and outputs at its boundary are elementary flows [30]. The inputs can be all the inputs of the production or can be input to a single; the same is valid for output. Even for a quite subjective operation, the definition of the system boundaries can be carried out according to following criteria: life cycle boundaries, geographical boundaries and environmental load boundaries [30].

According to the extent of the study, different system boundaries can be defined. As presented in Figure 2, if the entire life of a product or system is considered, boundaries should begin with the raw material extraction and end with the final disposal. This case is called as 'cradle to grave'. When the destination of a product is not known, the analysis should be continued to the end of manufacturing and the boundary will be defined as cradle to gate 3. Each life-cycle step will carry out its own gate-to-gate analysis and the entire cradle-to-grave process will be the result of the composition of a set of gate-to-gate systems.

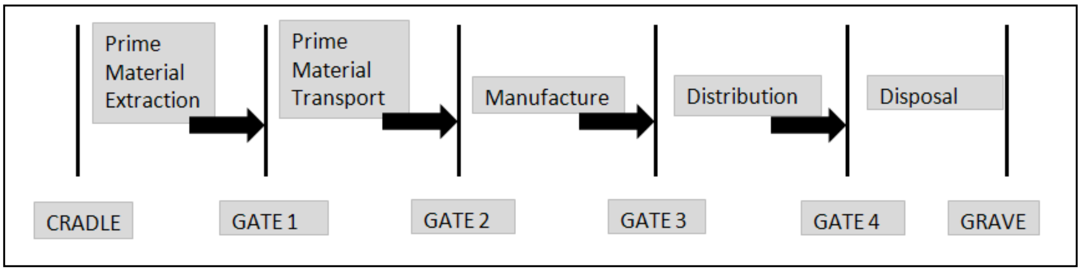



Figure 2. Product life-cycle span steps [30]

The other type of system boundaries is geographical boundaries considering the geographic limits for the establishment of product system. They can be considered life-cycle boundaries when the different life-cycle steps are conducted in some region. During site specific LCA studies, these criteria are recommended. Last type of system boundaries is environmental load boundaries. There are different types of environmental load which are renewable and non-renewable raw materials, energy losses, air and liquid emissions, solid waste, radiation and noise. As demonstrated in Figure 3, LCA can be carried out considering the entire list of inputs and outputs (total LCA) or taking into account some of these (partial LCA). For instance, partial LCA 1 comprises only air and liquid emissions and is carried out cradle to gate 2. Partial LCA 2 takes into account only solid waste and energy losses and goes from gate 1 to grave [30].

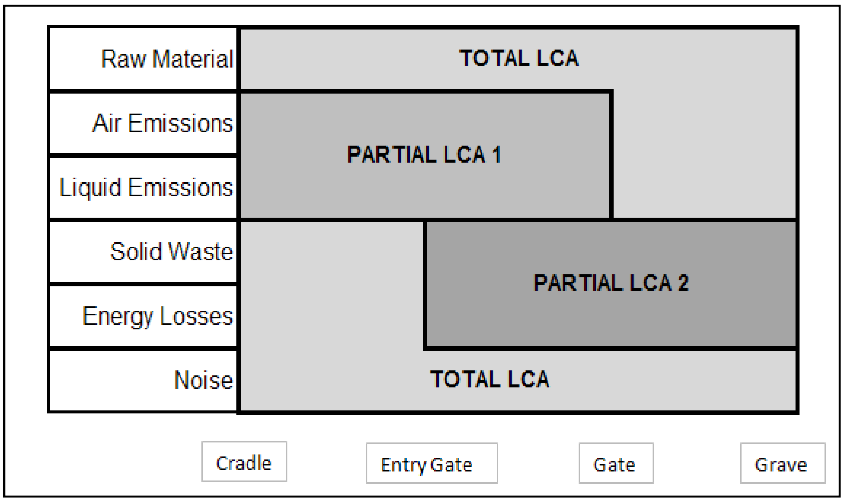



Figure 3. Boundaries in LCA [30]

The functional unit is a quantitative description of the service performance of the investigated product system [31]. Since the functional unit is the measure of the performance delivered by the system under study, it is used as a basis for calculation and usually also as a basis for comparison between different systems fulfilling the same function. When different alternatives are available for a product or service for comparison, the functional unit must be clear to enable a sound comparison of the alternatives considered. Moreover, it must be measurable and when two products with different life times are compared, it is important that the period of use is considered for its establishment [30].

Data requirement is one of the important points when conducting a LCA and it depends on the goal of the study. For each process of the product system, input and output data set is needed related to the function or product generated by the process. Data collection is generally the most complicated and time consuming steps in LCA. Moreover, the quality of the data used is directly affects the quality of the final result of LCA [27]. Data quality indicators such as time, geography, type of technology, precision, completeness, representativeness, consistency and reproducibility should be taken into consideration in a level of detail depending on the premises of the goal and scope definition step.

### 2.2. Inventory analysis

Life cycle inventory (LCI) analysis is the second phase of LCA. It is an inventory of input and output data with regard to the system being studied. It involves data collection, the most demanding step in performing LCAs, to meet the goals of the defined study regarding environmental loads or environmental effects generated by a product or process during its life-cycle is identified and evaluated [27]. Environmental loads are the amount of substances, radiation, noises or vibrations emitted to or removed from the environment that cause potential harmful effects. Environmental loads can be raw materials, energy consumption, air and water emissions, waste generation, radiation, noise, vibration, odours, etc. what is commonly known as environmental pollution. Since environmental loads must be quantifiable, other types of effects such as aesthetic, social, etc. are not considered in LCI [30].

In order to prepare a LCI, each environmental load generated by the process must be added as material and energy inputs and the output associated with it. In other words, the inventory basically consists of environmental load balance in which the environmental loads assigned to a product are the sum of input environmental loads plus the ones generated by the process. Data collection; the most time consuming part of LCA, must be based on process establishing qualitative and quantitative information about inputs and outputs. Data collection from different data sources, such as, electronic databases, literature data, unreported data and measurements/computation shows large differences in the availability of input and output data. Input data are usually accessible since energy and raw material consumption is recorded by the companies. With respect to the output data, except the information about products and by-products, it is difficult to achieve. This difficulty is generally due to the absence of control records of all releases. When the control record of releases is available, it is difficult to allocate the existing data to the individual product depending on the size of the company in the study. Nevertheless, in some cases output data can be calculated by carrying out mass and energy balances from some inputs. This method can be entirely adequate in many cases, and sometimes, even better than using data from direct measurements of the releases and emissions [30].

### 2.3. Impact assessment

The third step of LCA is the life cycle impact assessment (LCIA). In order to better understand the environmental importance of a product system, LCIA aims to provide additional information for assessment of LCI results. LCA establishes information for interpretation providing a wide range of environmental and resource points and affected impact categories. At this point, impact potentials are selected and category indicator results are calculated for each impact category. The collection of these results defines the LCIA profile of the product system, which provides information on the relevance of resource use and emissions associated with it [30].

There are several obligatory and optional steps within the impact assessment phase.

Obligatory steps of LCIA are:

1. Selection of impact categories, category indicators and characterization models,
2. Classification - Assignment of inventory results to impact categories,
3. Characterization - Calculation of category indicator results.

Optional steps of LCIA are:

1. Normalization - Calculating the magnitude of category indicator results relative to reference values,
2. Grouping - sorting and possibly ranking of the impact categories,
3. Weighting – quantitative comparison of impact potentials of the product or service,
4. Data quality analysis - better understanding the reliability of the collection of indicator results.

The obligatory steps convert the results of life cycle inventory into indicator results. These are selection of impact categories, category indicators and characterization models, classification and characterization. The optional steps can be used depending on the goal and scope of the study. These are normalization, grouping and weighting of the indicator results and the data quality analysis [32]. Normalization exerts a baseline for comparison of different types of environmental impact categories having the same unit. The result of normalization is an input to grouping or weighting. Grouping is a qualitative step in which results across impact categories are sorted and ranked. Such a ranking can provide structure to help draw conclusions on the relative importance of different impact categories. In the weighing step, by assigning a weighing factor to each impact category, the relative importance of different impact categories within an LCA study can be assessed.

There are different impact categories representing environmental issues of concern to which LCI results may be assigned. Impact category is divided into two; category midpoints and category endpoints [33]. The impact category indicator at the midpoint level (category midpoints) could be the dose, while the impact category indicator at the endpoint level (category endpoints) which are of direct societal concern, could be at the level of damage to human health, resources, and ecosystem quality [33]. Although indicators near endpoint level can have significant uncertainties, indicators at endpoint level are much easier to understand than indicators at midpoint [35]. Moreover category endpoints can enhance the interpretation of category midpoint results for decision making.

Quantifiable representation of impact category is the life cycle impact category indicator [29]. For example, the climate change category midpoint represents emissions of greenhouse gases (LCI results) using infrared radiative forcing as the category indicator [32]. The data from the inventory analysis are grouped together into a number of impact categories. This grouping is performed by including data from the inventory analysis into different impact categories. One data can be included to more than one category midpoint; for instance, NOx can be assigned to a category midpoint like acidification and eutrophication [36]. LCIA aims to examine the product system using impact categories and category indicators connected with the LCI results. The LCIA phase also provides information for the life cycle interpretation phase. There are three major category endpoints that should be considered in the LCIA, these are resources, human health and ecosystem quality. The three category endpoints can be divided into more specific impact categories, category midpoints, presented in Table 2. There are also different category midpoints besides the ones listed in Table 2 such as, desiccation, land use, ionizing radiation, odor, noise, waste heat.

Table 2. List of impact categories

<table>
<tr><th>Mid-point impact categories</th><th>End-point impact categories</th></tr>
<tr><td>Carcinogens</td><td rowspan="6">Human Health</td></tr>
<tr><td>Non-carcinogens</td></tr>
<tr><td>Respiratory inorganics</td></tr>
<tr><td>Ionizing radiation</td></tr>
<tr><td>Ozone layer depletion</td></tr>
<tr><td>Respiratory organics</td></tr>
<tr><td>Aquatic ecotoxicity</td><td rowspan="6">Ecosystem Quality</td></tr>
<tr><td>Terrestrial ecotoxicity</td></tr>
<tr><td>Terrestrial acid/nutri</td></tr>
<tr><td>Land occupation</td></tr>
<tr><td>Aquatic acidification</td></tr>
<tr><td>Aquatic eutrophication</td></tr>
<tr><td>Global warming</td><td>Climate Change</td></tr>
<tr><td>Non-renewable energy</td><td rowspan="2">Resources</td></tr>
<tr><td>Mineral extraction</td></tr>
</table>

Udo de Haes et al. (1999) have proposed classifying impacts in input and output related categories. In Table 3, an overview of input and output related impact categories currently used in LCIA is presented with its possible indicators. Input-related categories represent the environmental impacts associated with material and energy inputs to the system; and output refers to damages due to emissions or pollutants [30].

Table 3. Impact Categories and Possible Indicators [29]

| Impact Categories | Possible Indicator |
|---|---|
| *Input-Related Categories* | |
| Extraction of abiotic resources | Resource depletion rate |
| Extraction of biotic resources | Replenishment rate |
| *Output-Related Categories* | |
| Climate change | kg $CO_2$ as equivalent unit for GWP* |
| Stratospheric ozone depletion | kg CFC-11 as equivalent unit for ODP** |
| Human toxicity | |
| Eco-toxicity | Aquatic eco-toxicity potential-AETP |
| Photo oxidant formation | kg ethene as equivalence unit for photochemical ozone creation potential |
| Acidification | Release of H as equivalence unit for AP |
| Nutrification | Stoichiometric sum of macronutrients as equivalence unit for the nutrification potential |

*GWP: Global Warming Potential

**ODP: Ozone Depletion Potential

### 2.4. Interpretation

An LCA only provides data about the environmental releases, consumptions, or impacts of the system under the study [36]. To conclude the LCIA, analysis and interpretation of the results are carried out to evaluate environmental performance of the product or process under study. This is a comparative assessment, two or more products can be compared or some information about the environmental performance of the product can be included [30]. Proposed improvement options are determined and assessed to reduce the environmental impact of product or system. Determination and assessment can be performed by scenario modeling. Scenario modeling allows testing the potential impact of improvement options for processes within the product's life cycle [36].

# CHAPTER 3

# IRON AND STEEL INDUSTRY

Iron and steel industry include production of iron by reducing iron ore and scrap; and later production of steel by removing impurities in iron. The difference between iron and steel is due to the relative amounts of impurities in the two metals, the liquid iron being saturated with carbon and containing undesirable amounts of silicon, manganese, phosphorus, and sulfur, which must be removed during steel making process [40]. In order to produce steel, the carbon content of liquid iron (approximately 4%) is reduced to less than 1%. The higher carbon content in metal increases the hardness and brittleness.

Generally, four routes are currently used for the production of steel.

1. Classic blast furnace (BF)/basic oxygen furnace (BOF) route
2. Direct melting of scrap (electric arc furnaces (EAF))
3. Smelting reduction
4. Direct reduction

The BOF process and the EAF have taken the place of less energy efficient steel making processes such as the Thomas process and Open-Hearth Process (Bessemer, Siemens-Martin) [40]. In the EU, the last Siemens-Martin ovens were taken out of operation at the end of 1993. In the EU and in Turkey, only the BOF and the EAF processes are being used in steel production [15]. And, the energy requirement for BOF process is much higher than for EAF process [8].

There are six major activities in integrated steel production; (1) coke making, (2) sintering, (3) iron making (blast furnace process), (4) steel making (basic oxygen furnace process), (5) casting, and (6) rolling [40]. Flow diagram of production process is presented in Figure 4.

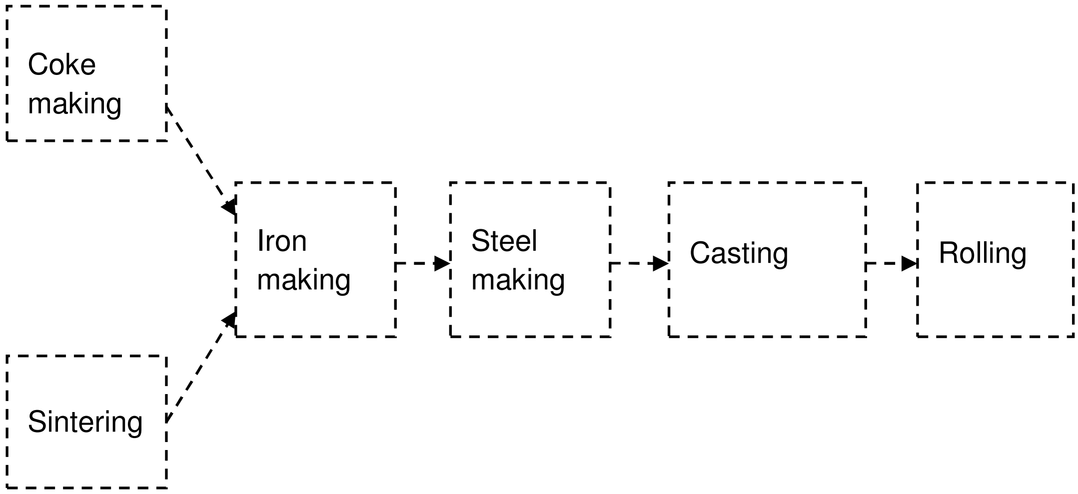



Figure 4. Flow diagram of integrated iron and steel production process

### 3.1. Coke making

Coal processing involves production of coke, coke oven gas and by-product chemicals during the coke making process. Coal, which is a complex mixture of organic compounds, must be converted into coke, which is nearly elemental carbon to be used in blast furnaces. The steps of coke making are; (1) coal charging, (2) heating / firing of the chambers, (3) coking, (4) coke pushing, and (5) coke quenching [15]. The flow of coke making process is presented in Figure 5.

The first step in coke making process is the charge of coal through ports in the top of the oven. After charging, the pyrolysis of coal comes [40]. Coal pyrolysis means the heating of coal in the absence of air for about 14-24 h indirectly heating the coal up to 1000-1100 °C to produce gases, liquids and a solid residue (char or coke). At the end of the heating cycle, the coke is pushed from the oven into a container called coke quenching car. There are two different quenching methods, wet quenching and dry quenching. In wet quenching, the container takes it to the quench tower, to cool the coke with a water spray. In dry quenching, inert quenching gas circulates around the container, which is isolated from the atmosphere. Then, the gas is cooled by a heat exchanger and thermal energy is gained [15]. The coke is then screened and sent to the blast furnace or to storage. Volatile compounds arising from the coal are collected and processed to produce coke oven gas and other coal by-products, such as tar, ammonium sulfate and benzene, and also coke breeze is produced during the coke quenching, handling, and screening operations [42].

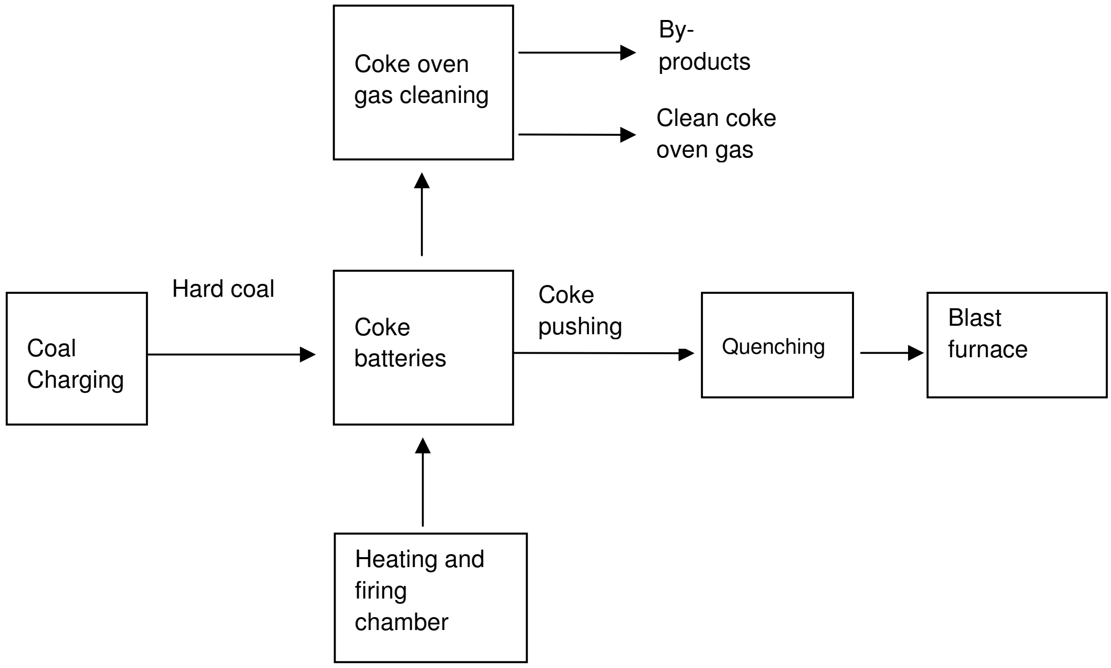



Figure 5. Flow diagram of Coke making

Coke is the primary reducing agent in blast furnaces and cannot be completely replaced by other fuels such as coal [15]. Coke has the purposes of providing the heat necessary to smelt iron and reducing the iron oxides to iron by carbon monoxide formed during cokes partial combustion [44].

Explosion may occur in the blast furnaces due to dust-like structure of coal, thus coke is preferred on account of its resistance creating a skeleton in blast furnaces. In addition, coke has very porous structure than coal. This porous structure and difference in particle size provides gas and liquid permeability to ease burning [45].

### 3.2. Sintering

Sintering is an agglomeration process of fine particles. Through sintering process, iron-rich materials, such as mill scale and processed slag can be recycled [42]. The main three reasons for sintering are: (1) loading and unloading during transport from the mine the ore into powder, that was caused by blockages in powder form to be blast furnaces; brought to a certain size to be permeable; (2) excess sulfur, arsenic and moisture in the ore will lead to breakage in finished steel, thus vaporized during sintering; (3) since giving iron ore directly to blast furnaces will reduces efficiency, the actual blending of raw materials are turned into semi-finished products called sinter [45].

The sintering process converts fine iron ore, additives and recycled metallurgical dusts into an agglomerated product that is proper for charging to blast furnaces in terms of size [40]. The recycled metallurgical dusts from downstream operations are coarse dust and sludge from blast furnace gas (BF gas) cleaning, sludge from basic oxygen furnace gas (BOF gas) cleaning, mill scale from rolling and casting scale. The additives are lime, limestone and MgO bearing raw materials (dolomite, dunite, magnesite) [45]. The mixture of recycled metallurgical dusts and additives are moistened and mixed with coke breeze (fine coke, particle sizes of < 5 mm) and subjected to high heat (1300-1480°C) under an ignition hood. The most frequently used fuel is coke breeze in sintering process. Coke breeze may be produced directly in a coke oven plant on-site or off-site or may be obtained by coke crushing [15].

### 3.3. Blast Furnaces

Blast furnace (BF), into which iron bearing materials (iron ore lump, sinter and/or pellets) are charged from the top of the blast furnace along with limestone and coke, is a closed system to prevent escape of BF gas [15].

Hot air is enriched with oxygen and reducing agents, and then charged into the tuyere providing a counter-current of reducing gases. Various reducing agents are available; these may be coke, coal, oil, natural gas, or plastics. The use of reducing agents depends on preference except coke, since coke serves as a carrier of the bulk column in the blast furnace, it is indispensable. The air blast reacts with the reducing agents producing mainly carbon monoxide, which reduces iron oxides to iron.

Fluxes and additives are added to decrease the melting point, improve sulfur uptake by slag, provide the required liquid pig iron quality and allow for further processing of the slag. The limestone holds impurities in ore, forming a liquid slag. Since slag is lighter than metal, it floats on top of metal. The slag and the liquid iron are tapped off separately. Meanwhile, the sinter, pellet, iron ore and coke are periodically injected on the tuyere, and heated air is blasted. The liquid iron is transported to steel plant and the slag is processed to produce aggregate, granulate or pellet for road construction and cement manufacture. The BF gas, collected from the top of the blast furnace, is subjected to the treatment [15]. Whereafter BF gas is cleaned; it is used for heating or for electricity production. During gas cleaning, dust from dry cleaning and sludge from water treatment are generated and can be reused in the sintering plant [42].

### 3.4. Basic Oxygen Furnace

The purpose of oxidation process is to reduce the carbon content to a specified level (from approximately 4% to less than 1%, but often lower), to adjust the contents of desirable foreign elements and to remove undesirable impurities to the greatest possible extent. The steps of basic oxygen furnace (BOF) steel production are (1) transfer and storage of liquid iron, (2) desulfurization of liquid iron, (3) oxidation in the BOF, (4) secondary metallurgical treatment.

Desulfurization is a commonly used process as an upstream of blast-furnaces. Desulfurization is generally applied off-site. Commonly used desulphurisation agents are calcium carbide, caustic soda, soda ash, lime and magnesium impregnated materials.

The waste products from the BOF process include slag, carbon monoxide, and dust in the form of iron oxides. The BOF gas, which contains large amounts of carbon monoxide, is generally recovered to be used as an energy source. During the steelmaking process, slag is formed. Usually, the slag is cooled and crushed, after which metallic iron is recovered by magnetic separation. In BOF process, undesirable impurities are removed by means of oxidation process with the off-gas or the liquid slag. The main elements oxidized are carbon, silicon, manganese, phosphorus, and sulfur. The oxidizing reactions are exothermic thus increasing the temperature of the molten iron. The required energy to raise the temperature and melt the input materials is supplied by the exothermic oxidation reactions, so that no additional heat input is required, on the other hand scrap, iron ore or other coolants are added to balance the temperature at approximately 1600-1650°C. The amount of scrap charged depends on the pre-treatment given to the pig iron and the required liquid steel tapping temperature. The oxidizing process in the converter is usually followed secondary metallurgy to enable the quality requirements.

### 3.5. Casting

Liquid steel can be cast by means of two methods; ingot casting or continuous casting. In ingot casting, the liquid steel is cast into moulds. The ingots are taken out of the mould after cooling, and transported to the rolling mills. In recent years, ingot casting has been replaced by continuous casting method, since continuous casting provides important benefits. For instance, it provides energy savings, reduction in emissions and water consumption due to the elimination of slab mills and billet mills; it improves working conditions, yield rates and productivity [15]. By elimination of several steps, in the continuous casting semi-finished products are directly produced.

### 3.6. Rolling

Rolling is forming of semi-finished product from casting process. Hot rolling, cold rolling and drawing of steel are the types of forming. In hot rolling semi-finished product from casting primarily heated the in annealing furnaces up to temperature of 1050-1300°C depending on the amount of carbon in steel [45]. The size, shape and metallurgical properties are changed by compression between electrically powered rollers. Products from hot rolling are generally classified in two basic types according to their shape: flat and long products. In cold rolling, thickness, mechanical and technological characteristics of hot rolled products changed by compression between rollers without heating [46].

# CHAPTER 4

# LITERATURE REVIEW

This chapter provides an overview of previous research on LCA for iron and steel production and introduces the framework that comprises the main focus of the research described in this thesis.

The first part of this chapter will describe relevant studies conducted by international organizations and the second part will provide an overview of previous research published in the Literature.

## 4.1. Studies Conducted by International Organizations

The steel industry is often considered to be an indicator of economic progress, on account of the critical role played by steel in infrastructural and overall economic development. The LCA on iron and steel industry is gaining an importance in terms of material and energy consumptions, and environmental concerns. The Society of Environmental Toxicology and Chemistry (SETAC) [47], the American Iron and Steel Institute (AISI), International Iron and Steel Institute (IISI) and The European Confederation of Iron and Steel Industries (EUROFER) are the spearhead organizations in this sector dealing with LCA.

AISI is heavily involved in efforts to evaluate the life cycle impacts of steel products. Its predecessor organizations date back to 1855 making it one of the oldest trade associations in the United States. There are studies conducted to integrate life cycle inventory data, life cycle impact assessments, and risk assessment into an overall life cycle evaluation. AISI launched a LCA program in 1994. This industry-wide life cycle impact assessment is currently evaluated by the referees. The study addresses all relevant environmental issues, including resource depletion, for the full life cycle of a steel product from mining of raw materials through the manufacturing and use phases of the product and ultimate disposal or recycling of the material used in the product [8].

IISI launched a comprehensive 'cradle-to-gate' data collection project in 1996, known as the IISI Worldwide Life Cycle Inventory Study for Steel Products - in order to gather the data necessary for initiating or participating in LCA's [8]. The aim is to quantify resources use, energy and environmental emissions associated with the processing of steel industry products from the extraction of raw materials in the ground through to the steel factory gate. This exercise has subsequently been updated for 1999/2000 data for steelmaking operations [20] and the current data set was released in February 2010 [3]. 55 industries from 37 countries have participated in this study. They are 29 blast furnace, 15 electric arc furnace, 11 hot and cold rolling mills. One of three integrated steel producers in Turkey with blast furnace, Eregli Iron & Steel Co. (ERDEMIR) has also participated in this study. As the output of the study, the industries participated in gained the ability to compare their raw material and energy consumptions together with emissions of IISI [49]. An integral part of the project was the development of a common worldwide methodology for collating and evaluating steel product LCI data. Since this innovative project was completed, the results have been communicated to external audiences undertaking LCA studies for steel-using products, and to steel producers active in benchmarking and in other environmental improvement programs. An ongoing program is underway at IISI to further improve the electronic database resulting from the study [20]. The LCI results consist of approximately 800 flows which can be simplified into a smaller number of flows depending on how the data is to be used providing worldwide and European averages only. Request for LCI data of IISI can be made by filling in the online questionnaire describing the application of the data. The world steel LCA Manager receives approximately 200 data requests annually. The request is then discussed with the LCA Manager [3].

The other spearhead organization; EUROFER and ISSF have undertaken a commitment to provide the best possible information to the industry stakeholders in the area of LCA, delivering transparent and authoritative data on the production of stainless steel from its raw materials. The experience gained from the life cycle studies at EUROFER, and the IISI is being extended in order to complete a LCI for global stainless steel. The datasets involved in this study is expected to cover major stainless producers in Europe, Japan, Korea, and North America with the focus on global averages for the production of flat products [50].

Since 2004, globally largest industry project on climate change called "ULCOS Project" has been initiated in Europe with regard to the $CO_2$ emission from iron and steel industry [15]. (ULCOS stands for Ultra–Low Carbon dioxide ($CO_2$) Steelmaking.) The European Steel Industry has initiated a consortium of 48 European industries and research organizations from 15 European countries that have started a work to enable abatements in carbon dioxide emissions from steel industry. The aim of the ULCOS program is to reduce the carbon dioxide emissions of today's best routes by at least 50%. In the frame of ULCOS project, LCA analyses are performed to assess of the environmental impacts of metallurgical processes on the environment and choice of new technologies [15].

### 4.2. Research Studies

In addition to the above-mentioned LCA investigations by several international organizations, there are a few studies published in the Literature about life cycle assessment in iron and steel industry. A limited number of LCA studies have examined the impacts of steel production of which, some have compared the environmental impacts of different metal products, some have dealt with the method selection for impact assessment and some have used LCA methodology for the selection of the best alternative for blast furnace slag recycling and for the comparison of integrated steel production with electric arc furnaces.

There exists a limited number of LCA studies emphasizing on the environmental impacts of steel production only. The only product-based study is conducted by Tongpool et al. [12] covering slab, hot-rolled, cold-rolled, hot-dipped galvanized and electro-galvanized steels to assess the environmental impacts via LCA. Functional unit was selected as “one ton of steel product” at the factory gate and the system boundary was selected from cradle to gate. For allocation of environmental impacts to products and co-products, mass allocation method was used. The impact assessment methods of IPCC 2007 GWP 100a (Intergovernmental Panel on Climate Change, Global Warming Potential, 100 years) and Eco-indicator 99 were applied via SimaPro 7.1 software. According to the mid-point impact category results, the slab showed the lowest impacts and the hot-dipped galvanized steel showed the highest impacts in the impact categories of global warming potential, fossil fuels, ecotoxicity, minerals, carcinogens, and respiratory inorganics. The reason of this is that slab was in the upstream and the hot-dipped galvanized steel was in the downstream of the studied products. The main causes of the impacts were attributed to these inputs; steel, energy, and zinc [12].

Burchart-Korol [13] conducted two process-based LCA studies, the first one is a LCA study on conventional blast furnace iron-making process and the second one is an environmental impact assessment for sintering process. In the first study conducted by Burchart-Korol, Eco-indicator 99 and IPCC GWP 100a life cycle impact assessment methods were used via SimaPro 7 software as in the study of Tongpool et al. [12]. As distinct from study of Tongpool et al. [12] the boundary of the study was selected from gate-to-gate. Functional unit was taken as one ton of liquid steel. The environmental impacts of inputs were evaluated taking the production as a whole and using the inventory data of Central Mining Institute of Poland. With regard to IPCC GWP method, coke which is the main fuel in the process had the largest impact on greenhouse gas emissions followed by sinter, blast furnace gas and coke oven gas respectively. Eco-indicator 99 method evaluates the effects of BF iron making process on end-point impact categories, which are human health, ecosystem quality and resources. The results indicate that the highest impact on the environment occurs in the category of human health (83%) [13]. The second study conducted by Burchart-Korol [14] was also a process-based LCA study. In this study, Eco-indicator 99 method was preferred to calculate the environmental impacts using the same inventory data with his first study. According to the impact assessment results, the highest environmental effect during iron ore sintering process is on human health caused by respiratory effects due to inorganic pollutants and dust

[14]. On one hand, it can be concluded from the two studies conducted by Burchart-Korol [13] using the same impact assessment method and same inventory data, sintering process, a sub-process of steel making, shows similar impacts with iron-making process. On the other hand, although the same impact assessment methods were used in the first study of Burchart-Korol [13] and in the study of Tongpool et al. [12], they are not comparable since they have different basis (product-based/process-based), so they consider the issue from various aspects. For instance, Tongpool et al. [12] compared the proportional impacts of different steel products, while Burchart-Korol [13] assessed the production process. Additionally, since Tongpool et al. [12] used mid-point impact category results, the impact categories were not compared each other, and it was concluded that slab showed the lowest impacts in all impact categories covered.

Another process-based LCA study was conducted by Huang et al. [15] in order to identify factors that influence $CO_2$ emissions from a specific integrated steelworks in China and to propose measures to reduce $CO_2$ emissions, using software called Tornado Chart tool. The boundary was selected as 'cradle to gate' in this study covering upstream processes, transportation, production and by-products recycling, and the inventory data were obtained from Gabi 4 software. According to the results, blast furnace gas in blast furnaces, liquid steel unit consumption of continuous casting, slab unit consumption of hot rolling and hot metal ratio of steel making are determined as the main influencing factors of $CO_2$ emissions in steelworks. Herewith, the main inputs of sub-processes were determined as the main influencing factors of $CO_2$ emissions. Ultimately, proposed measures were through removing $CO_2$ contained in blast furnace gas, decreasing the hot metal ratio of basic oxygen furnace, recycling blast furnace gas, and optimizing the products' structure [15]. As distinct from the study of Burchart-Korol [13] which takes the production process as a whole, Huang et al. [15] evaluated the sub-processes separately. Additionally, they have different boundaries, different inventory data and different impact categories making comparison difficult. While Huang et al. [15] assessed the process in terms of $CO_2$ emissions only, Burchart-Korol [13] assessed the process in terms of human health, ecosystem quality and resources end-point impact categories.

Caneghem et al. [16] conducted a study to show the effect of impact assessment methods on the assessment results. The study was conducted in a major steelwork in Belgium to assess the relative contribution of the individual resources to abiotic depletion during steel production. The contribution of both energetic and non-energetic resources to the total abiotic depletion was calculated by the CML (Centrum voor Milieukunde Leiden, Center for Environmental Studies), CExD (Cumulative Exergy Demand), EPS (Environmental Priority Strategies), Eco-indicator 99 and mass and energy methods. Mass (a reference for non-energetic resources) and energy (a reference for energetic resources) method was used for comparison with other methods. Recommendations for reduction of abiotic depletion were made for each method, based on the relative contribution of the considered resources. The energetic resources in steel industry were natural gas, coke oven gas, fuel, cokes, anthracite, coal, powdered coal and electricity, the non-energetic ones are iron ore, iron scrap, lime(stone). In the study, boundaries were selected as gate-to-gate, and coke making unit was excluded from the boundary of the steelwork. According to the results of the assessment, CML method was found mainly to focus on further improving energy efficiency, while EPS method was mainly to focus on material efficiency improvement and Eco-indicator 99 and CExD methods focus on both energy and material efficiency improvement. Similarly, Pizzol et al. [11] also conducted a study using different methods for assessment of impacts on human health. The result of the study indicated that there is no agreement between the results of the methods showing the impacts on human health. According to the studies of Caneghem et al. [16] and Pizzol et al. [11], it can be concluded that the difference has resulted from the classification and characterization techniques of the impact assessment methods.

In literature, there also exist a number of LCA studies conducted on metal industry comparing their environmental impacts of different metal industries. Seppala et al. [8] performed a product-based LCA study in Finnish metal industry compassing inventory data of steel plates and coils, steel bars, steel wires, stainless steel, copper, nickel, zinc and aluminium. The LCI data was gathered for concentrate (mining and concentration); scrap (collection, transportation and processing of external scrap); other materials (production of additives and chemicals); production (of metals);

energy (grid electricity used in the production stage); transports (of raw materials); and by-products (credits). An impact assessment method, called DAIA (Decision Analysis Impact Assessment), developed by Seppala was used. Covered impact categories are eutrophication, ozone formation, acidification and climate change. For integrated steel industry, the main environmental effects occurred during production stage due to significant carbon dioxide emissions. So, the impact assessment results showed that the main influencing point of integrated steel production was the production process and the impacts on climate change followed by acidification [8]. Another product-based LCA study was conducted by Norgate et al. [10]. This 'cradle-to-gate' LCA study aims to assess environmental impacts of a number of metal production processes in Australia. The assessed metals were copper, nickel, aluminium, lead, zinc, steel, stainless steel and titanium. The covered impact categories were global warming potential, energy requirements and solid waste burden. Environmental impacts of electric arc furnaces producing stainless steel were not much when compared to titanium, aluminium and nickel, but higher than integrated steel production. The results depicted that steel and lead (by the blast furnace process) had the lowest cradle-to-gate environmental impacts in terms of all impact categories covered [10]. Since Norgate et al. [10] used mid-point impact category results, the impact categories were not compared each other as in the study of Tongpool et al. [12].

LCA is also applied in some studies to select the best alternative. Lee and Park [17] conducted a LCA study to propose a recycling option for granulated blast furnace slag best suited for the maximization of the environmental credit concerning from cradle-to-gate. It was reported that the environmental credit becomes higher when the environmental loads of the substituted product system are high and the environmental loads of the recycling process are low. In this study, weight allocation method was used. The recycling options for granulated blast furnace slag were to use it as a raw material for Portland cement, slag cement, slag powder and silicate fertilizer. Moreover, three different perspectives were taken into account, these were life cycle inventory on $CO_2$, characterized impact on global warming, and weighted impact of the product system using the Eco-indicator 99 method. From all three perspectives, the use of granulated blast furnace slag as raw material for slag cement resulted in the highest environmental credit followed by Portland cement, slag powder and silicate fertilizer. Since the environmental credits of using as a raw material for Portland cement and slag cement are approximate values, the two recycling options were proposed by the authors. Similarly, Birat [18] conducted a study focusing on using of blast furnace slag as a substitute to clinker in cement industry. And, he stated that $CO_2$ emissions can be reduced by 44% through this replacement. In addition to this, it was emphasized that allocation has a great impact on the results and mass allocation of slag shows the highest among different allocation methods.

Li et al. [19] performed a LCA study in order to compare blast furnace/basic oxygen furnace (BF/BOF) and direct reduction iron/electric arc furnace (DRI/EAF) processes for both iron and steel productions. The boundary was selected as cradle-to-gate, and the only products defined in the study were iron and steel, other by-products were regarded as waste. In this study, the BF/BOF process was selected as reference process. They reported that the environmental impact of the DRI/EF process is only 60.22% of that of the BF/BOF process for the production of per unit iron. This was because the sintering and coke making processes were omitted in the DRI/EAF process. For the production of per unit steel, the environmental impact of the DRI/EF process was only 52.4% of that of the BF/BOF process. The difference was mainly attributed to from the difference in the input materials; the BF/BOF process mainly uses molten ore causing resource depletion.

Summary of previously conducted research studies is presented in Table 4. According to the mentioned research studies, it is hard to come to a conclusion or make a comparison, since they have different concepts, different inventory data, different boundaries and different impact assessment methods.

Table 4. Summary of research studies on LCA in iron and steel industry

| **Objective** | **Functional unit** | **System boundary** | **Impact assessment method/Impact category** | **Result** | **Reference** |
|---|---|---|---|---|---|
| To assess the environmental impacts of slab, hot-rolled, cold-rolled, hot-dipped galvanized and electro-galvanized steels | One ton of steel product | Cradle to gate | IPCC 2007 GWP and Eco-indicator 99 (SimaPro) [global warming potential, fossil fuels, ecotoxicity, minerals, carcinogens, and respiratory inorganics] | Slab showed the lowest impacts and the hot-dipped galvanized steel showed the highest impacts in the impact categories of global warming potential, fossil fuels, ecotoxicity, minerals, carcinogens, and respiratory inorganics<br><br>Main causes of the impacts were attributed to these inputs; steel, energy, and zinc | Tongpool et al. [12] |
| To assess the environmental impacts of blast furnace iron-making process | One ton of liquid steel | Gate to gate | Eco-indicator 99 (SimaPro) [human health, ecosystem quality and resources] | Coke had the largest impact on greenhouse gas emissions followed by sinter, blast furnace gas and coke oven gas respectively. | Burchart-Korol [13] |
| | | | IPCC GWP 100a (SimaPro) [global warming] | The highest impact on the environment occurs in the category of human health among the end-point categories; human health, ecosystem quality and resources. | |
| To evaluate the main contributor of environmental impact of sintering process | - | Gate to gate | Eco-indicator 99 (SimaPro) | The highest environmental effect is on human health caused by respiratory effects due to inorganic pollutants and dust | Burchart-Korol [14] |

Table 4. Summary of research studies on LCA in iron and steel industry - continued

| **Objective** | **Functional unit** | **System boundary** | **Impact assessment method/Impact category** | **Result** | **Reference** |
|---|---|---|---|---|---|
| To identify factors that influence $CO_2$ emissions from a specific integrated steelworks | - | Cradle to gate | Software called Tornado Chart tool | Blast furnace gas in blast furnaces, liquid steel unit consumption of continuous casting, slab unit consumption of hot rolling and hot metal ratio of steel making are determined as the main influencing factors of $CO_2$ emissions | Huang et al. [15] |
| To show the effect of impact assessment methods on the assessment results | - | Gate to gate (coke making process is excluded) | CML, CExD, EPS, Eco-indicator 99 | CML method focus on further improving energy efficiency, while EPS method focus on material efficiency improvement and Eco-indicator 99 and CExD methods focus on both energy and material efficiency improvement.<br>The difference is resulted from the classification and characterization techniques of the impact assessment methods | Caneghem et al. [16] |
| To compare the environmental impacts of steel plates and coils, steel bars, steel wires, stainless steel, copper, nickel, zinc and aluminium | - | Cradle to gate | DAIA (Decision Analysis Impact Assessment)<br>[eutrophication, ozone formation, acidification and climate change] | The main influencing point of integrated steel production was the production process and the impacts on climate change followed by acidification | Seppala et al. [8] |
| To assess environmental impacts of copper, nickel, aluminium, lead, zinc, steel, stainless steel and titanium | - | Cradle to gate | Global warming potential, energy requirements and solid waste burden | Steel and lead (by the blast furnace process) had the lowest cradle-to-gate environmental impacts in terms of all impact categories covered | Norgate et al. [10] |

Table 4. Summary of research studies on LCA in iron and steel industry- continued

| Objective | Functional unit | System boundary | Impact assessment method/Impact category | Result | Reference |
|---|---|---|---|---|---|
| To propose a recycling option for granulated blast furnace slag | - | Cradle to gate | Life cycle inventory on $CO_2$, characterized impact on global warming, and weighted impact of the product system using the Eco-indicator 99 method | The use of granulated blast furnace slag as raw material for slag cement resulted in the highest environmental credit followed by Portland cement, slag powder and silicate fertilizer. | Lee and Park [17] |
| To assess the reduction in environmental impacts by using of blast furnace slag as a substitute to clinker in cement industry | - | - | $CO_2$ emissions | $CO_2$ emissions can be reduced by 44% through using of blast furnace slag as a substitute to clinker in cement industry | Birat [18] |
| To compare BF/BOF and DRI/EAF processes for both iron and steel productions | - | Cradle to gate | - | For the production of per unit iron and steel, the environmental impact of the DRI/EF process was lower than that of the BF/BOF process, because sintering and coke making processes were omitted in the DRI/EAF process and the BF/BOF process mainly uses molten ore causing resource depletion. | Li et al. [19] |

## 4.3. LCA studies in Turkey

In Turkey, as being one of the leading countries of the world's steel production, the concept of LCA has become widespread by the day. However, there is not yet any LCA study conducted on iron and steel industry in Turkey. As mentioned in the above parts of this chapter, Turkish Iron and steel producers participated in a study conducted by the International Iron and Steel Institute (IISI) throughout the World in 2000 [49]. The industries participated in this study, could compare their raw material, energy consumptions and emission levels with the levels determined by IISI. In addition, there is a study regarding the specific energy consumption of three integrated iron and steel producers in Turkey, conducted by Ertem et al. [21]. The specific energy consumption analysis was performed by using the data of 2003–2005 in three integrated plants; Karabük Iron and Steel Co. (KARDEMIR); Iskenderun Iron and Steel Co. (ISDEMIR); and Eregli Iron and Steel Co. (ERDEMIR). As the reference control volume, plant boundaries were selected; in other words, study was conducted as gate to gate, only the production process was incorporated into the analysis. Specific energy consumptions of three integrated steel plants were determined as follows: 30.3 GJ/Ton Crude Steel (TCS) for KARDEMIR; 29.8 GJ/TCS for ISDEMIR; and 21.5 GJ/TCS for ERDEMIR. The results of the specific energy consumption analysis indicated that ERDEMIR has the lowest specific energy consumption for steelmaking process in Turkey, and within the range of average values around the world [21]. However, energy consumptions of the other two steel plants in Turkey fall above the average. As a result, both studies provide a comparison capability of the amounts of raw material, energy consumptions and emissions, but not a real assessment of the environmental impacts of the industry.

# CHAPTER 5

# METHODOLOGY

## 5.1. Study Approach

This study aimed to give a general view of integrated iron and steel production in Turkey, concerning their material and energy consumptions, emissions and, hence, environmental impacts through conducting a LCA study with cradle to gate approach. To assess the whole life cycle, utility services were also included to the boundary of the study together with upstream process and transportation.

In LCA studies, data quality and databases are of particular importance concerning the reliability of the study outputs. LCA calculations can be accomplished either by hand or using a software. In hand calculation, creating a database is a challenging step, and can misguide the LCA. However, softwares have the databases from different sources. There are many commercial softwares available in the market, diversified in terms of their databases, assessment methods and compliance to ISO 14040 standards. Based on the market search among the available LCA softwares; SimaPro seemed as the most appropriate to be used in this study. The reasons for the selection were the compliance with ISO 14040 series; the quality of databases provided and impact assessment methods used; the technical support provided by the supplier; and the ease of use. Moreover, being one of the most widely used softwares worldwide was also considered as a factor in this selection.

The selected software; SimaPro version 7.2.4, consists of goal and scope definition, inventory analysis, impact assessment and the interpretation stages as required by ISO 14040 series.

In the context of the present thesis, a field study was carried out inone of the three integrated iron and steel production facilities in Turkey in order to collect the inventory data. The selected facility has the features to reveal the average values of integrated iron and steel industry in Turkey having the share of about 35% in steel production via integrated means. Thus, this facility is considered as a representative sample of Turkish integrated iron and steel industry in terms of manufacturing technologies and production capacity.

Firstly, the production processes of the integrated iron and steel production facility were examined in detail, considering all inputs to and all outputs from the processes. Data required for LCA study was provided by the facility.

After the data has been obtained covering the inputs and outputs of each process together with the amount, data were introduced to SimaPro software. Each production step (sub-processes, and utility services) was defined individually. Most of the materials produced in the facility were defined manually though a few of them were taken from the databases as they are raw materials and some energy sources. The data not specific to country were directly taken from the database; such as magnesite, fluorspar and ferrosilicat. And country-specific ones were selected according to the suitability to the country conditions such as geographical similarities. For instance, since most of the natural gas of Turkey came from Russia, the natural gas data specific to Russia was selected. Moreover some of them were adopted to Turkey, such as electricity and hard coal.

Related to the stages of life cycle analysis, the details are presented in the following sections.

## 5.2. Life Cycle Methodology

### 5.2.1. Goal and Scope Definition

The goal of the study was to assess the environmental impacts of integrated iron and steel industries in Turkey and to compare the impacts associated with the sub-processes as well as the impacts associated with the final products. The assumptions made while conducting the study are listed in APPENDIX C.

Within the scope of the study, the system boundary was assigned as “cradle to gate”. Upstream processes, transportation, production processes and utility services were included to cradle to gate boundary. The upstream processes are acquisitions of raw materials, energy and auxiliary materials. The transportation stage indicates the transportation of materials such as raw materials, auxiliary materials and fuels. The production processes for steel production is divided into two, the main production system and the utility services. The main production process comprises the sub-processes; coke production, sintering, blast furnaces, basic oxygen furnaces, continuous casting and hot rolling. The flow chart of the facility is presented in APPENDIX A.

The utility services include energy and water facilities and mechanical workshop. Energy facility comprises boiler, turbo generator, turbo blower, pure water, waste heat, and oxygen plants producing steam, electricity, compressed air, steam and oxygen respectively. Water facility supplies pure water, service water and sea water. Service water is the mixture of pure and well water. In this study, all water types (pure water, service water and sea water) were considered separately. Lastly, mechanical workshop is responsible for repair and manufacturing of machine parts.

Within the scope of upstream processes, the information about acquisitions of raw materials, energy and auxiliary materials were not obtained from the facility as also stated in Section 5.1, but, instead was taken from the inventories in the database of SimaPro. The selected databases were presented in Figure 6. Except a library specifically related to foods, ’LCA Food DK’, all libraries were selected to be used. Primarily Ecoinvent database was preferred; in case the information was not available in this database, the other databases were used. Used data from the database were also adapted to conditions of Turkey. For example, the electricity provided by the network was adapted using the percentages of energy sources specific to electricity production in Turkey; the energy sources are natural gas, domestic coal, and hydraulic sources and their percentages are 55%, 25% and 20% respectively. The details are given in Section 5.2.3.1.

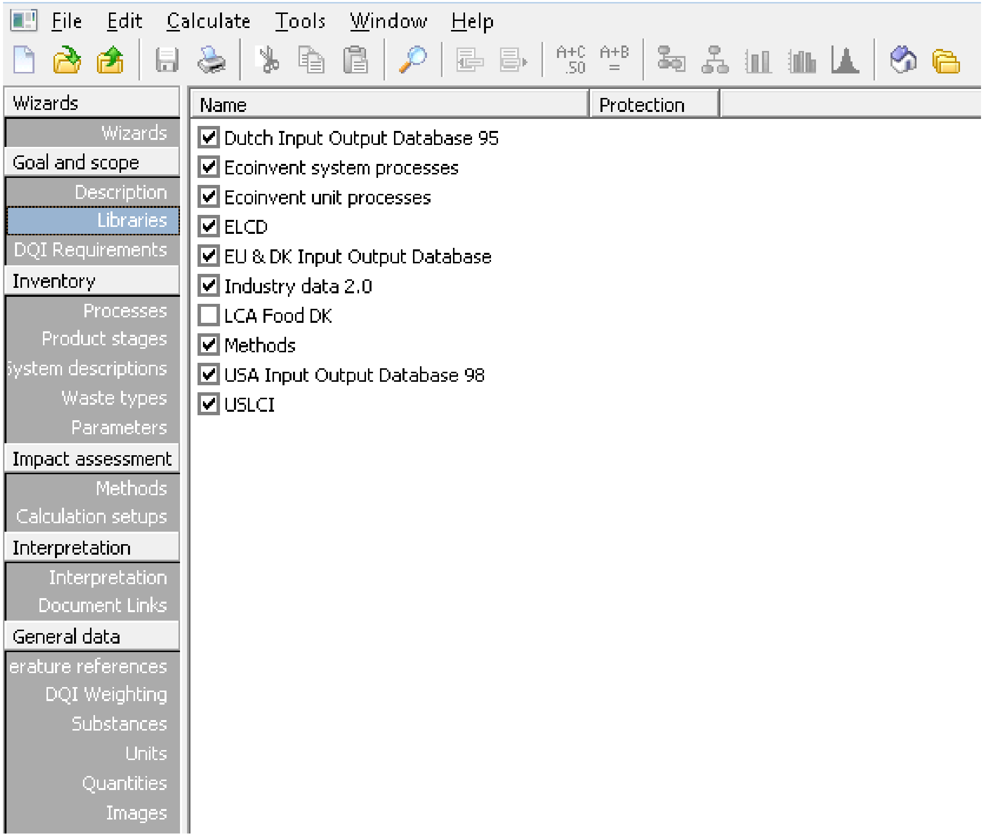



Figure 6. Databases of SimaPro used in the study

The functional unit, enabling alternative products to be compared, of this study were selected as 1 ton of product. In this respect, the functional unit for the first task (Section1.2) was considered as 1 ton of product from a corresponding sub-process whereas the functional unit for the second task (Section 1.2) was considered as 1 ton of final steel product. The final steel products are of basically two types, one being semi-finished products, namely, slab and billet; and the other being finished products, namely, coil and wire rod.

In the goal and scope definition step, there exist data quality indicator requirements (time, geography, type of technology and representativeness of the data, etc.) to identify the adequacy of inventory data to be used in the study. The data quality indicator requirements can be specified by means of SimaPro as presented in Figure 7. The study was conducted using the 2009 data of a facility in Turkey. Thereby, according to the data used in studies, “time” was selected as ‘2005-2009’ (Figure 7); and “geography” was identified as Eastern Europe and Middle East Asia (Figure 8) from SimaPro to be able to check the reliability of data.

As presented in Figure 9, in “type tab”, “technology and representativeness” of the study were specified. In some parts of production “average technology” is applied and in some parts “modern technology” is implemented, therefore both “average” and “modern” technology options were selected. Since actual data of the facility was used, “data from specific plant and company” option was selected along with some “estimations”. Allocation and system boundaries were specified in this part. System boundaries were selected as mentioned in the upper part of this section, and studies were formed according to the boundaries. In Section 5.2.3, applied allocation procedure is addressed.

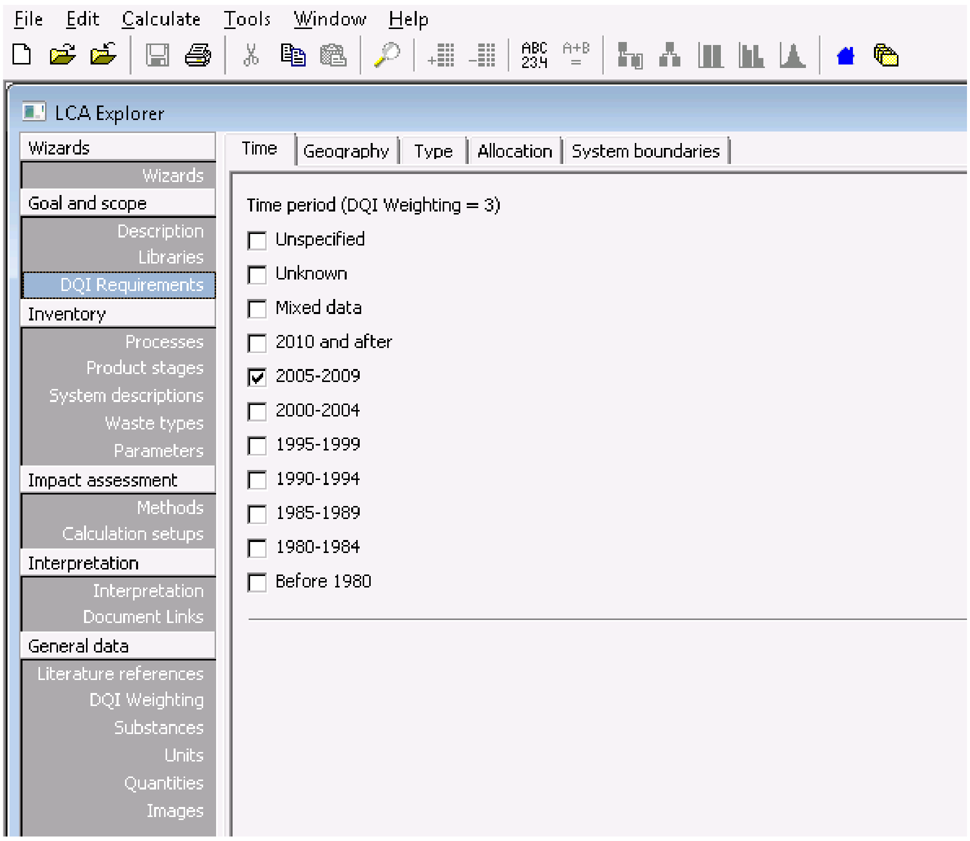



Figure 7. Data quality indicator requirements of LCA: Time

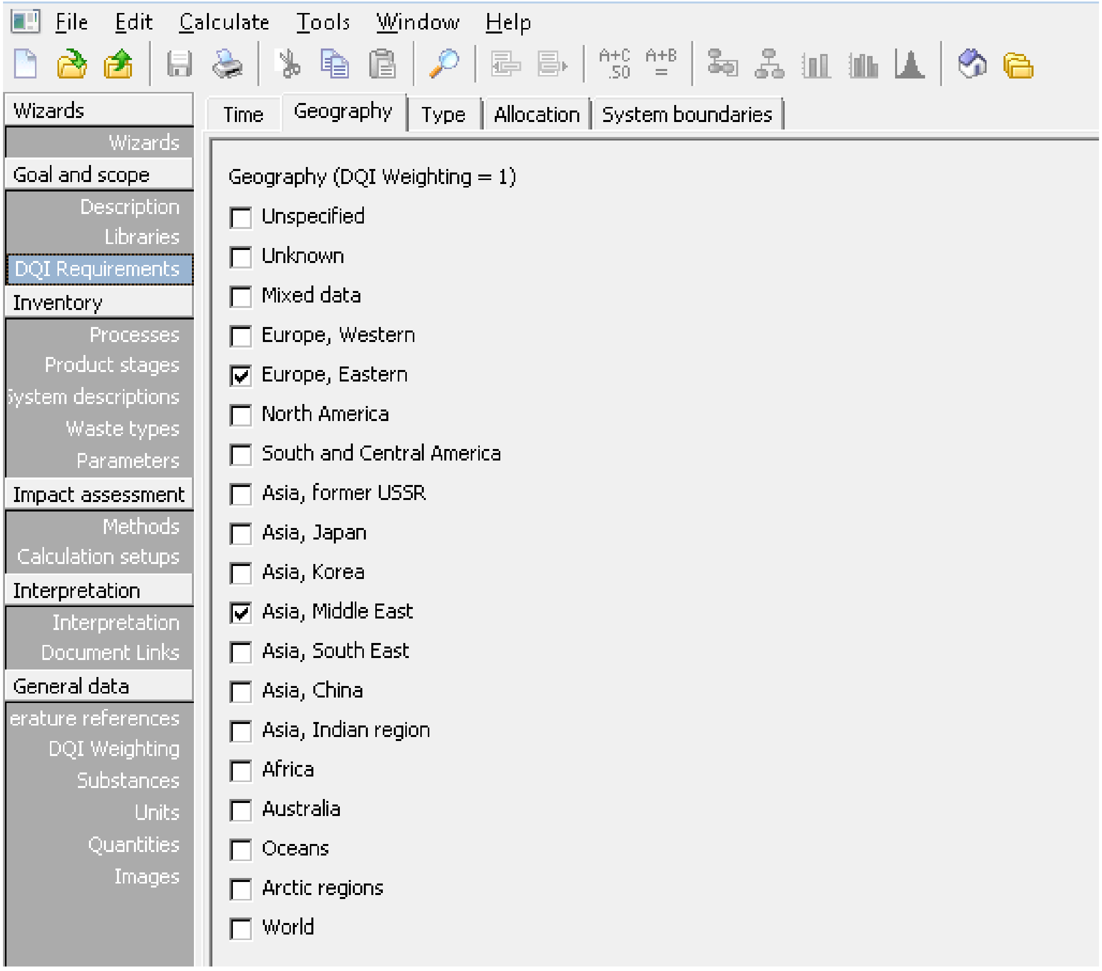



Figure 8. Data quality indicator requirements of LCA: Geography

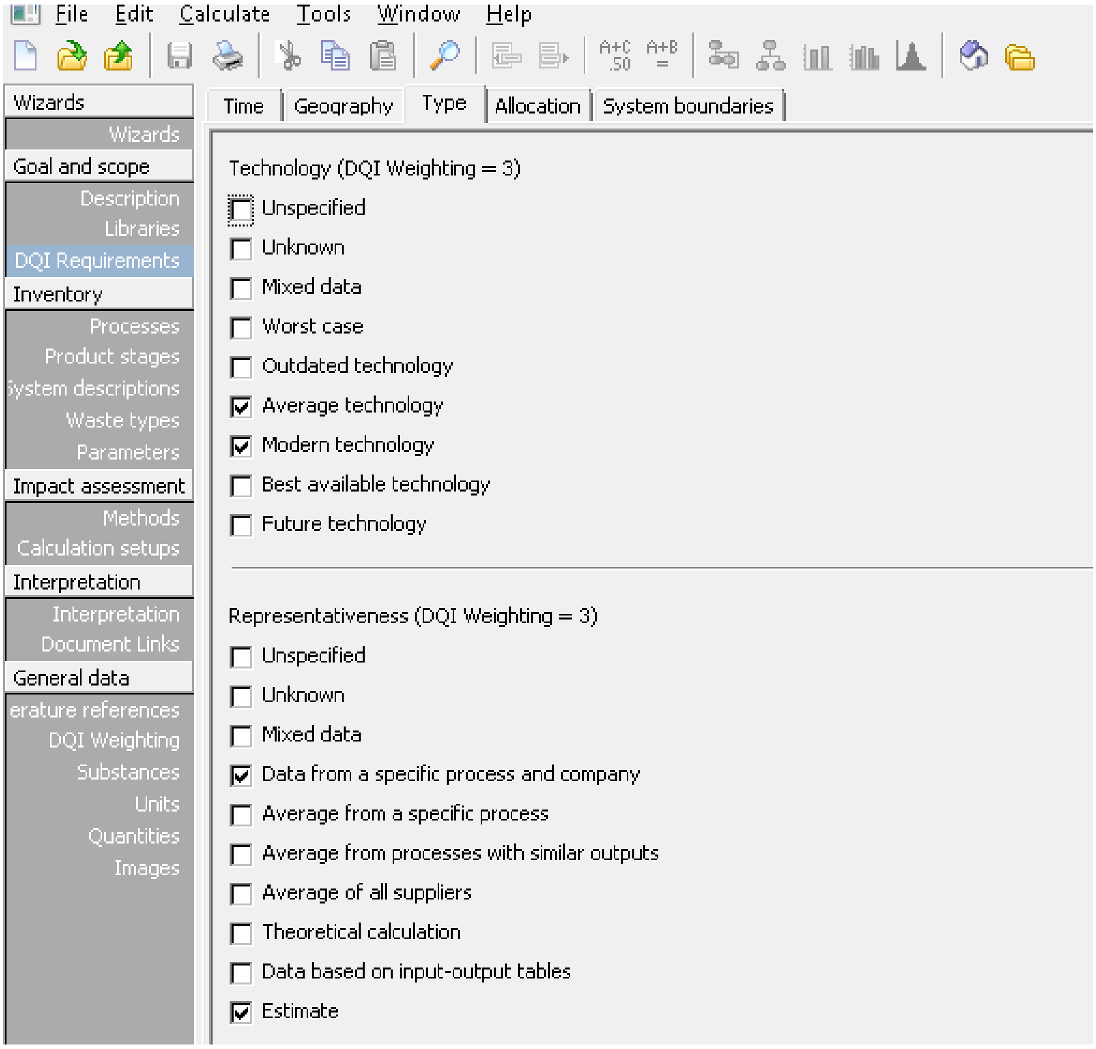



Figure 9. Data quality indicator requirements of LCA: Type

### 5.2.2. Inventory Analysis

As a core part of LCA, inventory analysis can be defined as the quantitative accounting of material inputs and outputs of processes in a system to produce better understanding of the flow of materials through an industry. Since the objective of the study is to conduct a LCA study for the integrated iron and steel industry in Turkey, country specific inventory data collection for Turkey was aimed.

The quality of the data used in LCA is of crucial importance. The input and output analysis for the sub-processes in the facility were conducted using the data belonging to 2009. In analyzing the steel production in the facility, all the inputs (energy, raw material, water etc.) and outputs (product, by-product, waste etc.) of each sub-process were described together with their amounts. A number of trips were made to the facility to understand production processes. During these visits, steel production processes were studied on site, information obtained from the literature was discussed with the technical staff of the plant. Since facility gives a lot of importance to input data, such as raw material and energy consumption amounts, these data were registered and thus were readily available. Output data were sometimes difficult to find, except the main products and co-products. This difficulty is mainly based on the absence of register of releases. Some of the incomplete data was gathered through consultation with technical staff and some were adapted to conditions in Turkey by consultation with technical staff as well. The information about the facility and the details of production steps are provided in APPENDIX B. Moreover, there are many assumptions made in the study listed in APPENDIX C..

The sub-processes were coke making, sintering, iron-making (blast furnaces), steelmaking (basic oxygen furnaces), continuous casting and rolling. Besides these sub-processes, utility services of the facility were also examined covering energy and water facilities and mechanical workshop.

The amounts were given for "one ton of target product" for sub-processes. For instance, in coke making unit, the amount of consumed materials are given for "one ton of coke". The target products are sinter, liquid iron, liquid steel, billet and slab, and wire rod and coil, in sinter making, blast furnaces, basic oxygen furnaces, casting and hot rolling, respectively. For water facilities, the functional unit is taken as 1 $m^3$ water for each type of water. The case is different for energy facilities, because there is not a single target product in energy facilities and it is not possible to define a base. Therefore, the amounts of inputs and emissions were given for 1 GJ of total energy produced.

In SimaPro, emissions to air, water and soil are categorized as outputs. Besides raw material and energy consumptions, air and water emissions were also taken into account. Air emission levels were calculated according to a report of the facility [45] including emission concentration (mg/$Nm^3$) and the gaseous flow rate ($m^3$/hour) and then adapted to the software. $CO_2$ emissions were also calculated based on the information taken from the facility. There exists a treatment plant in coke making unit for the treatment of ammonia water from coke by-product unit; the details of which are given in APPENDIX B. The concentrations of wastewater discharged to the sea from treatment plant are taken for emissions to water. Data about emissions to soil is not available, thus this part is excluded in the study.

The inventory data belonging to each sub-process and utility service are given in the following sub-sections.

#### 5.2.2.1. Coke making

In coke making unit, the target product is coke and the amount of inputs and outputs are given for one ton of coke produced. Since there is no data recorded for the amount of generated treatment sludge, is could not be added to the inventory (Table 5).

Table 5. Material inputs and outputs of coke making unit

| Material | Amount | Unit |
|---|---|---|
| **INPUTS** | | |
| Hard coal | 1.3356 | ton/ton coke |
| Sulfuric acid | 0.0111 | ton/ton coke |
| Sodium hydroxide | 0.0015 | ton/ton coke |
| Oil | 0.0002 | ton/ton coke |
| Fusi | 0.0009 | ton/ton coke |
| Pure water | 0.0599 | $m^3$/ton coke |
| Service water | 18.5371 | $m^3$/ton coke |
| Electricity | 0.0922 | GJ/ton coke |
| Coke oven gas | 3.1717 | GJ/ton coke |
| Natural gas | 0.0005 | GJ/ton coke |
| Steam | 0.6754 | GJ/ton coke |
| Nitrogen | 0.0367 | GJ/ton coke |

Table 5. Material inputs and outputs of coke making unit - continued

| Material | Amount | Unit |
|---|---|---|
| **OUTPUTS** | | |
| **Products and co-products** | | |
| Coke | 1.0000 | ton/ton coke |
| Tar | 0.0418 | ton/ton coke |
| Ammonium sulphate | 0.0123 | ton/ton coke |
| Benzene | 0.0062 | ton/ton coke |
| Fusi | 0.0009 | ton/ton coke |
| Coke oven gas | 7.5224 | GJ/ton coke |
| **Emissions to air** | | |
| Carbon monoxide | 1.7664 | kg/ton coke |
| Sulfur dioxide | 0.1167 | kg/ton coke |
| Nitric oxide | 0.2373 | kg/ton coke |
| Nitrogen dioxide | 0.3639 | kg/ton coke |
| Dust | 0.2750 | kg/ton coke |
| Carbon dioxide | 94.2101 | kg/ton coke |
| **Emissions to water** | | |
| COD | 0.2904 | kg/ton coke |
| Cyanide | 0.0050 | kg/ton coke |
| Phenol | 0.0019 | kg/ton coke |
| Phosphorus | 0.0016 | kg/ton coke |
| Ammonia | 0.0002 | kg/ton coke |
| Suspended solids | 0.0812 | kg/ton coke |

#### 5.2.2.2. Sintering

Target product is sinter in sintering unit, thus the amount of inputs and outputs are given for one ton of sinter production (Table 6).

Table 6. Material inputs and outputs of sintering unit

| Material | Amount | Unit |
|---|---|---|
| **INPUTS** | | |
| Magnesite | 0.0016 | ton/ton sinter |
| Iron ore | 0.8902 | ton/ton sinter |
| Limestone | 0.1970 | ton/ton sinter |
| Dolomite | 0.0109 | ton/ton sinter |
| Dunite | 0.0312 | ton/ton sinter |
| Coke breeze | 0.0798 | ton/ton sinter |
| Sinter dust | 0.6918 | ton/ton sinter |
| Pellet dust | 0.0395 | ton/ton sinter |
| Basic oxygen furnace slag | 0.0184 | ton/ton sinter |
| Flue dust | 0.0227 | ton/ton sinter |
| Gas cleaning sludge | 0.0047 | ton/ton sinter |
| Mill scale | 0.0271 | ton/ton sinter |
| Service water | 1.1328 | $m^3$/ton sinter |
| Electricity | 0.1896 | GJ/ton sinter |
| Coke oven gas | 0.1100 | GJ/ton sinter |
| **OUTPUTS** | | |
| **Products and co-products** | | |
| Skip sinter | 1.0000 | ton/ton sinter |
| Sinter dust | 0.6918 | ton/ton sinter |
| **Emissions to air** | | |
| Carbon monoxide | 45.1008 | kg/ton sinter |
| Sulfur dioxide | 5.1371 | kg/ton sinter |
| Nitric oxide | 0.7990 | kg/ton sinter |
| Nitrogen dioxide | 1.2269 | kg/ton sinter |
| Hydrogen chloride | 0.0100 | kg/ton sinter |
| Hydrogen fluoride | 0.0005 | kg/ton sinter |
| Dioxin | 0.0000019 | g/ton sinter |
| Furan | 0.0000019 | g/ton sinter |
| Dust | 1.6759 | kg/ton sinter |
| Carbon dioxide | 388.1348 | kg/ton sinter |

.

#### 5.2.2.3. Iron making

Since target product is liquid iron in iron making unit, the amount of inputs and outputs are given for one ton of liquid iron production (Table 7).

Table 7. Material inputs and outputs of iron making unit

| Material | Amount | Unit |
|---|---|---|
| **INPUTS** | | |
| Sinter | 0.8222 | ton/ton liquid iron |
| Pellet | 0.6502 | ton/ton liquid iron |
| Iron ore | 0.1276 | ton/ton liquid iron |
| Coke | 0.4409 | ton/ton liquid iron |
| Limestone | 0.0046 | ton/ton liquid iron |
| Dolomite | 0.00004 | ton/ton liquid iron |
| Pure water | 0.0684 | $m^3$/ton liquid iron |
| Service water | 0.0407 | $m^3$/ton liquid iron |
| Manganese ore | 0.0187 | ton/ton liquid iron |
| Quartzite | 0.0277 | ton/ton liquid iron |
| Air | 1.3337 | ton/ton liquid iron |
| Pulverized coal | 2.2430 | GJ/ton liquid iron |
| Natural gas | 0.0006 | GJ/ton liquid iron |
| Coke oven gas | 0.2539 | GJ/ton liquid iron |
| Blast furnace gas | 1.3728 | GJ/ton liquid iron |
| Electricity | 0.0694 | GJ/ton liquid iron |
| Steam | 0.1420 | GJ/ton liquid iron |
| Oxygen | 0.2345 | GJ/ton liquid iron |
| Nitrogen | 0.1368 | GJ/ton liquid iron |
| **OUTPUTS** | | |
| **Product and co-products** | | |
| Liquid iron | 1.0000 | ton/ton liquid iron |
| Blast furnace gas | 4.8078 | GJ/ton liquid iron |
| Liquid slag | 0.2858 | ton/ton liquid iron |
| Flue dust | 0.0085 | ton/ton liquid iron |
| Scale and scrap | 0.0128 | ton/ton liquid iron |
| Gas cleaning sludge | 0.0077 | ton/ton liquid iron |

Table 7. Material inputs and outputs of iron making unit - continued

| Material | Amount | Unit |
|---|---|---|
| **Emissions to air** | | |
| Carbon monoxide | 2.8152 | kg/ton liquid iron |
| Sulfur dioxide | 0.0229 | kg/ton liquid iron |
| Nitric oxide | 0.0478 | kg/ton liquid iron |
| Nitrogen dioxide | 0.0734 | kg/ton liquid iron |
| Dust | 1.1435 | kg/ton liquid iron |
| Carbon dioxide | 355.4365 | kg/ton liquid iron |

### 5.2.2.4. Steel making

Since target product is liquid iron in iron making unit, the amount of inputs and outputs are given for one ton of liquid iron production (Table 8).

Table 8. Material inputs and outputs of steel making unit

| Material | Amount | Unit |
|---|---|---|
| **INPUTS** | | |
| Liquid iron | 0.9047 | ton/ton liquid steel |
| Steel scrap | 0.2197 | ton/ton liquid steel |
| Iron dust | 0.0001 | ton/ton liquid steel |
| Iron ore | 0.0035 | ton/ton liquid steel |
| Desulphurization scale | 0.0048 | ton/ton liquid steel |
| Anthracite | 0.0020 | ton/ton liquid steel |
| Coke breeze | 0.0006 | ton/ton liquid steel |
| Coke | 0.0013 | ton/ton liquid steel |
| Lime | 0.0502 | ton/ton liquid steel |
| Pure water | 0.3152 | ton/ton liquid steel |
| Service water | 8.5296 | $m^3$/ton liquid steel |
| Magnesite | 0.0002 | ton/ton liquid steel |
| Fluorite | 0.0004 | ton/ton liquid steel |
| FeSi | 0.0016 | ton/ton liquid steel |
| Fe Mn | 0.0014 | ton/ton liquid steel |
| FeCr | 0.00002 | ton/ton liquid steel |
| Al | 0.0008 | ton/ton liquid steel |

Table 8. Material inputs and outputs of steel making unit - continued

| Material | Amount | Unit |
|---|---|---|
| Natural gas | 0.1536 | GJ/ton liquid steel |
| Coke oven gas | 0.2356 | GJ/ton liquid steel |
| Electricity | 0.2424 | GJ/ton liquid steel |
| Steam | 0.2182 | GJ/ton liquid steel |
| Oxygen | 0.3825 | GJ/ton liquid steel |
| **OUTPUTS** | | |
| **Product and co-products** | | |
| Liquid steel | 1.0000 | ton/ton liquid steel |
| Basic oxygen furnace gas | 0.3929 | GJ/ton liquid steel |
| Converter slag | 0.1092 | ton/ton liquid steel |
| Gas cleaning sludge | 0.0406 | ton/ton liquid steel |
| Desulphurization slag | 0.0271 | ton/ton liquid steel |
| **Emissions to air** | | |
| Carbon monoxide | 0.0068 | kg/ton liquid steel |
| Sulfur dioxide | 0.0001 | kg/ton liquid steel |
| Nitric oxide | 0.0050 | kg/ton liquid steel |
| Nitrogen dioxide | 0.0078 | kg/ton liquid steel |
| Dust | 0.5140 | kg/ton liquid steel |
| Carbon dioxide | 284.0000 | kg/ton liquid steel |

#### 5.2.2.5. Casting

The target products are billet and slab in casting unit. They are discussed separately, so the amount of inputs and outputs are given for one ton of billet as shown in Table 9 and the amount of inputs and outputs are given for one ton of slab as shown in Table 10.

Since the basic oxygen furnace and casting units were evaluated together, air emissions from casting were also evaluated under basic oxygen furnaces. Emissions from casting unit were not known separately except for carbon dioxide. The amount of carbon dioxide emissions was generally higher that of other emissions [15], so it was thought that exclusion of other emissions would not affect the result of the study to a great extent.

Table 9. Material inputs and outputs of billet casting

| Material | Amount | Unit |
|---|---|---|
| **INPUTS** | | |
| Liquid steel | 1.0164 | ton/ton billet |
| LPG | 0.0002 | ton/ton billet |
| Pure water | 0.0865 | $m^3$/ton billet |
| Service water | 11.3892 | $m^3$/ton billet |
| Natural gas | 0.0007 | GJ/ton billet |
| Coke oven gas | 0.1576 | GJ/ton billet |
| Electricity | 0.0473 | GJ/ton billet |
| Oxygen | 0.0157 | GJ/ton billet |
| Nitrogen | 0.0363 | GJ/ton billet |
| Argon | 0.0007 | GJ/ton billet |
| **OUTPUTS** | | |
| **Product** | | |
| Billet | 1.0000 | ton/ton billet |
| Billet losses | 0.0142 | ton/ton billet |
| **Emissions to air** | | |
| Carbon dioxide | 7.4387 | kg/ton billet |

Table 10. Material inputs and outputs of slab casting

| Material | Amount | Unit |
|---|---|---|
| **INPUTS** | | |
| Liquid steel | 1.0470 | ton/ton slab |
| LPG | 0.0001 | ton/ton slab |
| Pure water | 0.0053 | $m^3$/ton slab |
| Service water | 38.2762 | $m^3$/ton slab |
| Coke oven gas | 0.1115 | GJ/ton slab |
| Natural gas | 0.0879 | GJ/ton slab |
| Electricity | 0.0428 | GJ/ton slab |
| Electricity from network | 0.0086 | GJ/ton billet |
| Electricity in facility | 0.0342 | GJ/ton billet |

Table 10. Material inputs and outputs of slab casting - continued

| Material | Amount | Unit |
| --- | --- | --- |
| Oxygen | 0.0027 | GJ/ton slab |
| Nitrogen | 0.0035 | GJ/ton slab |
| Argon | 0.0012 | GJ/ton slab |
| **OUTPUTS** | | |
| **Product** | | |
| Slab | 1.0000 | ton/ton slab |
| Slab losses | 0.0478 | ton/ton slab |
| **Emissions to air** | | |
| Carbon dioxide | 16.5248 | kg/ton slab |

#### 5.2.2.6. Hot rolling

The target products are wire rod and coil in hot rolling unit. Thus, the amounts of inputs and outputs for one ton of each target product were given separately (Table 11).

Table 11. Material inputs and outputs of wire rod hot rolling

| Material | Amount | Unit |
| --- | --- | --- |
| **INPUTS** | | |
| Billet | 1.0440 | ton/ton wire rod |
| Service water | 44.2339 | $m^3$/ton wire rod |
| Natural gas | 1.4343 | GJ/ton wire rod |
| Electricity | 0.4761 | GJ/ton wire rod |
| Electricity from network | 0.0952 | GJ/ton wire rod |
| Electricity in facility | 0.3809 | GJ/ton wire rod |
| Oxygen | 0.0016 | GJ/ton wire rod |
| **OUTPUTS** | | |
| **Product** | | |
| Wire rod | 1.0000 | ton/ton wire rod |
| Mill scale | 0.0105 | ton/ton wire rod |
| Other losses | 0.0335 | ton/ton wire rod |

Table 11. Material inputs and outputs of wire rod hot rolling - continued

| Material | Amount | Unit |
|---|---|---|
| **Emissions to air** | | |
| Carbon monoxide | 0.0006 | kg/ton wire rod |
| Sulfur dioxide | 0.0004 | kg/ton wire rod |
| Nitric oxide | 0.0387 | kg/ton wire rod |
| Nitrogen dioxide | 0.0594 | kg/ton wire rod |
| Dust | 0.0191 | kg/ton wire rod |
| Carbon dioxide | 49.0577 | kg/ton wire rod |

Table 12. Material inputs and outputs of coil hot rolling

| Material | Amount | Unit |
|---|---|---|
| **INPUTS** | | |
| Slab | 1.0277 | ton/ton coil |
| Service water | 167.1421 | $m^3$/ton coil |
| Coke oven gas | 2.0540 | GJ/ton coil |
| Electricity | 0.5428 | GJ/ton coil |
| Electricity from network | 0.1086 | GJ/ton coil |
| Electricity in facility | 0.4343 | GJ/ton coil |
| Oxygen | 0.0011 | GJ/ton coil |
| Nitrogen | 0.0030 | GJ/ton coil |
| **OUTPUTS** | | |
| **Product** | | |
| Coil | 1.0000 | ton/ton coil |
| Mill scale | 0.0204 | ton/ton coil |
| Other losses | 0.0073 | ton/ton coil |
| **Emissions to air** | | |
| Carbon monoxide | 0.0456 | kg/ton coil |
| Sulfur dioxide | 1.8982 | kg/ton coil |
| Nitric oxide | 0.3869 | kg/ton coil |
| Nitrogen dioxide | 0.6059 | kg/ton coil |
| Dust | 0.3989 | kg/ton coil |
| Carbon dioxide | 41.9339 | kg/ton coil |

#### 5.2.2.7. Utility services

##### 5.2.2.7.1. Energy facilities

The case is different for energy facilities, because there is not a single target product in energy facilities and it is not possible to define a base. Therefore, the amounts of inputs and outputs different from the products were given for 1 GJ of total energy produced (Table 13). There are five products in energy facilities, steam, electricity, oxygen, nitrogen and argon. 1 GJ of total energy is distributed to the products by means of their production percentages. For instance, 72.89 % of total energy produced is steam, so for 1 GJ of total energy produced in energy facilities, 0.7289 GJ of steam is produced.

Table 13. Material inputs and outputs of energy facilities

| Material | Amount | Unit |
|---|---|---|
| **INPUTS** | | |
| Tar | 0.0028 | ton/GJ energy |
| Pure water | 0.0073 | $m^3$/GJ energy |
| Sea water | 13.9642 | $m^3$/GJ energy |
| Service water | 0.4028 | $m^3$/GJ energy |
| Natural gas | 0.0340 | GJ/GJ energy |
| Electricity | 0.0535 | GJ/GJ energy |
| Electricity from network | 0.0107 | GJ/GJ energy |
| Electricity in facility | 0.0428 | GJ/GJ energy |
| Coke oven gas | 0.1701 | GJ/GJ energy |
| Blast furnace gas | 0.3055 | GJ/GJ energy |
| Basic oxygen furnace gas | 0.0394 | GJ/GJ energy |
| Steam | 0.6676 | GJ/GJ energy |
| Nitrogen | 0.0005 | GJ/GJ energy |
| **OUTPUTS** | | |
| **Products** | | |
| Steam | 0.7289 | GJ/GJ energy |
| Electricity in facility | 0.1296 | GJ/GJ energy |
| Oxygen | 0.0761 | GJ/GJ energy |
| Nitrogen | 0.0636 | GJ/GJ energy |
| Argon | 0.0018 | GJ/GJ energy |

Table 13. Material inputs and outputs of energy facilities - continued

| Material | Amount | Unit |
|---|---|---|
| **Emissions to air** | | |
| Carbon monoxide | 0.0072 | kg/GJ energy |
| Sulfur dioxide | 0.3066 | kg/GJ energy |
| Nitric oxide | 0.1324 | kg/GJ energy |
| Nitrogen dioxide | 0.2038 | kg/GJ energy |
| Dust | 0.0244 | kg/GJ energy |
| Carbon dioxide | 101.5833 | kg/GJ energy |

#### 5.2.2.7.2. Water facilities

For water facilities, the functional unit is taken as 1 $m^3$ water for each type of water. The data of amount of water processed was not available, therefore the amount is assumed to be one $m^3$ for one $m^3$ of water processing for all types of water; pure water (Table 14), service water (Table 15) and sea water (Table 16).

Table 14. Material inputs and outputs of pure water facility

| Material | Amount | Unit |
|---|---|---|
| **INPUTS** | | |
| Electricity | 0.0067 | $GJ/m^3$ pure water |
| Steam | 0.3263 | $GJ/m^3$ pure water |
| Steam water | 1.0000 | $m^3/m^3$ pure water |
| **OUTPUTS** | | |
| Pure water | 1.0000 | $m^3/m^3$ pure water |

Table 15. Material inputs and outputs of service water facility

| Material | Amount | Unit |
|---|---|---|
| **INPUTS** | | |
| Electricity | 0.0011 | $GJ/m^3$ service water |
| Steam water | 1.0000 | $m^3/m^3$ service water |
| **OUTPUTS** | | |
| Service water | 1.0000 | $m^3/m^3$ service water |

Table 16. Material inputs and outputs of sea water facility

| Material | Amount | Unit |
|---|---|---|
| **INPUTS** | | |
| Electricity | 0.0005 | GJ/$m^3$ sea water |
| Steam water | 1.0000 | $m^3/m^3$ sea water |
| **OUTPUTS** | | |
| Sea water | 1.0000 | $m^3/m^3$ sea water |

#### 5.2.2.7.3. Mechanical workshops

Mechanical workshop is not a production unit. Therefore, the product was defined as "1 mechanical workshop". The material and energy consumptions and emissions of mechanical workshop were calculated for one ton of finished product. Since the total annual amount of the production year for 2009 were taken from the facility, the amount of material and energy consumptions and emissions from this unit were divided to the amount of total final products of the facility.

Table 17. Material inputs and outputs of mechanical workshops

| Material | Amount | Unit |
|---|---|---|
| **INPUTS** | | |
| Coke oven gas | 0.0011 | GJ/ton final product |
| Electricity | 0.0052 | GJ/ton final product |
| Steam | 0.0013 | GJ/ton final product |
| Oxygen | 0.0010 | GJ/ton final product |
| Service water | 0.0002 | $m^3$/ton final product |
| **OUTPUTS** | | |
| **Products** | | |
| mechanical workhop | 1.0000 | point/ton final product |
| **Emissions to air** | | |
| Carbon monoxide | 0.000030 | kg/ton final product |
| Sulfur dioxide | 0.0088 | kg/ton final product |
| Nitric oxide | 0.0027 | kg/ton final product |
| Nitrogen dioxide | 0.0042 | kg/ton final product |
| Dust | 0.0005 | kg/ton final product |

### 5.2.3. Data integration to SimaPro

Under the main title of ‘Processes’ in Inventory part of SimaPro, several sub-titles are available as shown in Figure 10, these are ‘Material’, ‘Energy’, ‘Transport’, ‘Processing’, ‘Use’, ‘Waste scenario’ and ‘Waste treatment’. There exist defined materials, energies or processes taken from the databases of SimaPro. In this study, most of the materials used or produced were defined manually. Only the raw materials and some energy sources were taken from the databases. Some of the materials were defined under ‘Material’ sub-title.

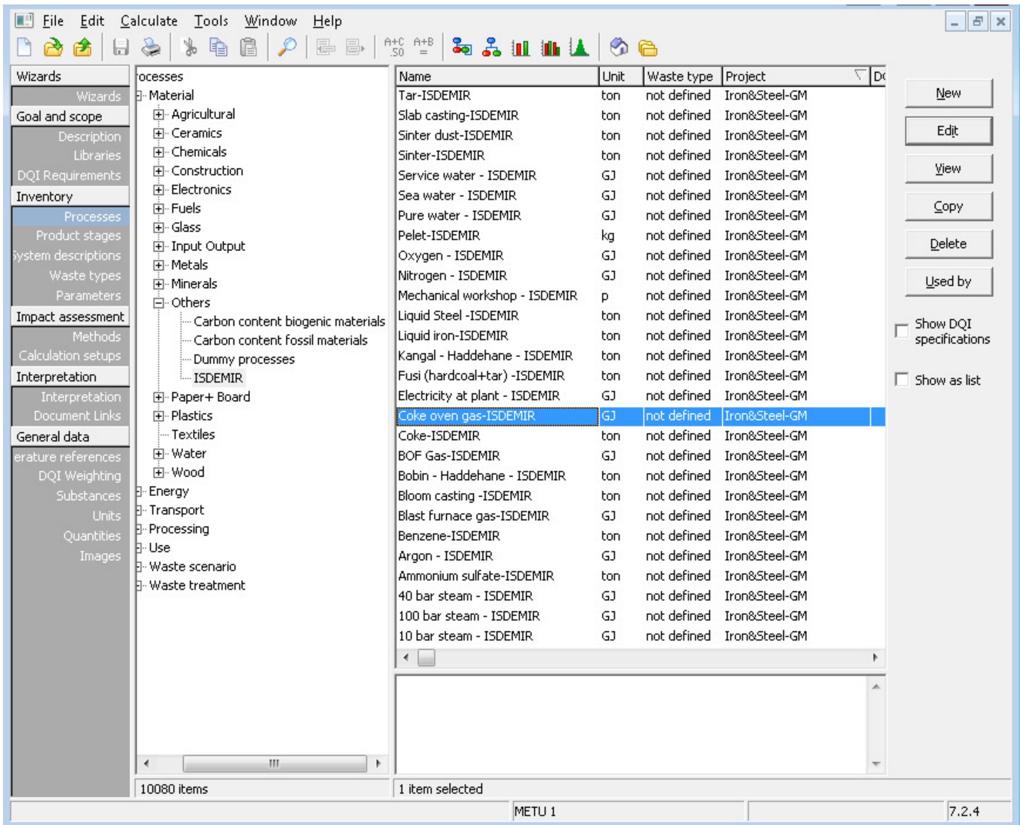



Figure 10. Processes in Inventory of SimaPro

Coke and sinter are the materials used in blast furnaces, and also the liquid iron the product of blast furnaces is also an input material to basic oxygen furnaces to produce liquid steel. Also semi-finished products and finished products are all materials. Since all products of sub-processes are the materials consumed to produce the subsequent product, they were defined as a material under ‘Material’ sub-title. In addition to that, in terms of energy and water facilities, the produced energies and waters were defined as materials.

A new folder was created under ‘Materials’ as ‘IISI TR’, indicating integrated iron and steel industry in Turkey, to define the materials specific to Turkey in it. Creating new pages under this title, all materials were defined.

The screenshot of empty page of SimaPro was presented in Figure 11. The page is divided into three; products, inputs and outputs, and the sub-titles were given below.

Products

- ‘Known outputs to technosphere. Products and co-products’
- ‘Known outputs to technosphere. Avoided products’.

Inputs

- ‘Known inputs from nature (resources)’
- ‘Known inputs from technosphere (materials/fuels)’
- ‘Known inputs from technosphere (electricity/heat)’

Outputs

- ‘Emissions to air’
- ‘Emissions to water’
- ‘Emissions to soil’
- ‘Final waste flows’
- ‘Social issues’
- ‘Economic issues’
- ‘Known outputs to technosphere. Waste and emissions to treatment.’

All the outputs of the mentioned processes except emissions to air and water were defined as products and co-products under the title of ‘Known outputs to technosphere, products and co-products’. However, mechanical workshop was excluded since there was not a product at the end of the process. The amounts of the produced materials were entered, and the units were selected. Mass allocation was used for products and co-products calculated with their mass percentages, only energy allocation was made for energy facilities. Allocation is an important point since the allocation of environmental impacts was also conducted by means of these percentages. After that ‘Known outputs to technosphere, Avoided products’ comes. Avoided products are the co-products, which results in negative contribution to environmental impacts. This means consumption of a material was avoided by production of a material in this unit, so its environmental impacts are subtracted. For instance, coke oven gas used as an energy source can avoid consumption of another energy source, such as electricity. Here, electricity is the avoided product. If the amount of electricity was entered as avoided product, SimaPro will subtract the emissions and resource use associated with the production of electricity. However, there was a gap in this software. The gap is that the avoided product cannot be linked with the material produced. This means that electricity consumption was not avoided by the coke oven gas production, it was avoided by the coke making unit.

After defining the products and co-products, inputs of the units were entered. The materials directly taken from the natural sources were entered under the title of ‘Known inputs from nature (resources)’. The materials, such as manganese, oil, magnesite, aluminium, air, etc., were taken from the databases. ‘Known inputs from technosphere (materials/fuels)’ and ‘Known inputs from technosphere (electricity/heat)’ has the same purpose. The inputs having mass and volume units were defined under materials/fuels, and the inputs having energy units were defined under electricity/heat.

Some inputs were not available in databases of the software and there was not sufficient information to define the materials. In such cases, inputs having similar characteristics were used. For instance, dunit was not available in the databases, since dunit has similar characteristics with dolomite, both Mg bearing materials; the amount of dunit was entered as dolomite.

Outputs of the units were entered to the title of ‘Emissions to air’ and ‘Emissions to water’. Air emission levels were calculated according to a report of the facility including emission concentration ($mg/Nm^3$) and the gaseous flow rate ($m^3$/hour) and then adapted to the software. In terms of emissions to water, coke making unit was taken into account. There exists a treatment plant in coke making unit for treatment of ammonia water from coke by-product unit. The concentrations of treated wastewater discharged to the sea from treatment plant are taken for emissions to water. Data about emissions to soil is not available, thus this part is excluded in the study. Similarly, social and economic issues were also excluded. Besides that, materials were not defined under the titles of ‘Final waste flows’ and ‘Known outputs to technosphere, waste and emissions to treatment’, since the waste flows of each unit were defined as products and co-products. The reason was that most of the wastes were recycled without processing to the units of the facility. If there is a processing such as incineration, landfilling or recycling, it would be defined here. In the facility, some of the wastes were processed; however, the details of the individual processes were not known and it was not defined individually. For instance, blast furnace slag was granulated and then sent to cement plant. The material consumptions for the granulation process were included to blast furnace unit; therefore, the waste blast furnace slag was defined under products and co-products title.

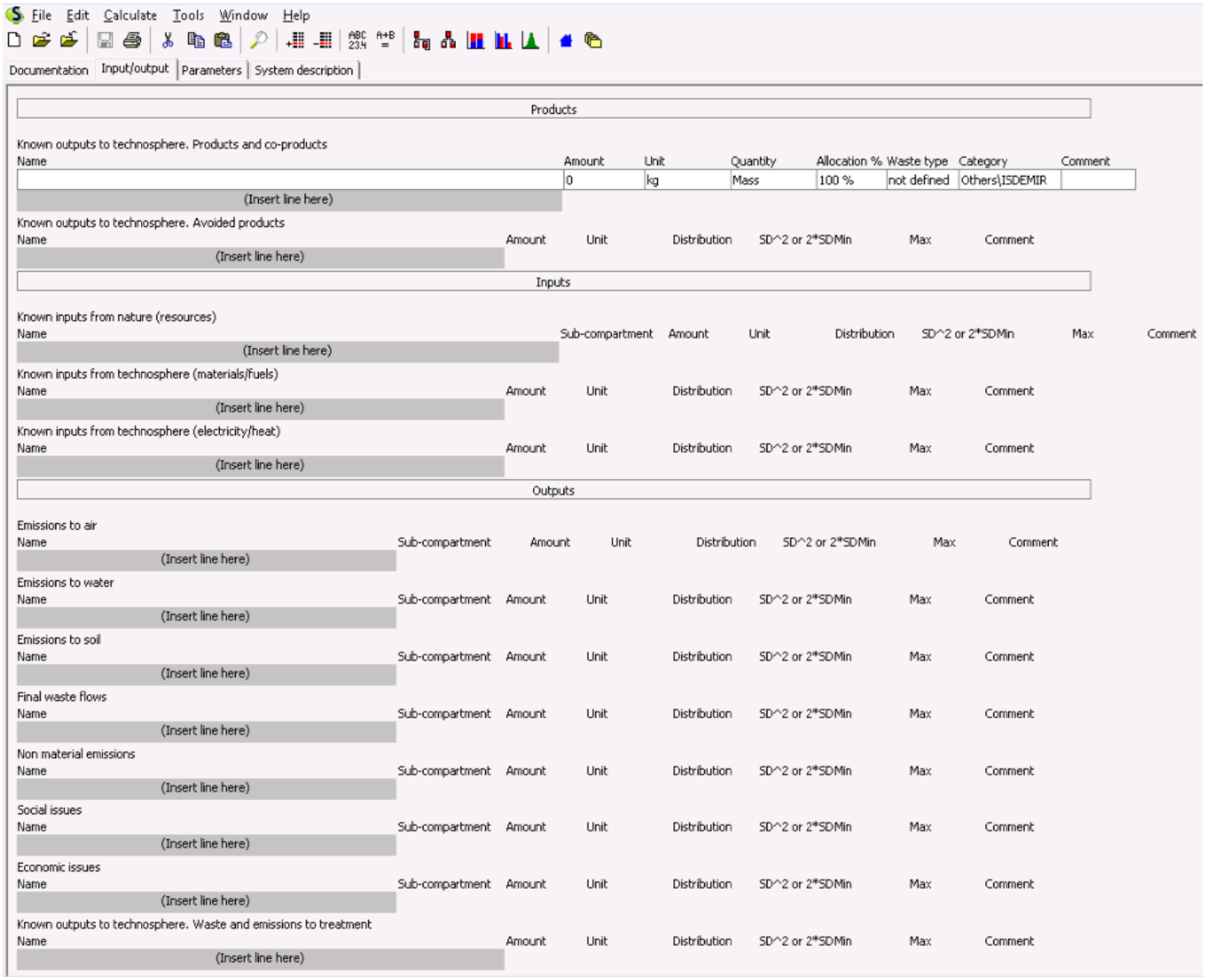



Figure 11. The screenshot of empty page of SimaPro

In the facility steam, oxygen, nitrogen, argon and electricity were generated in the energy facilities and then sent to other units. The allocation of environmental impact were distributed to products in terms their energy percentages. The screenshot of energy facilities was presented in Figure 39. 80% of the electricity consumed was generated in the facility, and 20% of it is taken from electricity network. All electricity consumptions were divided into two in proportion to their percentages (80% and 20%). Coke oven gas, blast furnace gas, basic oxygen furnace gas and tar were the consumed energy sources in energy facilities which were generated in sub-processes and defined under sub-processes. The information of some consumed energy sources was taken from databases, such as natural gas, electricity taken from electricity network, liquefied petroleum gas and anthracite coal.

The outputs of the units were the air and water emissions. The information about air emissions were taken from the emission report of the facility [45] and then adapted to the software. In terms of water emissions, the discharge concentrations of wastewater treatment plant were converted to mass by multiplying by volume of the water.

#### 5.2.3.1. Material defining to SimaPro

Most of the materials consumed in or produced from the units were integrated to SimaPro manually. Some of them were taken from the databases of the software. These exceptions taken from the databases were the raw materials and some energy sources. Magnesite, fluorspar, ferrosilicat, ferromanganese, ferrochromium, aluminium, oil, quartzite and air are not country-specific materials and taken from database directly. However, the characteristics of iron ore, scrap, dolomite, sodium hydroxide, sulfuric acid, lime, limestone, LPG, natural gas, anthracite coal, hard coal and electricity from network vary country to country. At this point, most of the materials were selected according to the geographical location of the countries. Generally, the data from European countries were preferred due to the closeness to Turkey. For instance, European data was used for dolomite, sodium hydroxide, sulfuric acid and scrap, the data from Germany was used for pulverized coal, the data from Switzerland was used for LPG, lime and limestone. Due to unavailability of appropriate data for Turkey, North American data was used for anthracite coal, and global data was used for iron ore. Since most of the natural gas of Turkey came from Russia, the data of natural gas specific to Russia was selected. Moreover, some of the data were adapted to Turkey, such as electricity and hard coal. The list of assumptions made during data integration to the software is presented in APPENDIX C.

For example, the electricity taken from the network was adapted to Turkey using the data taken from the Electricity Production Sector Report of 2009 as presented in Table 18. The minor generation supplies were excluded, and percentages ware calculated on the basis of natural gas, domestic coal, and hydraulic sources. According to the calculations, natural gas, domestic coal, and hydraulic sources generation were 55%, 25% and 20% in 2009 [52].

The natural gas is mainly taken from Russia, thus for electricity generation natural gas production in Russia was used from the database of the software. Natural gas, domestic coal and hydraulic energy used for electricity production have been already defined in databases; this information was taken from the inventories.

Table 18. Supply percentages of energy generation in Turkey [52]

| **Energy Supply** | **% (2009)** |
|---|---|
| **Natural Gas** | 48.6 |
| **Domestic coal** | 21.7 |
| **Hydraulic Source** | 18.5 |
| **Imported Coal** | 6.6 |
| **Fuel Oil** | 3.4 |
| **Wind** | 0.76 |
| **Geothermal & Biogas** | 0.34 |

In addition to this, some of the energy utilized was generated in the facility in energy facilities. Energy facilities were defined as well, the details of energy generation were taken from the activity reports of the facility.

Moreover, hard coal is taken from the databases, in order to calculate the transportation distance; the information about the supplier countries of is taken from the facility and adapted to SimaPro. For instance, hard coal used in coke plants is imported from USA, Australia, Canada, Indonesia, and Zonguldak. Since the states where coal was taken were known as well as the countries, approximate distances were calculated by means of Google maps. For very long intercontinental distances, only sea routes are taken into consideration due to the negligible distances of land routes. The hard coals from mentioned countries were defined individually and then combined under hard coal mix of the facility.

In this part, the integration of materials to SimaPro was examined, and the details of the sub-processes in SimaPro were given. Assumptions made in material defining were also given in this part. The sub-processes of production, energy and water facilities and mechanical workshop were covered separately. First of all, sub-processes of production were defined; in the meantime the products of energy and water facilities were also defined, since the products of energy and water facilities were consumed by the sub-processes. Relevant analyses are presented in the following sub-sections for each sub-process.

##### 5.2.3.1.1. Coke making

The product of coke making units was coke, and the co-products were coke oven gas, tar, ammonium sulfate and benzene. Fusi was used as an energy source in coke batteries without processing; therefore fusi was also defined as a co-product of this unit. The environmental impacts were distributed to the products and co-products in proportion to their mass percentages. The allocations of products calculated with their mass percentages are shown in APPENDIX D in Figure 31. All products except coke oven gas were in mass units. The amount of coke oven gas was converted to mass via the density of 0,490 Kg/m³ [53], and converted to energy by using the calorific value of 4407 kcal/$m^3$.

The information about hard coal was taken from the inventory of SimaPro. While taking hard coal from databases, some modifications were made as mentioned before and the defined hard coal mix of the facility was used.

In defining the inputs of coke making unit, the information of hard coal, sulfuric acid, sodium hydroxide, oil, natural gas and electricity from network was taken from the inventories in the database of SimaPro. And, the others were defined manually as shown in APPENDIX D.

The outputs of the unit were only emissions to air. The emissions were carbon dioxide, carbon monoxide, sulfur dioxide, nitric oxide, nitrogen dioxide and dust. These data was selected from the database through airborne emissions. The recorded emissions to water were chemical oxygen demand, cyanide, phenol, phosphorus, ammonia and suspended solids. These data was selected from the database through waterborne emissions.

#### 5.2.3.1.2. Sintering

The product of this unit was sinter. And, sinter dust was recycled to the sintering unit without processing; therefore sinter dust was also defined as a co-product of this unit. The allocations of the environmental impacts were distributed to the products and co-products in proportion to their percentages. The allocations of products calculated with their mass percentages are shown in Figure 32 in APPENDIX D.

In defining the inputs of sintering unit, the information of iron ore, limestone, dolomite, magnesite and electricity from network were taken from the inventories in the database of SimaPro. Some of the inputs are not available in the software; the unavailable materials were defined as the materials having similar characteristics. In sintering unit, coke breeze was defined as coke; pellet and pellet dust as sinter and sinter dust, dunit as dolomite. And the mill scale input is assumed to be 50 % of wire rod mill scale and 50 % of coil mill scale. And similarly, the gas cleaning sludge is taken as 50 % blast furnace gas cleaning sludge and 50 % basic oxygen furnace gas cleaning sludge. Remainings were defined manually.

The outputs of the unit were emissions to air. The emissions to air were carbon dioxide, carbon monoxide, sulfur dioxide, nitric oxide, nitrogen dioxide, hydrogen chloride, hydrogen fluoride, dioxin, furan, and dust. These data was selected from the database through airborne emissions and the amounts were entered.

##### 5.2.3.1.3. Iron making

The product of blast furnace was liquid iron, and the co-products were blast furnace gas, blast furnace slag, blast furnace flue dust, iron scrap and blast furnace gas cleaning sludge. Blast furnace gas was an input to energy facilities, blast furnace flue dust and flue gas cleaning sludge were sent to sintering unit, iron scrap is utilized in blast furnaces and blast furnace slag is sent to cement factor as a raw materials, therefore they were also defined as co-products of this unit. The allocations of the environmental impacts were distributed to the products and co-products in proportion to their percentages. All products except blast furnace gas were in mass units and the energy unit of blast furnace gas was converted to mass via the density of 1,290 kg/m$^3$ [53]. The allocations of products calculated with their mass percentages are shown in Figure 33 in APPENDIX D.

In defining the inputs of iron making unit, the information of iron ore, manganese ore, quartz, air, limestone, dolomite, natural gas and electricity from network were taken from the inventories in the database of SimaPro. And, the others were defined manually. Pellet input to blast furnaces was also taken as sinter input due to their similar characteristics. Pulverized coal input to blast furnaces is taken from database as pulverized lignite.

The outputs of the unit were emissions to air. The emissions were carbon dioxide, carbon monoxide, sulfur dioxide, nitric oxide, nitrogen dioxide and dust. These data was selected from the database through airborne emissions.

#### 5.2.3.1.4. Steel making

The product of basic oxygen furnace was liquid steel, and the co-products were basic oxygen furnace gas, converter slag, basic oxygen furnace gas cleaning sludge and desulfurization slag. Basic oxygen furnace gas was an input to energy facilities, and the others were sent to sintering unit, so they were also defined as co-products of this unit. The allocations of the environmental impacts were distributed to the products and co-products in proportion to their percentages. All products except basic oxygen furnace gas were in mass units and the volume unit of basic oxygen furnace gas was converted to mass via the density of 1,429 kg/m$^3$ [15] as mentioned in inventory part. The allocations of products calculated with their mass percentages are shown in Figure 34 in APPENDIX D.

In defining the inputs of steel making unit, the information of magnesite, fluorspar, ferrosilicat, ferromanganese, ferrochromium, aluminium, anthracite coal, iron ore, steel scrap, quicklime, natural gas and electricity from network were taken from the inventories in the database of SimaPro. Since iron dust is not available in software, it is taken as iron ore from the software. And, the other inputs were taken from the manually defined items.

The outputs of the unit were emissions to air. The emissions were carbon dioxide, carbon monoxide, sulfur dioxide, nitric oxide, nitrogen dioxide and dust. These data were selected from the database through airborne emissions.

#### 5.2.3.1.5. Casting

**Billet casting**

The product of this unit was billet. Since billet losses were sent to basic oxygen furnaces as an input, it was also defined as a co-product of billet casting unit (Figure 35, in APPENDIX D).

The inputs of the unit were generally energy inputs, the information of liquefied petroleum gas was taken from the inventories in the database of SimaPro and the other inputs were taken from manually defined energy facilities.

Since the basic oxygen furnace and casting units were evaluated together, the air emissions from billet casting were also evaluated under basic oxygen furnaces. Emissions from casting unit were not known separately except for carbon dioxide as mentioned in Section 5.2.2.5. The data of carbon dioxide was selected from the database through airborne emissions.

**Slab casting**

The product was slab. Since slab losses were sent to basic oxygen furnaces as an input, slab losses was also defined as a co-product of this unit (in Figure 36 in APPENDIX D).

The inputs of the unit were generally energy inputs, the information of liquefied petroleum gas was taken from the inventories in the database of SimaPro and the others were taken from manually defined energy facilities.

Since the basic oxygen furnace and casting units were evaluated together, the air emissions from slab casting were also evaluated under basic oxygen furnaces as in the case of billet casting and mentioned in Section 5.2.2.5. The data of carbon dioxide was selected from the database through airborne emissions.

##### 5.2.3.1.6. Hot rolling

**Wire rod hot rolling**

The product of this unit was hot rolled wire rod. Since wire rod losses were sent to basic oxygen furnaces as an input, it was also defined as a co-product of wire rod hot rolling unit. Although mill scales were processed before sending to sintering, since the environmental effects were combined with sintering unit and not individually known, it was also defined as a co-product of wire rod hot rolling unit as in the case of coil rolling (in Figure 37 of APPENDIX D).

The inputs of the unit were generally energy inputs, the information of natural gas and electricity from network were taken from the inventories in the database of SimaPro and the others were taken from manually defined energy facilities manually.

The outputs of the unit were emissions to air. The emissions were carbon dioxide, carbon monoxide, sulfur dioxide, nitric oxide, nitrogen dioxide and dust. These data was selected from the database through airborne emissions.

**Coil hot rolling**

The product of this unit was hot rolled coil. Since coil losses were sent to basic oxygen furnaces as an input, it was also defined as a co-product of coil hot rolling unit. Although mill scales were processed before sending to sintering, since the environmental effects were combined with sintering unit and not individually known, it was also defined as a co-product of coil hot rolling unit. Since it was not processed in this unit, the environmental impacts of processing mill scales were included in the sintering unit (Figure 38, APPENDIX D).

The inputs of the unit were generally energy inputs, the information of inputs were taken from manually defined energy facilities except electricity from network.

The outputs of the unit were emissions to air. The emissions were carbon dioxide, carbon monoxide, sulfur dioxide, nitric oxide, nitrogen dioxide and dust. These data was selected from the database through airborne emissions.

#### 5.2.3.1.7. Utility services

##### 5.2.3.1.7.1. Energy facilities

The products of energy facilities were steam, electricity, oxygen, nitrogen and argon; they are all defined under products and co-products. For generation of these energies, energies generated from other units in the facility are utilized. The inputs of the unit were generally energy inputs and the information of natural gas and electricity from network were taken from the inventories in the database of SimaPro. Since the outputs of the facility are inputs to the same facility as well, they were taken from newly defined energy facilities manually (Figure 39, APPENDIX D).

The outputs of the unit were emissions to air. The emissions were carbon dioxide, carbon monoxide, sulfur dioxide, nitric oxide, nitrogen dioxide and dust. These data were selected from the database through airborne emissions.

##### 5.2.3.1.7.2. Water facilities

The products of water facilities were pure water (Figure 40, APPENDIX D), service water (Figure 41, APPENDIX D) and sea water (Figure 42, APPENDIX D). They were defined individually. For preparation of all types water, electricity both from network and generated in the facility was utilized. For production of pure water, steam generated in the facility was utilized additionally. There are no emissions recorded from water facilities.

##### 5.2.3.1.7.3. Mechanical workshops

Mechanical workshop is not a production unit. Therefore, the product was defined as 1 mechanical workshop (Figure 43, APPENDIX D). The material and energy consumptions and emissions of mechanical workshop were calculated for one ton of finished product.

### 5.2.4. Impact Assessment

As a first step, impact assessment methods should be selected. The capabilities of impact assessment methods embodied in SimaPro are presented in Table 19. The assessment steps are Characterization, Damage Assessment, Normalization, Weighting and Single Score. The details of assessment steps are indicated below. Each assessment method does not have to cover all the steps. There are endpoint and midpoint methods available in SimaPro. Midpoint methods include emission, fate, and exposure, and endpoint methods include emission, fate, exposure, effect, and damage. Midpoint methods have less uncertainty than endpoints; however interpretation of results is complicated. Although indicators near endpoint level can have significant uncertainties, the results of indicators at endpoint level are much easier to interpret than the results of indicators at midpoint. Therefore, a method covering the category indicators at endpoint level was favored in this study. By this way, the results of midpoint level can also be seen and to ease the interpretation step endpoint results were used. In SimaPro, it is also allowed to change the impact categories of methods and also to develop completely new methods. In this study, the method is taken as developed by the authors of the impacts assessment method.

Table 19. The capabilities of impact assessment methods

| IMPACT ASSESSMENT METHODS | Characterization | Damage Assessment | Normalization | Weighting | Single Score |
|---|---|---|---|---|---|
| CML 2 BASELINE 2000 | + | | + | | |
| CML 2001 | + | | + | | |
| ECO-INDICATOR 99 (E-H-I) | + | + | + | + | + |
| ECOLOGICAL SCARCITY 2006 | + | | | + | + |
| EDIP 2003 | + | | + | + | + |
| EPD (2008) | + | | | | |
| EPS 2000 | + | + | | + | + |
| IMPACT 2002+ | + | + | + | + | + |

Table 19. The capabilities of impact assessment methods - continued

| IMPACT ASSESSMENT METHODS | Characterization | Damage Assessment | Normalization | Weighting | Single Score |
|---|---|---|---|---|---|
| **ReCiPe Endpoint (E-H-I)** | + | + | + | + | + |
| **ReCiPe Midpoint (E-H-I)** | + | | + | | |
| **BEES** | + | | | | |
| **TRACI 2** | + | | | | |
| **CUMULATIVE ENERGY DEMAND** | + | | | + | + |
| **CUMULATIVE EXERGY DEMAND (CEXD)** | + | | | + | + |
| **ECOLOGICAL FOOTPRINT** | + | | | + | + |
| **ECOSYSTEM DAMAGE POTENTIAL (EDP)** | + | | | + | + |
| **GREENHOUSE GAS PROTOCOL** | + | | | + | |

*Characterization*

Characterization factors for each substance are determined by the authors of the impact assessment methods. These factors are readily available in SimaPro. The amount of substance is multiplied by its characterization factor expressing the relative contribution of the substance. For all substances contributing to an impact category at the midpoint level (category midpoints), the amounts are multiplied by their characterization factor, and then are summed up. The total amount represents the impact category indicator at the midpoint level. The unit of characterization factor is presented in Table 21.

*Damage assessment*

The impact category indicators at the midpoint level related to an impact category indicator at the endpoint level (category endpoints) are combined. Category endpoints are mentioned as damage categories. In this step, the units of category midpoints are converted to a common unit to make them additive. For instance, the units of all category midpoints having effect on Human Health are converted to DALY (Disability Adjusted Life Years). This conversion is done by damage factors which are different for all category midpoints, and readily available in SimaPro. Then the amounts in DALY can be added to one another. In Table 21, the damage factors are shown in the fourth column used to get midpoint categories into a common damage unit.

*Normalization*

In order to facilitate the interpretation step, normalization summarizes the contribution of impact categories to the overall environmental impact. The aim is to equalize the units of the endpoint impact categories. Contribution to overall environmental impact is determined after dividing the impact category by normalization factors, called as reference. Factors specific to impact assessment methods are also readily available in SimaPro. The reference is the average annual environmental load in a country or continent per person living there. After normalization the impact category indicators all get the same unit, which makes it easier to compare them. In SimaPro, the normalization factor is given as the inverse of the reference value (1/reference), so the impact category is multiplied by the normalization factors. Factors specific to IMPACT 2002+ methods are presented in Table 21. A sample calculation for hydrocarbon (air) in coke making process is presented in APPENDIX E.

*Weighting*

Weighting is an optional step conducted by using weighting factor. Weighting factor expresses the judgment on the importance of an impact category. This means the impact category indicator results at midpoint or endpoint are multiplied by weighting factors, and are added to create a total score.

*Single Score*

In single score step, the values from normalization or weighting are added together, and presented as a single value.

In order to select the impact assessment method to be used in this study, methods were screened and compared with each other in terms of the impact assessment steps, impact categories covered and their preferabilities in literature. Firstly, the assessment methods covering the normalization and single score steps were preferred to enable easy interpretation; these methods were Ecoindicator 99 (E-H-I), EDIP 2003, IMPACT 2002+ and ReCiPe Endpoint (E-H-I). The second elimination is based on the impact categories important for iron and steel industry. Respiratory inorganics, non-renewable energy sources and global warming are the most prominent impacts expected for iron and steel industry, and then come mineral extraction and carcinogens. Ecoindicator 99 (E-H-I) and IMPACT 2002+ methods cover both the prominent impacts for iron and steel industry and the secondary ones; and then comes the ReCiPe Endpoint (E-H-I) method covering only the prominent impacts. The midpoint impact category indicators of Ecoindicator 99 (E-H-I) and IMPACT 2002+ methods were presented in Table 20. The last elimination criterion was selected according to the preference of methods in literature. The mostly preferred methods for metals were determined as Ecoindicator 99 and Impact 2002+. Thereof, Ecoindicator 99 and Impact 2002+ embodied in SimaPro software were compared with each other. These methods differ from each in terms of their impact categories, characterization factors, normalization factors and weighting factors. Impact 2002+ grouped 15 midpoint categories under four damage categories (human health, ecosystem quality, climate change and resources) whereas Ecoindicator 99 grouped 11 midpoint categories under three damage categories (human health, ecosystem quality and resources). Moreover, in IMPACT 2002+, carcinogens, non-carcinogens, respiratory inorganics, ionizing radiation, ozone layer depletion and respiratory organics are grouped under human health; aquatic ecotoxicity, terrestrial ecotoxicity, terrestrial acidification/nutrificaiton and land occupation are grouped under ecosystem quality; global warming is taken under climate change; and non-renewable energy and mineral extraction are grouped under resources. The midpoint impact categories of aquatic acidification and aquatic eutrophication are grouped under ecosystem quality; however, since their damage factors are under development, they are not evaluated at present. On the other hand, in Ecoindicator 99, carcinogens, respiratory inorganics, radiation, ozone layer and respiratory organics are grouped under human health; ecotoxicity, land use and acidification/ eutrophication are grouped under ecosystem quality; and lastly fossil fuels and minerals are grouped under resources.

While comparing these two methods in term of their impact categories, firstly the impact categories that can substitute each other were taken into consideration. The list is presented in Table 20. For instance, as fossil fuels, included in Eco-indicator 99 method, is a non-renewable energy source can be substitute for non-renewable energy source included in IMPACT 2002+ method. In common with this example, climate change included in Eco-indicator 99 method can be substitute for global warming included in IMPACT 2002+ method.

IMPACT 2002+ method, combination of four methods (IMPACT 2002, Ecoindicator 99, CML and IPCC) covering Ecoindicator 99, is a comprehensive method; therefore, it was selected in this study as the assessment method. The summary table for the details of assessment steps is given in table 21 and the details of impact categories are presented in Table 22. The weighting step was excluded from the study as suggested by the authors of the IMPACT 2002+; the weighting factor ‘1’ is used as default value.

Table 20. Midpoint impact categories of IMPACT 2002+ and Ecoindicator 99 (H)

| **IMPACT 2002+** | **ECO-INDICATOR 99 (H)** |
|---|---|
| Carcinogens | Carcinogens |
| Non-carcinogens | |
| Respiratory inorganics | Respiratory inorganics |
| Ionizing radiation | Radiation |
| Ozone layer depletion | Ozone layer |
| Respiratory organics | Respiratory organics |
| Aquatic ecotoxicity | Ecotoxicity |
| Terrestrial ecotoxicity | |
| Terrestrial acid/nutrification | |
| Land occupation | Land use |
| Aquatic acidification | Acidification/ Eutrophication |
| Aquatic eutrophication | |
| Global warming | Climate change |
| Non-renewable energy | Fossil fuels |
| Mineral extraction | Minerals |

### 5.2.5. Interpretation

The last phase of LCA is interpretation step. In this step, the results of impacts assessment were evaluated. The normalized and single score results were used for evaluation of products of sub-processes and final products.

Table 21. Summary of Impact 2002+ Assessment Steps

| Midpoint category | Reference substance | Endpoint/ Damage category | Damage factor | Damage factor unit | Endpoint/ Damage unit | Normalization factors in SimaPro | Normalized unit |
|---|---|---|---|---|---|---|---|
| Carcinogens | kg $C_2H_3Cl$ eq | Human Health | 2,8E-06 | DALY / kg $C_2H_3Cl$ eq | Disability Adjusted LifeYears (DALY) | 141 Pt/DALY | Pt (Point) (1Pt=1000mPt) |
| Non-carcinogens | kg $C_2H_3Cl$ eq | | 2,8E-06 | DALY / kg $C_2H_3Cl$ eq | | | |
| Respiratory inorganics | kg PM2.5 eq | | 0,0007 | DALY / kg PM2.5 eq | | | |
| Ionizing radiation | Bq C-14 eq | | 2,1E-10 | DALY / Bq C-14 eq | | | |
| Ozone layer depletion | kg CFC-11 eq | | 0,00105 | DALY / kg CFC-11 eq | | | |
| Respiratory organics | kg $C_2H_4$ eq | | 2,13E-06 | DALY / kg $C_2H_4$ eq | | | |
| Aquatic ecotoxicity | kg TEG water | Ecosystem Quality | 5,02E-05 | PDF*$m^2$*yr / kg TEG water | Potentially Disappeared Fraction (PDF)*$m^2$*yr | 7,30E-5 Pt/PDF*$m^2$*yr | |
| Terrestrial ecotoxicity | kg TEG soil | | 0,00791 | PDF*m2*yr / kg TEG soil | | | |
| Terrestrial acid/nutrification | kg $SO_2$ eq | | 1,04 | PDF*$m^2$*yr / kg $SO_2$ eq | | | |
| Land occupation | $m^2$org.arable | | 1,09 | PDF*$m^2$*yr / m2org.arable | | | |
| Aquatic acidification | kg $SO_2$ eq | | under development | under development | under development | | |
| Aquatic eutrophication | kg $PO_4$ eq | | | | | | |
| Global warming | kg $CO_2$ eq | Climate Change | 1 | kg $CO_2$ eq / kg $CO_2$ eq | kg $CO_2$ eq | 0,000101 Pt/ kg $CO_2$ eq | |
| Non-renewable energy | MJ primary | Resources | 1 | MJ primary / MJ primary | MJ | 0,00000658 Pt/ MJ | |
| Mineral extraction | MJ surplus | | 1 | MJ primary / MJ surplus | | | |

Table 22. Details of impact categories covered by IMPACT 2002+ method

| **Midpoint category** | **Reference substance *** | **Description** | **Endpoint/ Damage category** | **Endpoint/ Damage unit** | **Description** |
|---|---|---|---|---|---|
| Carcinogens | kg $C_2H_3Cl$ eq | Carcinogenic effects of chloroethylene emitted into air. | Human Health | Disability Adjusted Life Years (DALY) | "DALY" characterizes the disease severity, accounting for both mortality (Years of Life Lost due to premature death) and morbidity. |
| Non-carcinogens | kg $C_2H_3Cl$ eq | Non-carcinogenic effects of chloroethylene emitted into air | | | |
| Respiratory inorganics | kg PM2.5 eq | Characterization factors are given for emissions into air only (particulate matter smaller than 2.5 µm into air) | | | |
| Ionizing radiation | Bq C-14 eq | Characterization factors are given for emissions into air and water (Carbon-14 into air) | | | |
| Ozone layer depletion | kg CFC-11 eq | Characterization factors are given for emissions into air only (CFC-11 into air) CFC-11 is known as Trichlorofluoromethane | | | |
| Respiratory organics | kg $C_2H_4$ eq | Emissions of organic substances into air causing respiratory effects | | | |
| Aquatic ecotoxicity | kg TEG water | Aquatic ecotoxicity representing surface fresh water ecotoxicity | Ecosystem Quality | Potentially Disappeared Fraction (PDF)*m2*yr | Potentially Disappeared Fraction of plant species |
| Terrestrial ecotoxicity | kg TEG soil | Characterization factors are given for emissions into air, water and soil (triethylene glycol into soil) | | | |

Table 22. Details of impact categories covered by IMPACT 2002+ method - continued

| **Midpoint category** | **Reference substance *** | **Description** | **Endpoint/ Damage category** | **Endpoint/ Damage unit** | **Description** |
|---|---|---|---|---|---|
| Terrestrial acid/nutri | kg $SO_2$ eq | Characterization factors are given for emissions into air only ($SO_2$ into air) | Ecosystem Quality | Potentially Disappeared Fraction (PDF)*m2*yr | Potentially Disappeared Fraction of plant species |
| Land occupation | $m^2$org.arable | The damage factors are based on empirical observations of the number of plant species per area type. (Organic arable land) | | | |
| Aquatic acidification | kg $SO_2$ eq | Characterization factors are given for emissions into air, water and soil. (kgeq $SO_2$ into air) | | Under development | - |
| Aquatic eutrophication | kg $PO_4$ eq | Characterization factors are given for emissions into air, water and soil kgeq $PO_4^{3-}$ into water | | | |
| Global warming | kg $CO_2$ eq | Characterization factors are given for emissions into air only ($CO_2$ into air) | Climate Change | kg $CO_2$ eq | Carbon dioxide equivalence |
| Non-renewable energy | MJ primary | Total primary energy extracted (MJ total primary non-renewable energy) | Resources | MJ | MJ primary non-renewable energy |
| Mineral extraction | MJ surplus | MJ-additional energy | | | |

* 'kg eq substances" ("kg-equivalent of a reference substances") expresses the amount of a reference substances that equals the impact of the considered pollutant.

# CHAPTER 6

# RESULTS AND DISCUSSION

In this section, the results obtained from the LCA study conducted for the iron and steel industry in Turkey are presented. In reading these results, the following points should be taken into consideration.  First of all; as is was also stated in Chapter 5, during the analysis, environmental impacts were calculated by means of IMPACT 2002+ method. The units of all mid-point impact categories were different in characterization step and, therefore the results are shown in percentages. And this makes it difficult to interpret. If more than one product were compared, the product having the most environmental impact was made equal to 100% and the environmental impacts of other products were proportioned to this product. However, it was also not possible to make comparison between different mid-point impact categories. At the end of damage assessment step, the units of mid-point impact categories under the same end-point impact categories were equalized. In order to compare all mid-point impact categories between each other, normalized results were preferred. The results of weighting step were same with normalization results since the weighting factor was selected ‘1’ as the default value of IMPACT 2002+ impact assessment method. In single score step, the normalization results were added together, and presented as a single value. The results of single score were presented to facilitate the understanding.

The results of standard IMPACT 2002+ method are regarded as dimensionless. The unit used for presentation of figures was Pt (point), unless otherwise specified.  It should be recalled that 1 Pt equals to 1000 mPt (milli-point) and also 1 MPt (million-point) equals to 1.000.000 Pt.

In configuration, normalized results of mid-point impact categories are used and for comparison purposes, single score presentation of the results are preferred in the text. Normalized values together with their percentages of mid-point impact categories and their contributions to end-point impact categories are presented in APPENDIX G. The contribution of inputs and outputs of all products assessed in Section 6.1 and 6.2 to end-point impact categories are covered in APPENDIX H and the contributions to mid-point impact categories are covered in APPENDIX I. APPENDIX J cover the normalized impact assessment results per mid-point impact categories of different production scenarios stated in Section 6.3.

Based on the LCA results, the impact contributors are evaluated under two titles; these are inputs and outputs (emissions). In reading the results provided in the following sections, it should be emphasized that the contribution of each input to total impact reflects the effect of each input exerted before it enters the facility. However, the effect of output reflects the impact of processes applied in the facility. In other words, in calculating the emissions' impacts, inputs are taken into account only for their previous impacts just in proportion to their used amounts. So, additional contribution of each input to the emissions during the processes is not known.

## 6.1. Sub-process based environmental impacts

In this part, sub-process based environmental impacts were assessed per one ton of product in order to detect the most polluting sub-process during the entire liquid steel production process. Environmental impacts of the sub-processes for one ton of product were calculated and the contributors to these impacts were identified. The products of coke making, sintering, blast furnaces and basic oxygen furnaces were coke, sinter, liquid iron and liquid steel, respectively. Therefore, the results obtained for each sub-process are presented as for the relevant product. And then, the environmental impacts are compared.

**Coke**

In coke making unit, the target product is coke and the co-products are coke oven gas, tar, ammonium sulfate, benzene and fusi. As stated in Section 5.2.3.1.1, calculated environmental impacts were allocated in terms of masses of products and co-products as also presented in APPENDIX D in Figure 31.

Figure 12 shows the normalized results obtained for the mid-point impact categories. As presented in Figure 12, the impacts on 'non-renewable energy' (0.109 Pt), which was categorized under 'Resources', showed the second highest rate after 'respiratory inorganics' (0.145 Pt) categorized under 'Human Health' end-point impact category. The impact on 'terrestrial ecotoxicity' (0.0185 Pt) appeared in the third rank. In accordance with this finding, the percentage contributions of these mid-point impact categories to the total impact were realized as 67.6, 50.86 and 8.58%, respectively (Table 30 in APPENDIX G). All other impact categories were found negligible. The compilation of the relevant data is given in Table 30 (in APPENDIX G) where the figures for the other impact categories can also be depicted for both mid-point and end-point impacts.

According to the single score results presented in Table 38 in APPENDIX H, the main contributors of total environmental impact were hard coal (136%) and steam (61.57%). The high contribution of steam can be resulted from the environmental impact of energy facility. Since energy facility has the aim of providing inputs to other units of the facility, they are not evaluated separately. At this point the contribution of energy facilities can be realized from contribution of steam which is one of the products of the energy facility. Electricity taken from the network (-136%) stated earlier as avoided product showed negative contribution to total environmental impact.

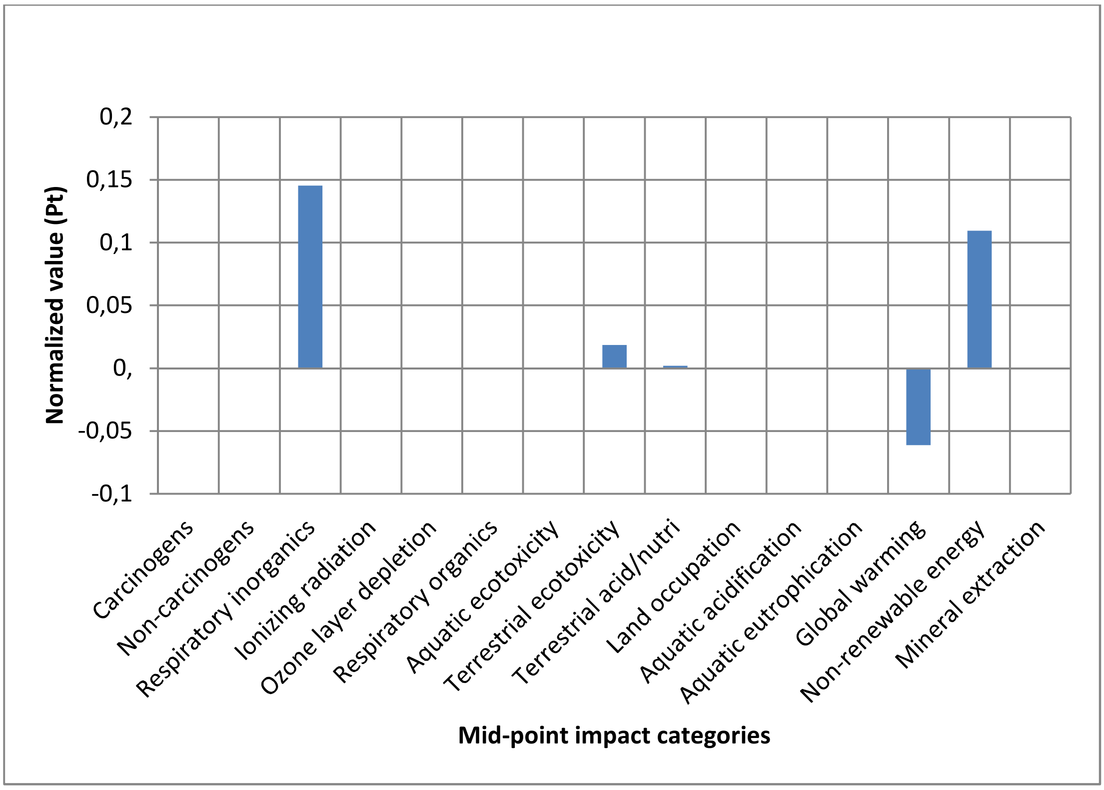



Figure 12. Normalized impact assessment results for 1 ton of coke

As a matter of fact, hard coal consumption has a great impact on 'non-renewable energy'. Burchart-Korol (2011) stated that the effect of coke has the largest impact on greenhouse gas emissions [13]; however, the present study reached the opposite finding. Global warming had a negative share in environmental impacts (-28.48%, as presented in Table 30); this is probably because the production of coke oven gas avoids the external energy consumption. It can be stated that, the negative contribution of coke oven gas is higher than the contribution of coke production and thus coke oven gas recycling reduces global warming potential.

**Sinter**

In sintering unit, the target product is sinter and besides this sinter dust is produced as a co-product. The calculated environmental impacts were allocated in terms of masses of sinter and sinter dust. 60 % of the environmental impacts of sintering unit were allocated to sinter as also presented in Figure 32 in APPENDIX D.

The normalized results of environmental impacts calculated by SimaPro for 1 ton of sinter product are presented in Figure 13 and the numerical data of environmental impacts per both for mid-point and end-point impact categories are given in Table 31 of APPENDIX G. From Figure 13, it can be depicted that sinter production had significant impacts on 'respiratory inorganics' (0.35 Pt) showing similar result with the study of Burchart-Korol on sintering process [14]. According to the LCA results presented in Table 47 in APPENDIX I , the main contributor to 'Respiratory Inorganics' was found as emissions from the process (50.18%), recycled sinter dust (28.26%) and iron ore (5.25%). Considering that 'Respiratory Inorganics' are categorized under 'Human Health' end-point impact category, the highest environmental impacts occurs in the category of 'Human Health'. The percentage contribution of 'Respiratory Inorganics' to the total impact was realized as 80.08% (in Table 31 of APPENDIX G). The impacts on 'Non-renewable Energy' (3.69%), 'Terrestrial Ecotoxicity' (1.85%) and 'Terrestrial Acidification/Nutrification' (0.51%) were relatively low. Since, in sintering unit, there are no avoided products, the global warming effect of sinter production (13.44%) is remarkable when compared with coke making unit. As known, global warming impact originates mainly from $CO_2$ emissions.

Regarding the environmental impact on 'Mineral Extraction' (0.07%), one would expect to observe a higher impact considering the high amounts of iron ore consumed; but this was not the case. This could indicate that impact on mineral extraction was low in comparison to impacts that are directly associated with the production process of sinter. Here, it should be emphasized that the impacts presented in Figure 13 represent the relative magnitudes of impacts.

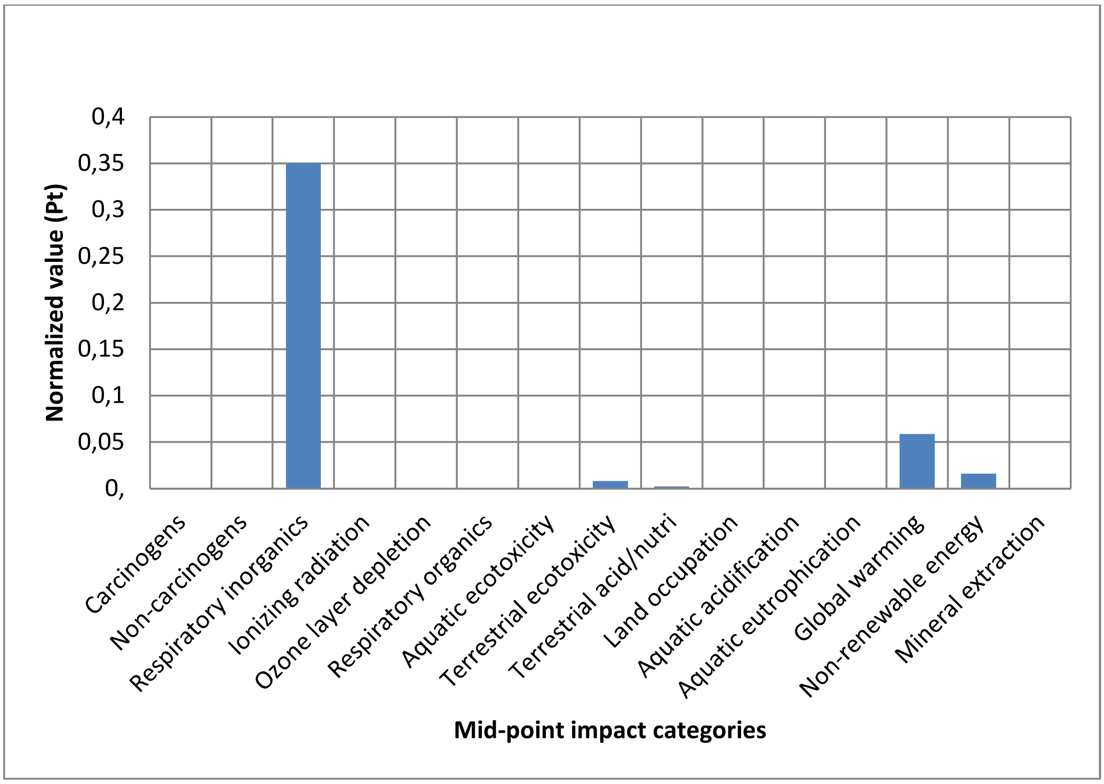



Figure 13. Normalized impact assessment results for 1 ton of sinter

**Liquid iron**

In blast furnaces, the target product is liquid iron. Besides this, the co-products are blast furnace gas, blast furnace slag, flue dust, scrap and gas cleaning sludge. The calculated environmental impacts were allocated in terms of masses of products and co-products as also presented in Figure 33 in APPENDIX D.

The normalized results of environmental impacts of 1 ton of liquid iron produced are presented in Figure 14. The highest environmental impact is observed to be in the category of 'Human Health' caused by respiratory effects (0.269 Pt). Liquid iron production exhibited similar results with sinter production. Since coke and sinter are the inputs to blast furnaces, their impacts were realized substantially, as expected, on 'Respiratory Inorganics'. As presented in Table 32 of APPENDIX G, the percentage contribution of ‘Respiratory Inorganics’ to the total impact was 89.51%. The main contributor to ‘Respiratory Inorganics’ category appeared to be as sinter (31.88%) which was followed by pellet (25.21%) and the total emission of blast furnaces with a contribution of 13.19%, based on the results of LCA presented in Table 48 in APPENDIX I. Since pellet was also introduced as sinter to the software due to their similar characteristics as mentioned in Section 5.2.3.1.3, the total impact of sinter and pellet is more pronounced for their cumulative amounts.

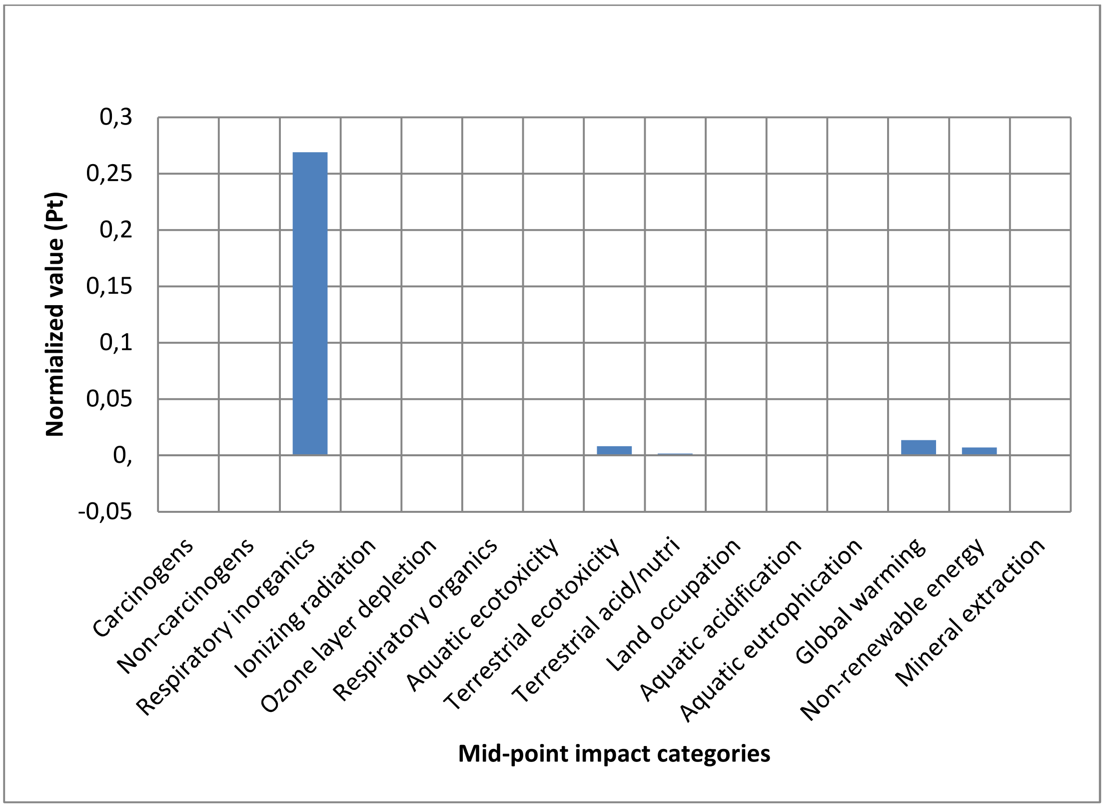



Figure 14. Normalized impact assessment results for 1 ton of liquid iron

Huang et al. [15] stated that the main contributor of $CO_2$ is blast furnace gas in iron making process and they proposed recycling of the produced gas. In the facility where inventory data was taken and also in all integrated iron and steel facilities in Turkey, the produced blast furnace gas is recycled. Therefore, in the present study the environmental impact on ‘Global Warming’ (4.50%) is not remarkable (Table 32 of APPENDIX G); moreover, the impact is further lowered by means of the avoided products.

The impacts on ‘Non-renewable Energy’ (2.36%), ‘Terrestrial Ecotoxicity’ (2.71%) and ‘Terrestrial Acidification/Nutrification’ (0.55%) are found to be relatively low as in the case of coke and sinter. The normalized environmental impacts per both mid-point and end-point impact categories and their contributions in percentages are given in Table 32 of APPENDIX G.

**Liquid steel**

As also stated earlier, the target product of basic oxygen furnaces is liquid steel and the co-products are basic oxygen furnace gas, slag, gas cleaning sludge, and desulfurization slag. The calculated environmental impacts were allocated in terms of masses of products and co-products as given in Figure 34 in APPENDIX D.

The normalized results of environmental impacts of 1 ton of liquid steel produced are presented in Figure 15. The compilation of the data belonging to normalized results is presented in Table 33 in APPENDIX G both for mid-point and end-point impact categories. From Figure 15, it can be depicted that the highest environmental impact is observed to be in the mid-point category of ‘Respiratory Inorganics’ (0.394 Pt). Compatible with this finding, Table 33 shows that liquid steel production has the highest environmental impacts in the category of ‘Human Health’ mainly caused by respiratory effects (70.2%) as in sinter and liquid iron production cases, possibly due to the fact that it is the downstream of the liquid steel production sub-processes. The main contributor of environmental impact on ‘Human Health’ is liquid iron with a percentage of 46.86%, as presented in Table 41 in APPENDIX H. Liquid steel has the second highest impact on ‘Global Warming’ impact category (16.9%). The impacts on ‘Non-renewable Energy’ (7.29%), ‘Terrestrial Ecotoxicity’ (2.27%) and ‘Terrestrial Acidification/Nutrification’ were relatively low as compared with ‘Respiratory Inorganics’ and ‘Global Warming’. The relevant data for the other impact categories can also be depicted for both mid-point and end-point impacts is given in Table 33 (in APPENDIX G).

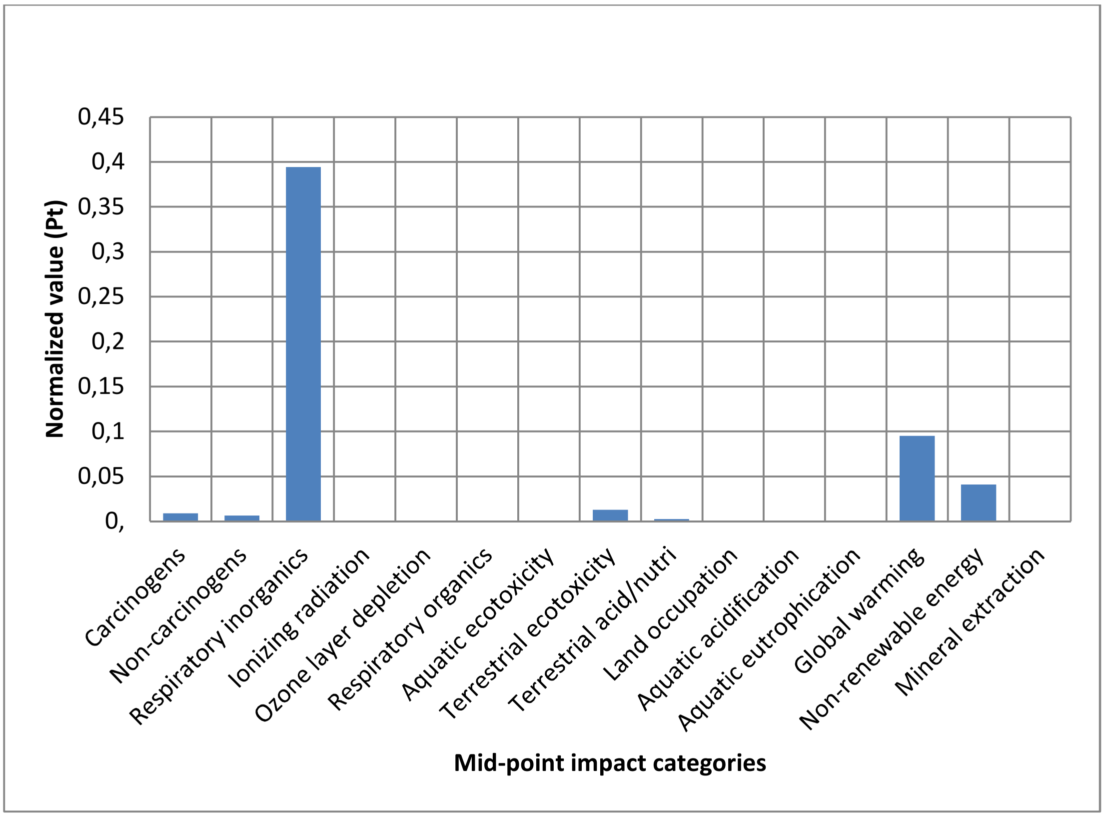



Figure 15. Normalized impact assessment results for 1 ton of liquid steel

**Comparison of environmental impacts of sub-process products**

Coke, sinter, liquid iron and liquid steel were compared in terms of their environmental impacts. The normalized results are presented in comparative manner in Figure 16 and gathered versions of normalized results are given in single score results, in Figure 17. As stated earlier, coke and sinter are independent processes, both being the inputs to blast furnace. Liquid iron, the product of blast furnaces, is sent to basic oxygen furnaces to produce liquid steel. Then, liquid steel is shaped in casting and hot rolling processes. Except sinter and coke production; blast furnaces, basic oxygen furnaces, casting and hot rolling are successive processes. Therefore, the environmental impacts of these processes should be expected to build up cumulatively. However, the expected cumulative increase was not observed in each sub-process of liquid steel production, namely, coke, sinter, liquid iron and liquid steel.

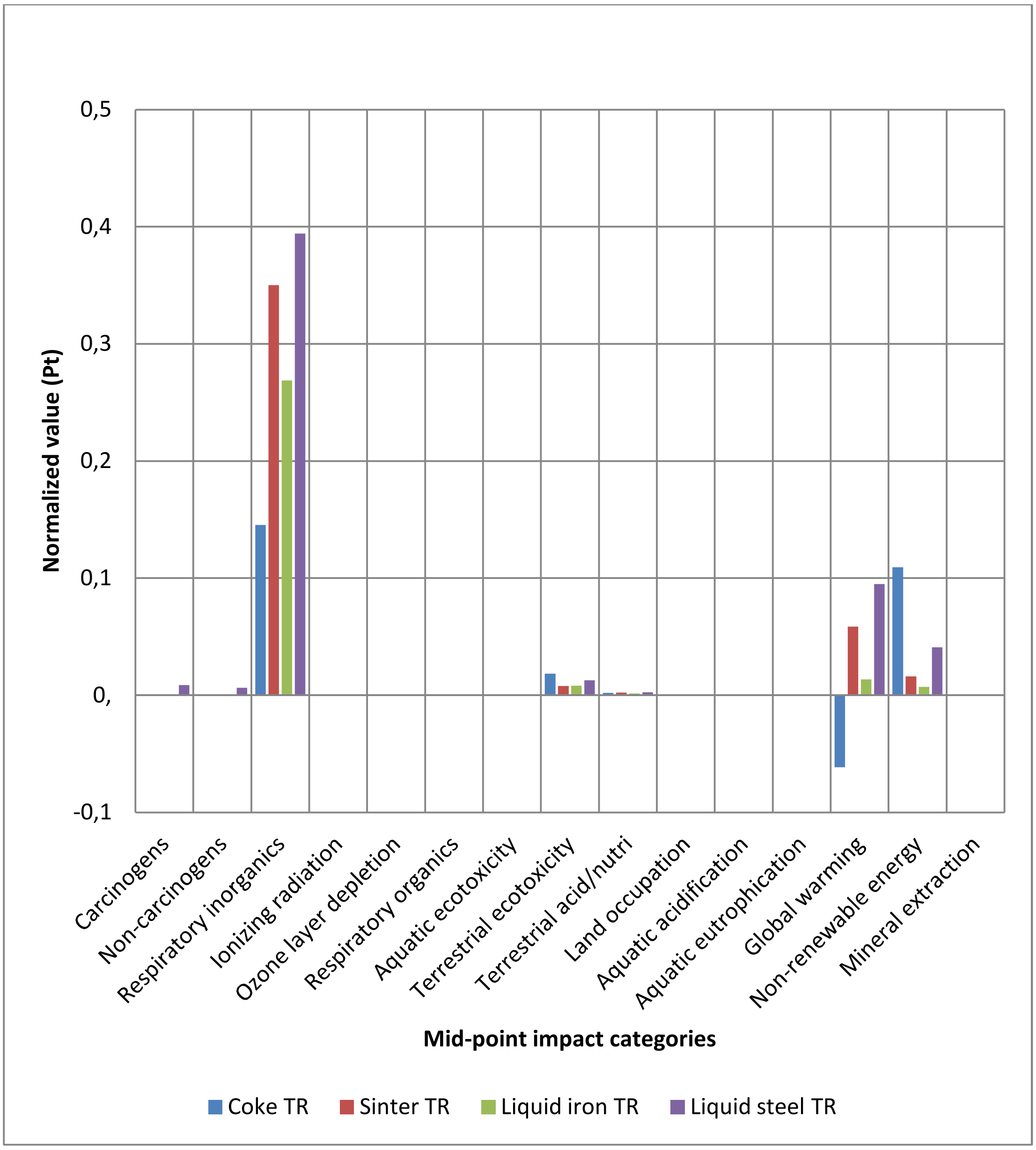



Figure 16. Comparison of normalized impact assessment results for 1 ton of each product

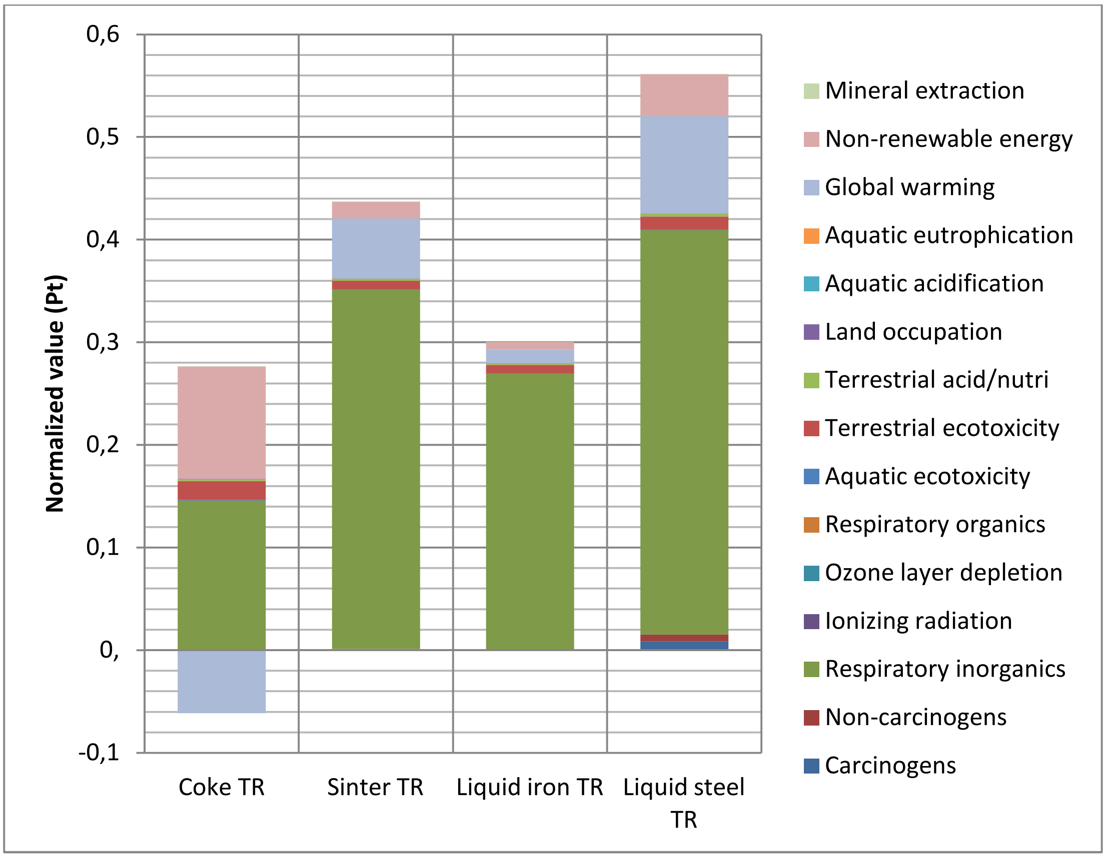



Figure 17. Comparison of single score results for 1 ton of each product

In fact, there is a cumulative increase in impacts except for the liquid iron. Coke and sinter are utilized to produce liquid iron, thus their impacts are expected to build up. According to the inventory data, per production of 1 ton of liquid iron, 1.47 tons of sinter (0.82 tons sinter and 0.65 tons pellet) and 0.44 tons coke are utilized as mentioned earlier in Section 5.2.2.3; hence the environmental impacts were expected to increase in these proportions. Although a certain effect of sinter was observed in terms of contribution to impact categories, considering the allocation given for blast furnaces (29.22% as presented in Figure 33 of APPENDIX D), the environmental impact of liquid iron was observed in proportion to its allocation percentage.

The cumulative increase is valid for liquid steel. For 1 ton of liquid steel production 0.9 tons of liquid iron is utilized and the allocation percentage of liquid steel was 79.59% (in Figure 34 of APPENDIX D). Thus, environmental impacts increased further in these proportions, as expected.

To summarize, since liquid steel is the downstream of the sub-process of liquid steel production, 1 ton of liquid steel was appeared as the most polluting step in terms of total environmental impacts. Sinter followed liquid steel in terms of environmental impacts in the category of ‘Human Health’ caused by respiratory effects and in the category of ‘Climate Change’ caused by global warming as well. Coke has the priority causing depletion of non-renewable energy sources, followed by liquid steel. Also, it was observed that the allocation percentages assigned for the products have a significant influence on the results especially for blast furnaces. The use of produced gases from coke making, blast furnaces and basic oxygen furnaces resulted in significant negative contribution to global warming potential, due to leading to avoid the consumption of other external energy sources.

## 6.2. Product based environmental impacts

The environmental impacts of one ton of product were calculated and the contributors to these impacts were assessed. As stated in Section 5.2.2 , the products are semi-finished products, billet and slab, and finished products, wire rod and coil.

**Semi-finished products: Billet and Slab**

In billet casting, the target product is billet. Billet losses are also defined as a co-product since they are sent to basic oxygen furnaces. The calculated environmental impacts were allocated in terms of masses of billet and billet losses. Billet had accounted for 98.6% of the products of billet casting unit (Figure 35 of APPENDIX G). Similarly, in slab casting unit, the target product is slab and slab losses are defined as co-products. The calculated environmental impacts were allocated in terms of masses of slab and slab losses. Slab had accounted for 95.44% of total products of slab casting unit (Figure 36 of APPENDIX D).

The normalized results of environmental impacts of 1 ton of billet and 1 ton of slab are presented in Figure 18 and Figure 19, respectively. The compilation of the data belonging to mid-point impact categories and the version adjusted to end-point impact categories is given in Table 34 and Table 35 in APPENDIX G, respectively.

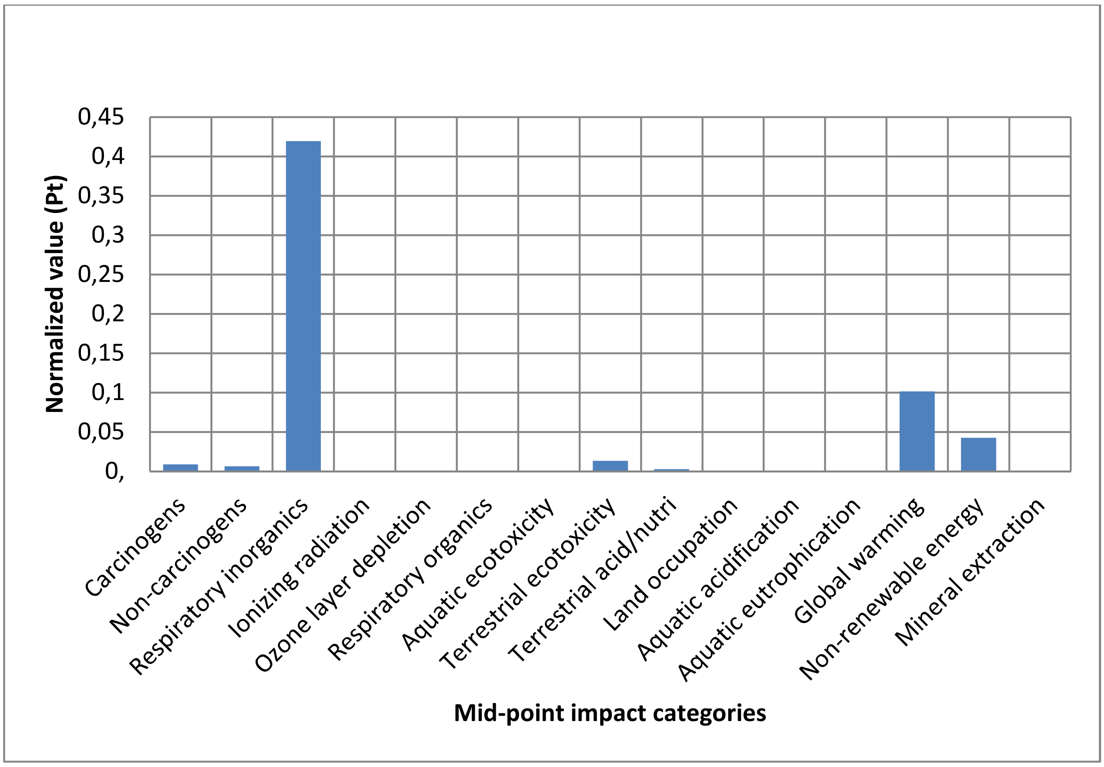



Figure 18. Normalized impact assessment results for 1 ton of billet

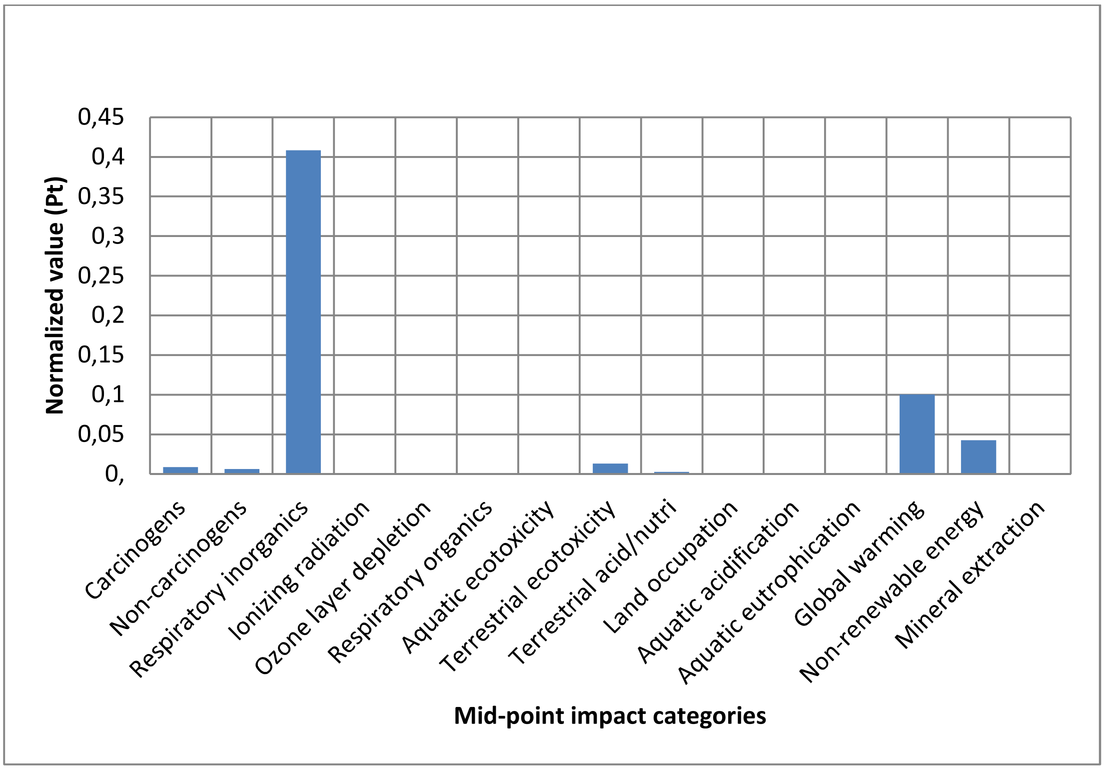



Figure 19. Normalized impact assessment results for 1 ton of slab

It can be depicted from Figure 18 and Figure 19 that the two semi-finished products had significant impacts on ‘Respiratory Inorganics’ (for billet 0.419 Pt, for slab 0.408 Pt) categorized under ‘Human Health’ followed by in the category of ‘Climate Change’ caused by ‘Global Warming’ (for billet 0.102 Pt, for slab 0.1 Pt). In accordance with this finding, the percentage contribution of these mid-point impact categories to the total impact were realized as 70.3 and 17.04% for billet, and 69.96 and 17.21 % for slab respectively (Table 34 and Table 35 in APPENDIX G). The main contributor to all impact categories, both end-point and mid-point, appeared as liquid steel consumption as presented in Table 42 and Table 43 in APPENDIX H (end-point impact categories) and in Table 50 and Table 51 in APPENDIX I (mid-point impact categories). The third highest impact is on the category of ‘Resources’ caused by depletion of non-renewable energy sources (for billet 0.0429 Pt, for slab 0.0428 Pt) and their percentage contributions presented in Table 34 and Table 35 (in APPENDIX G) are 7.19% for billet and 7.34% for slab. The impacts on ‘Carcinogens’ ‘Non-carcinogens’, ‘Mineral Extraction’, ‘Terrestrial Ecotoxicity’ and ‘Terrestrial Acidification/Nutrification’ were found negligible.

**Finished products: Wire rod and Coil**

The semi-finished products are sent to hot rolling unit to produce finished products; wire rod and coil. In hot rolling of billet, the target product is wire rod. Wire rod losses and mill scales are also defined as a co-product since they are sent to basic oxygen furnaces. The calculated environmental impacts were allocated in terms of masses of the products and co-products (Figure 37 in APPENDIX D). Wire rod had accounted for 95.79% of the products of wire rod hot rolling unit. In hot rolling of slab, the target product is coil. Coil losses and mill scales are also defined as a co-product as in case of wire rod hot rolling. As a result of mass allocation, wire rod had accounted for 97.3% of the products of wire rod hot rolling unit (Figure 38 in APPENDIX D).

The normalized results of environmental impacts of 1 ton of wire rod and 1 ton of coil are presented in Figure 20 and Figure 21, respectively. The compilation of the data belonging to mid-point and end-point impact categories is presented in Table 36 and Table 37, respectively.

From Figure 20 and Figure 21, it can be depicted that both wire rod and coil shows highest environmental impact in the mid-point category of 'Respiratory Inorganics' (0.499 and 0.590 Pt respectively). The finished products showed similar impacts as in the case of semi-finished products. For both mid-point and end-point impacts, the obtained normalized results of the relevant data is given in Table 36 and Table 37 (in APPENDIX G). From these figures, it can be realized that, the impacts of wire rod and coil on 'Respiratory Inorganics' were 68.55% and 72.47% of total environmental impact resulted from their production, respectively. The proportion of 'Respiratory Inorganics' is high in coil production due to the high amounts of emissions. 'Respiratory Inorganics' is followed by in the category of 'Climate Change' caused by 'Global Warming' (for wire rod 18.55%, for coil 15.97%). Based on the results of LCA presented in Table 44 and Table 45 in APPENDIX H, the main contributors to the impact categories were basically billet consumption (81.77%) in wire rod production and slab consumption (71.60%) in coil production. The third highest impact is on the category of 'Resources' caused by depletion of non-renewable energy sources (for wire rod 8.04%, for coil 6.89%). All other impact categories were found negligible. The compilation of the relevant data is given in Table 36 and Table 37 (in APPENDIX G) where the details of the other impact categories can also be depicted for both mid-point and end-point impacts.

Tongpool et al. [12] stated that downstream products show higher impacts on environment while upstream products show lower impacts. Similar findings were encountered in this study, while the upstream product liquid steel shows lower impacts, the downstream products, wire rod and coil, show higher impacts.

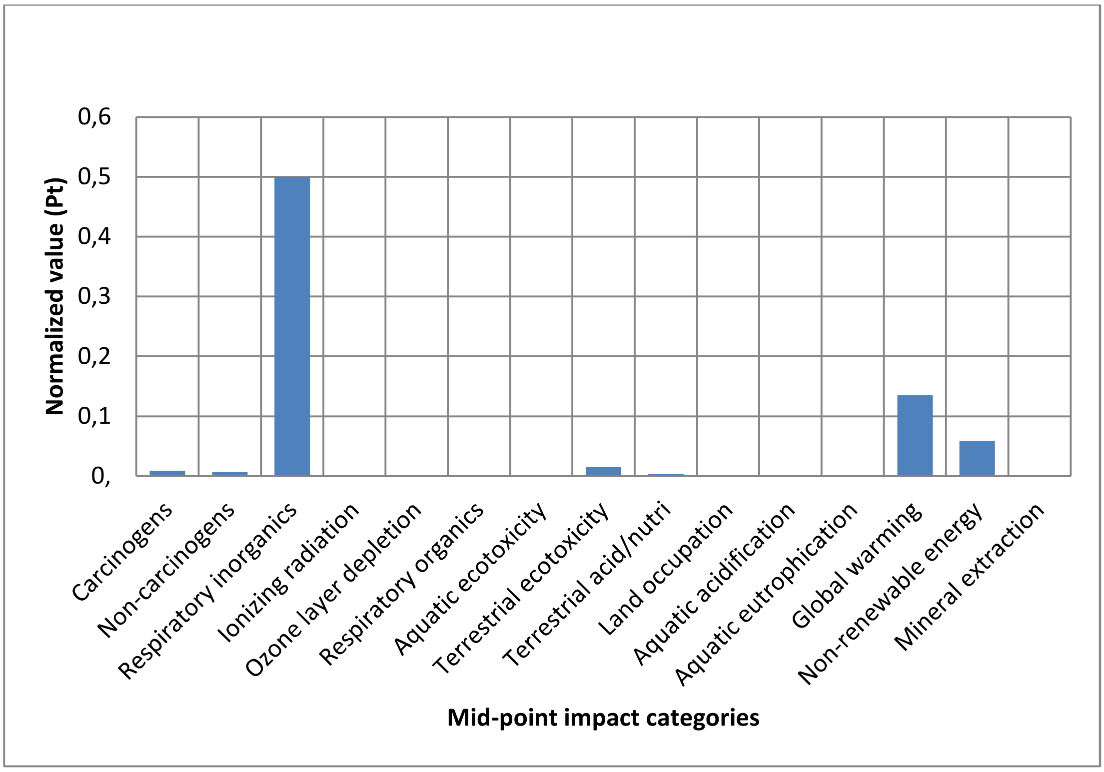



Figure 20. Normalized impact assessment results for 1 ton of wire rod

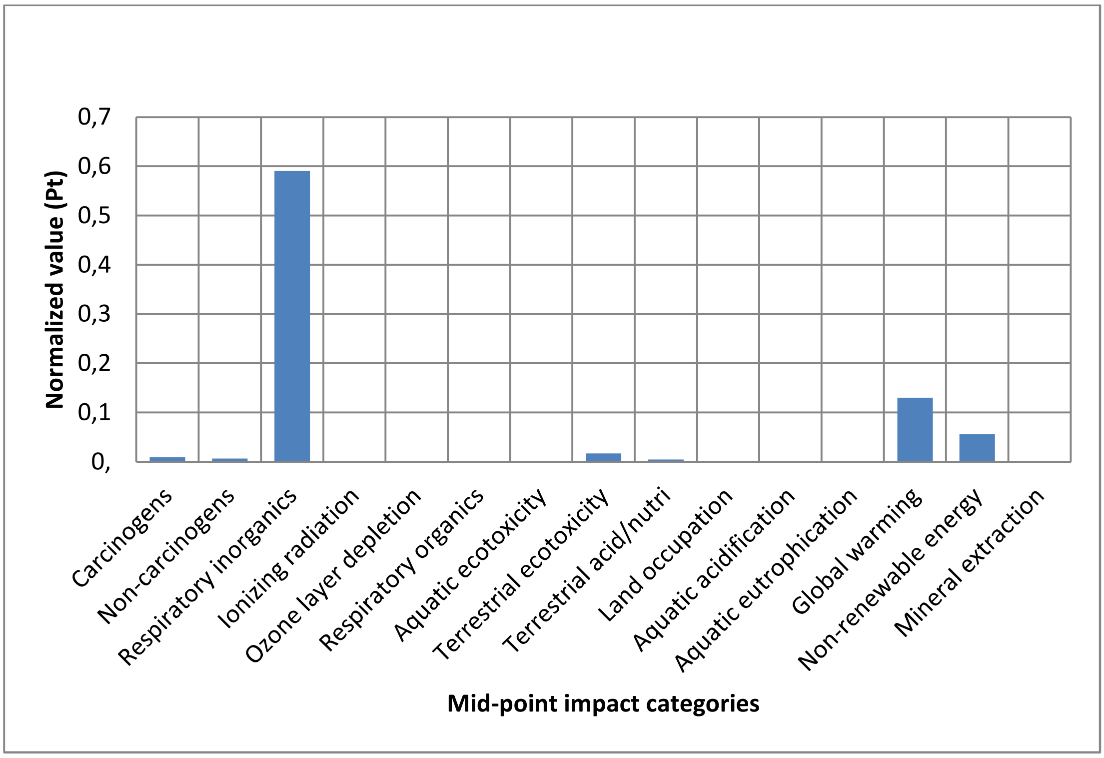



Figure 21. Normalized impact assessment results for 1 ton of coil

**Comparison of environmental impacts of final products**

Billet, slab, wire rod and coil were compared in terms of their environmental impacts per one ton of production. The normalized results are presented in Figure 22, and single score results (i.e. gathered versions of normalized results), are given in Figure 23. These figures show that the environmental impacts of finished products were higher than the semi-finished products as expected due to additional processing causing energy consumptions and also air emissions as well.

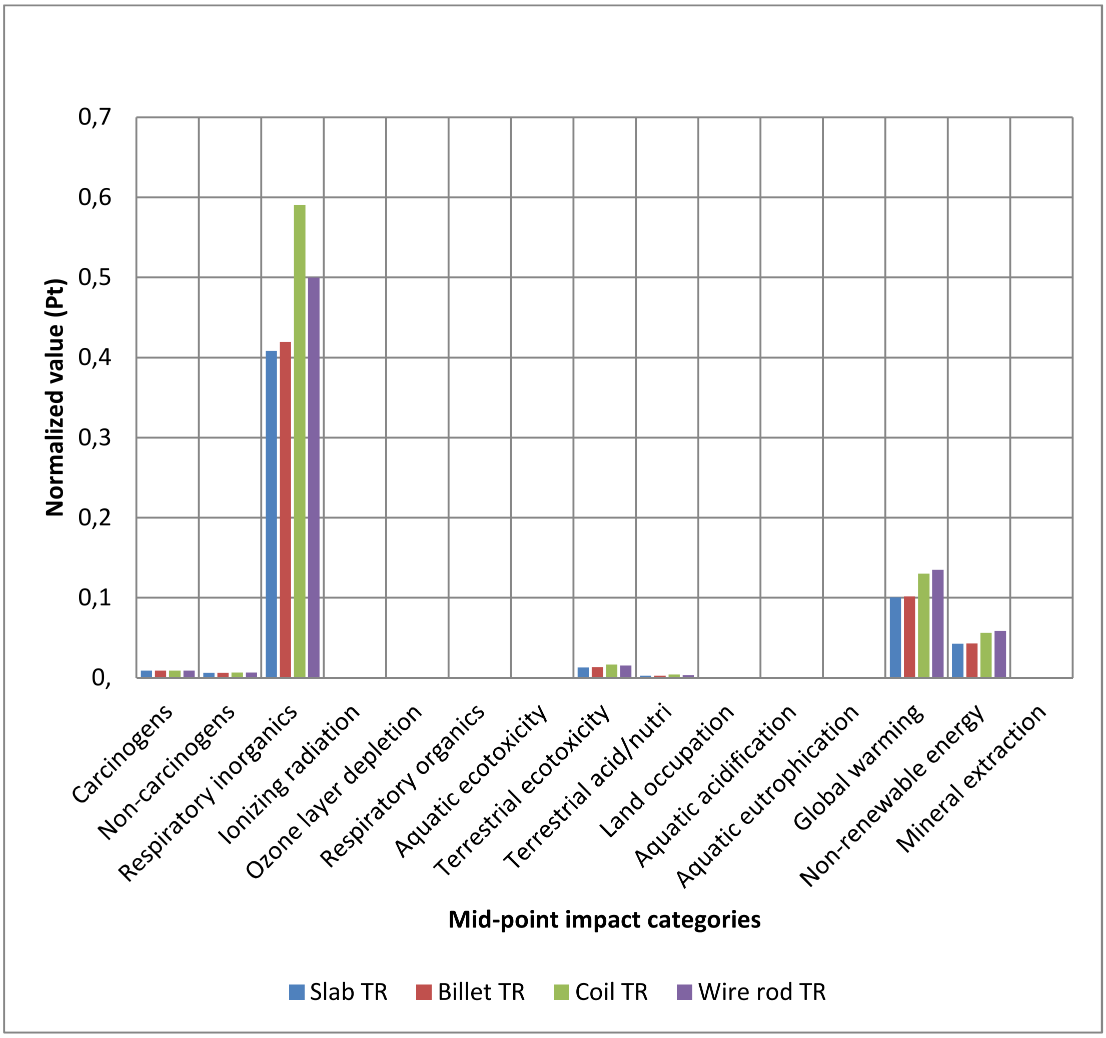



Figure 22. Comparison of normalized impact assessment results for 1 ton of each final product

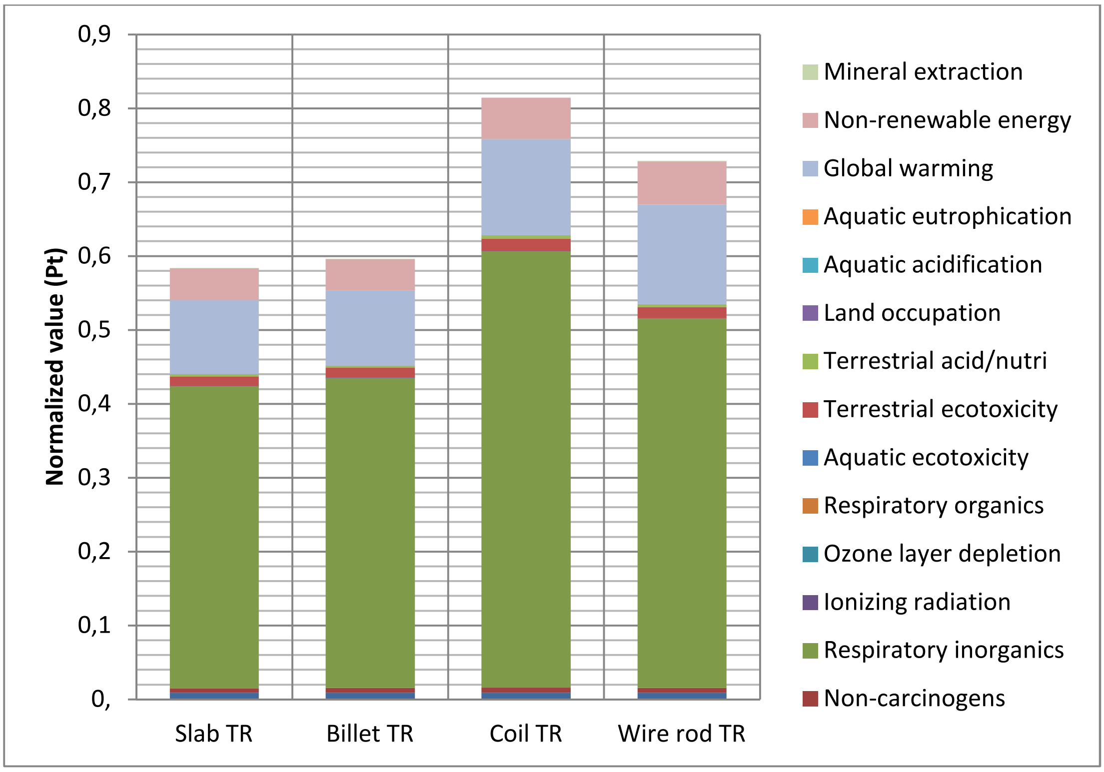



Figure 23. Comparison of single score results for 1 ton of each final product

According to the single score results presented in Figure 23, the comparison of two semi-finished products shows that the environmental impacts of 1 ton of billet (0.597 Pt) were higher than 1 ton of slab (0.584 Pt), despite the fact that the emissions per slab production (16.5 kg $CO_2$/ton slab) were higher than billet production (7.4 kg $CO_2$/ton billet), and also liquid steel utilized per one ton of slab (1.0470ton LS/ton slab) was higher than per ton of billet (1.0164 ton LS/ton billet) as mentioned in Section 5.2.2.5. The reason for this could be explained in terms of the allocation percentages of products. Since billet had accounted for 98.6% (Figure 35, APPENDIX D) of the products of billet casting unit and slab had accounted for 95.44% (Figure 36, APPENDIX D) of total products of slab casting unit, the impacts of 1 ton of billet show a higher rate. Coils exhibited the greatest impact (0.815 Pt) not only among the finished products but also among the all products.

Among the studied semi-finished and finished products, slab showed the lowest environmental impact and the coil showed the highest impact. Although having different impact rates, they have contributed to same impact categories. According to the normalized impact assessment results given in Table 34, Table 35, Table 36 and Table 37, all semi-finished and finished products showed the highest environmental impacts in the category of 'Human Health' caused by respiratory effects followed by 'Climate Change' caused by global warming and 'Resources' caused by non renewable energy sources, as in the case of liquid steel. Since the main inputs of both casting and rolling is liquid steel, most of the environmental impacts resulted from the liquid steel, so they showed similar features with it. The upstream product is liquid steel and the downstream products are wire rod and coil, and billet and slab are the mid-products, and therefore, the successive processes showed cumulatively building environmental impacts. The impacts on 'Terrestrial Ecotoxicity', 'Carcinogens' and 'Terrestrial Acidification/Nutrification' were relatively low as in case of all sub-processes.

### 6.3. Production scenarios

In this section, in an attempt to evaluate the effect of having different production scenarios implemented in the facilities, three different scenarios were considered and the evaluation was made per one ton of total product. First scenario was the real production percentages of the facility where field studies conducted. The second scenario was the case if all products are only semi-finished products from casting, and the third scenario was the case that all semi-finished products are sent to hot rolling and all products are only finished products. The results of three scenarios were then compared with each other.

In the facility, approximately 70% of total liquid steel produced is sent to billet casting and 30% of liquid steel is sent to slab casting. And, 25% of billet produces is sent to hot rolling unit to produce wire rods while 75% of slab produces is sent to hot rolling unit to produce coils. Briefly, 52.5% of all products stand for the billet. Remainings are belonging to the slab, the wire rod and the coil with sharing percentages of 7.5%, 17.5% and 22.5%, in respective orders. In the second scenario, it was considered that, of the products, 70% is for the billet and 30% is for the slab. Third scenario represented the case in which the production percentages for the wire rod and the coil are 70% and 30%, respectively. In this part, unlike in the previous evaluations (Sections 6.1 and 6.2), mechanical workshop is also included to see its contribution to the environmental effects, considering that this evaluation will be done for the facility studied. As it was also pointed in Section 5.2.3, the mechanical workshop had been excluded during the LCA evaluations conducted for the sub-processes and products as this unit does not lead to any product.

The details of production scenarios considered are given in Table 23.

Table 23. Details of production scenarios

| **Product** | **Scenario 1 (semi-finished + finished products)** | **Scenario 2 (semi-finished products)** | **Scenario 3 (finished products)** |
|---|---|---|---|
| **Billet** | 0.525 tons | 0.7 tons | |
| **Slab** | 0.075 tons | 0.3 tons | |
| **Wire rod** | 0.175 tons | | 0.7 tons |
| **Coil** | 0.225 tons | | 0.3 tons |
| **Mechanical workshop** | 1 p | 1 p | 1 p |
| **Total** | 1 ton + 1 mechanical workshop | 1 ton + 1 mechanical workshop | 1 ton + 1 mechanical workshop |

Figure 24 shows the results obtained for the first scenario. As seen from this figure, billet has the highest impact (313 mPt), as expected, due to its highest share among the products. Impacts of products are proportional with their amounts. The details of Figure 24 are presented in Table 54 (APPENDIX J) with their percentage contributions to total environmental impact. The impacts of slab, wire rod and coil are 43.8, 128, 183 mPt corresponding to 6.54, 19.04 and 27.37% of total impact in respective order. The environmental impacts of mechanical workshop appeared to be too low (normalized impact value: 1.88 mPt and contribution to total environmental impact: 0.28%) when compared with the impacts of final products as presented in Figure 24.

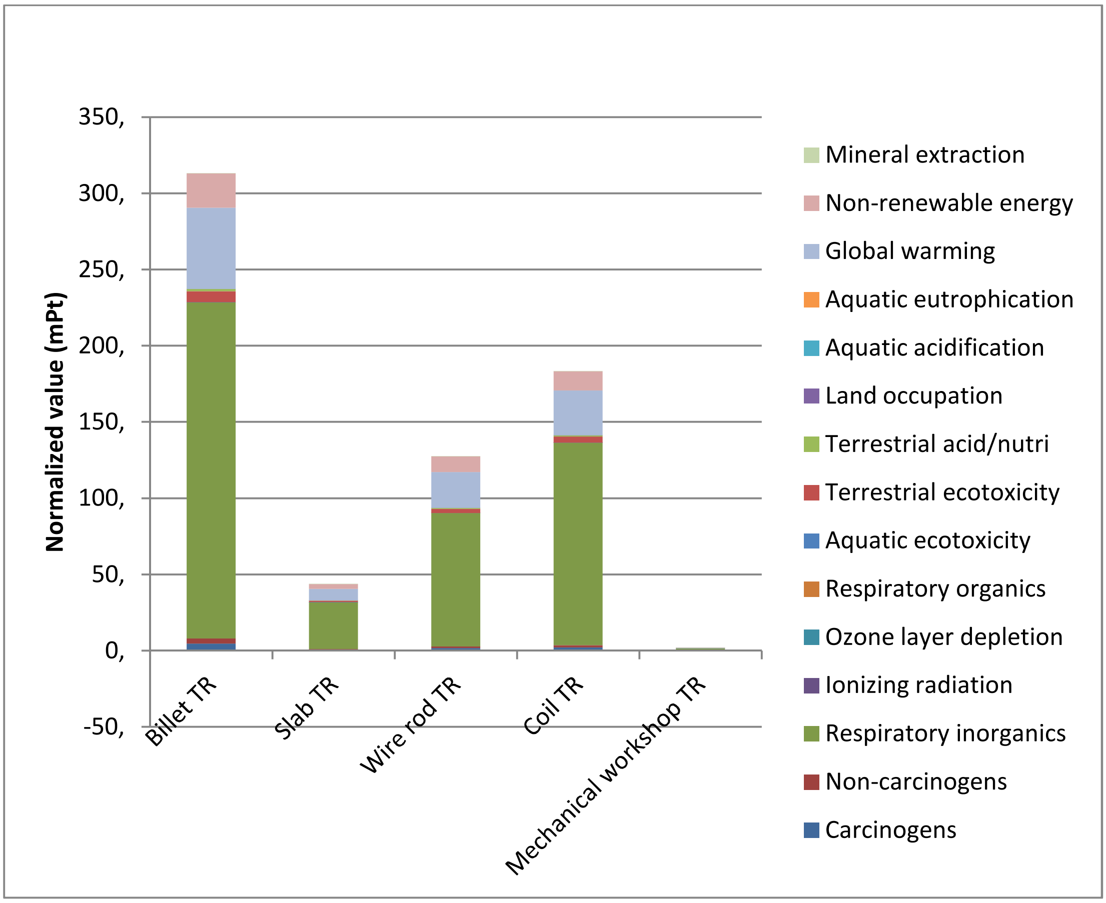



Figure 24. Single score results for Scenario 1

The results obtained for the Scenario 2 are presented in Figure 25 and the details of the result are given in Table 55 in APPENDIX J. From this figure, it can be depicted that the contribution of billet (418 mPt) to total environmental impact (595 mPt) corresponds to 70.23% (in Table 55 in APPENDIX J), as expected, in consequence of the proportionality with its amount. The impact of slab is 175 mPt corresponding to 29.45% of total impact. The environmental impacts of mechanical workshop (normalized impact value: 1.88 mPt and contribution to total environmental impact: 0.32%) appeared to be too low as in the case of Scenario 1.

The impact assessment results for the Scenario 3 are presented in Figure 26 and the details of the result with their percentage contributions to total environmental impact are given in Table 56 in APPENDIX J. It can be depicted from this figure that wire rod has the highest impact, the contribution of wire rod (510 mPt) to total environmental impact (756 mPt) corresponds to 67.44% of total impact as presented in Table 56 in APPENDIX J, as expected, proportional with its amount. The environmental impacts of mechanical workshop (normalized impact value: 1.88 mPt and contribution to total environmental impact: 0.25%) appeared to be too low as in the case of Scenario 1 and Scenario 2.

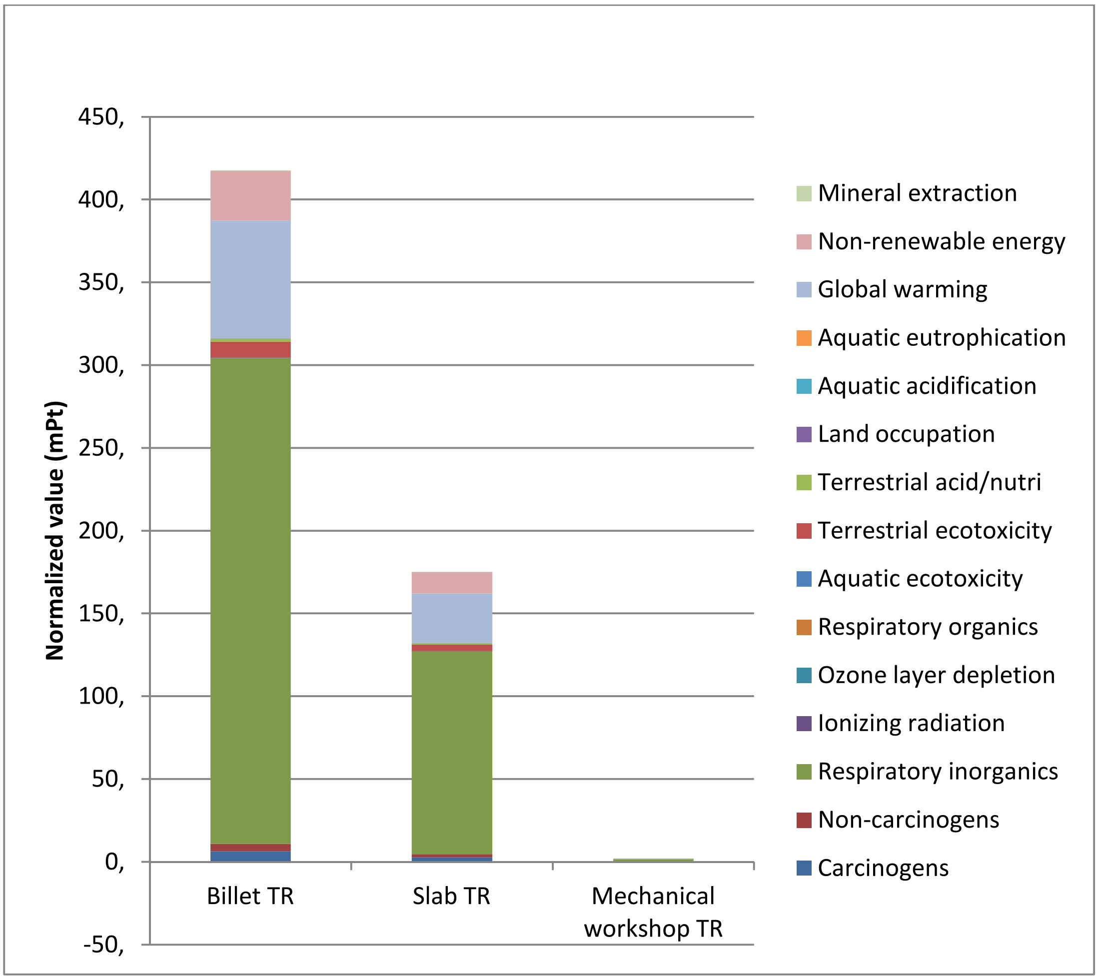



Figure 25. Single score results for Scenario 2

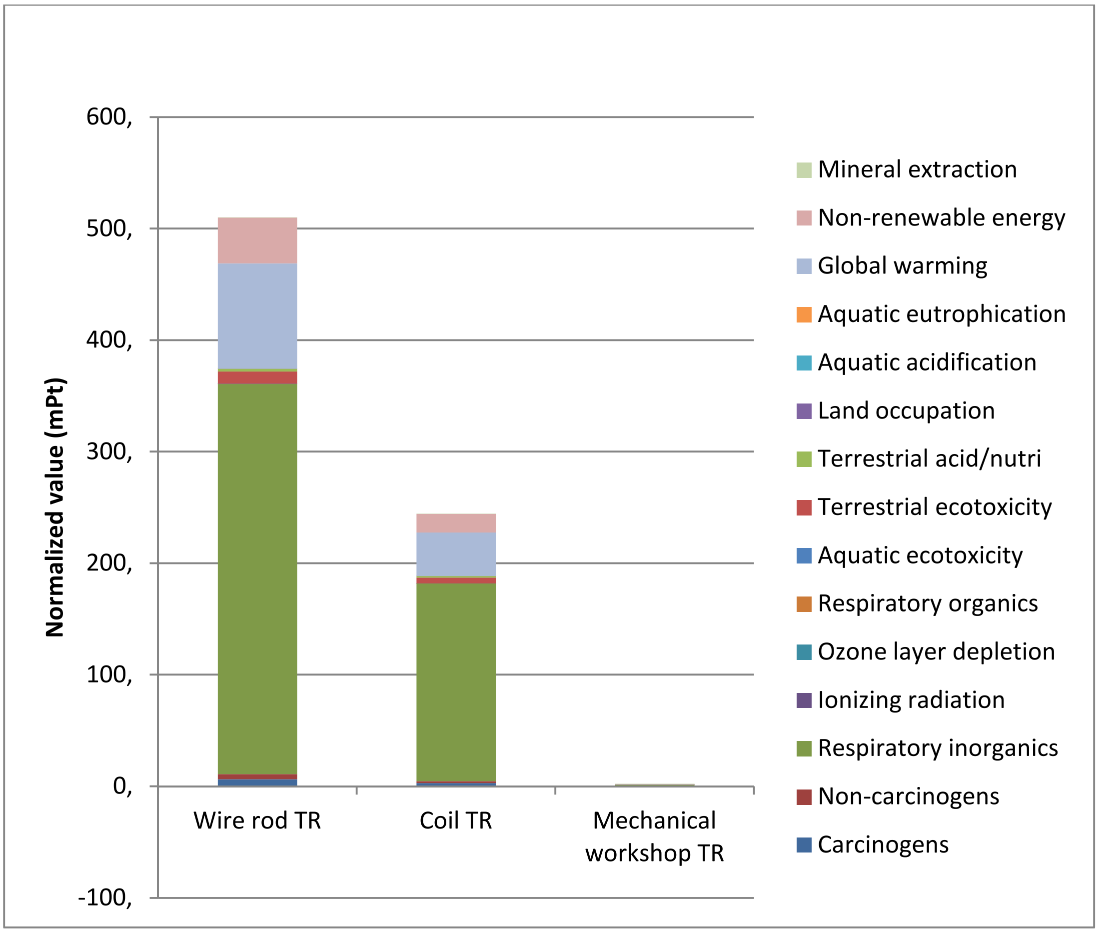



Figure 26. Single score results for Scenario 3

The results obtained for the production scenarios introduced to the LCA software were compared with each other. Gathered versions of normalized results are presented in terms of single score results in Figure 27. As depicted from this figure, Scenario 3 showed the highest impact than other scenarios, because higher processing results in higher environmental impact. The normalized value of total environmental impact of the first production scenario per one ton of product was calculated as 0.67 Pt. If all products of the facility were semi-finished products (Scenario 2), the total impact would come out to be 0.595 Pt whereas if all products of the facility were finished products (Scenario 3), the total impacts would be 0.756 Pt. In other words, if all products of the facility are the semi-finished products, the total environmental impact will be decreased by about 11%; on the contrary, when all products of the facility are the finished products, the total environmental impact will be increased by about 13% as compared to Scenario 1. According to the changes in environmental impacts of different production scenarios, hot rolling of one ton product corresponds to approximately 24% higher environmental impacts than casting of one ton of product, in a sense the hot rolling of casting products covers approximately 24% of the total environmental impacts of the full production cycle of one ton of product.

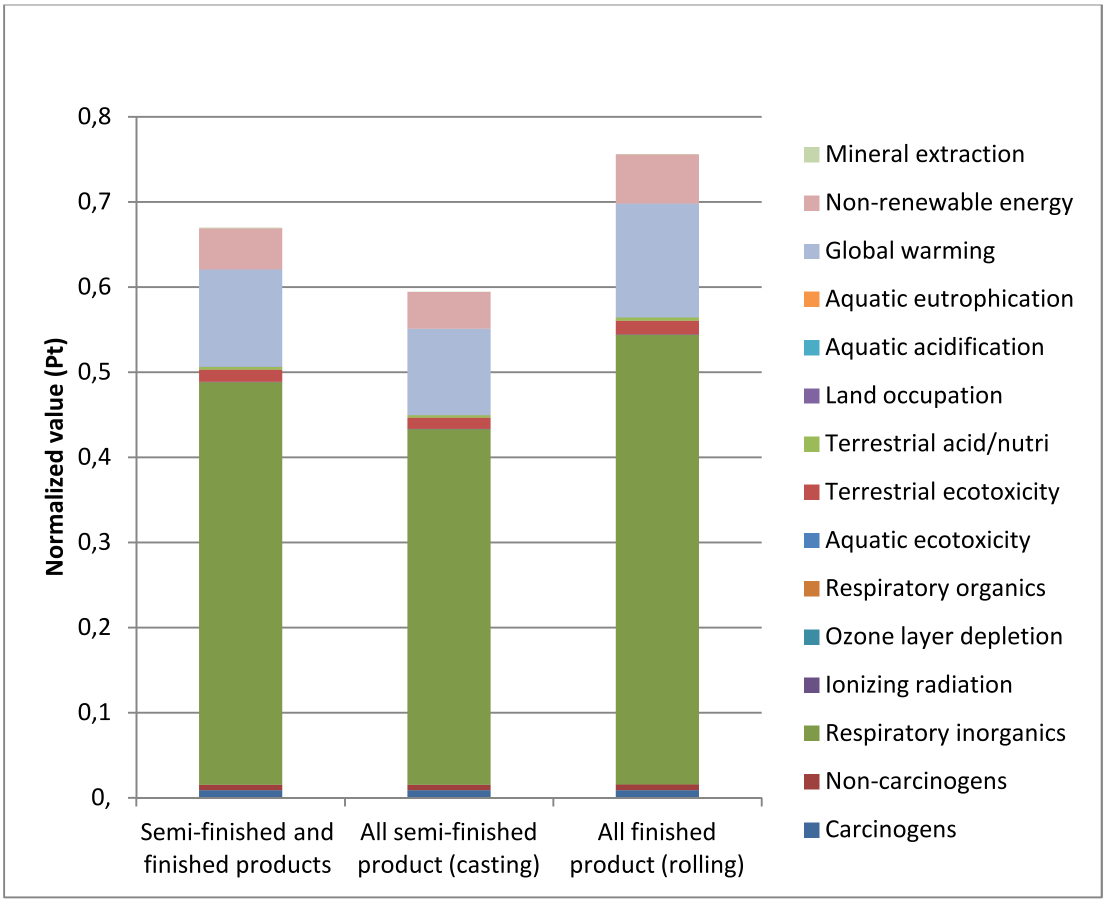



Figure 27. Comparison of single score results for three production scenarios

### 6.4. Suggestions for sustainable production

All semi-finished and finished products showed the highest environmental impact in the category of 'Respiratory Inorganics' and 'Global Warming'. In order to reduce the environmental impacts it is beneficial to give the priority to the processes having the highest contribution to those categories for reasonable investment. Therefore, to determine the main contributors of the mentioned impact categories, the results are combined and presented in a different way. Since coke, sinter and pellet are inputs to blast furnace, their contributions are presented separately and the contribution of liquid iron (LI) production from blast furnaces other than coke, sinter and pellet consumptions is indicated as 'LI-other' in the below presented Figures. Contribution of liquid steel (LS) production other than liquid iron consumption is indicated as 'LS-other'. Casting (C) process excluding liquid steel consumption and hot rolling (HR) process excluding semi-finished product consumptions are indicated as 'C-other' and 'HR-other', respectively. The calculation procedure for these figures is given in APPENDIX F.

From Figure 28, it can be depicted that liquid steel production excluding the contribution of liquid iron showed the highest impact in the category of 'Respiratory Inorganics'. As mentioned before in Section 5.2.2.4, since the basic oxygen furnace and casting units were evaluated together, air emissions from casting were also evaluated under basic oxygen furnaces. For this reason, although casting process showed the lowest impact in the category of 'Respiratory Inorganics', basic oxygen furnace and casting processes should be evaluated together and it is recommended to take measures for both liquid steel and casting processes. Liquid steel production is followed by hot rolling of both slab and wire rod for finished products, and followed by liquid iron production for semi-finished products. To lower the impacts of finished products, avoiding hot rolling process can be an alternative, but it may not be applicable because the production rates of products generally depend on demand of products. For this reason, it will be beneficial to use effective dust collection methods for emission reduction.

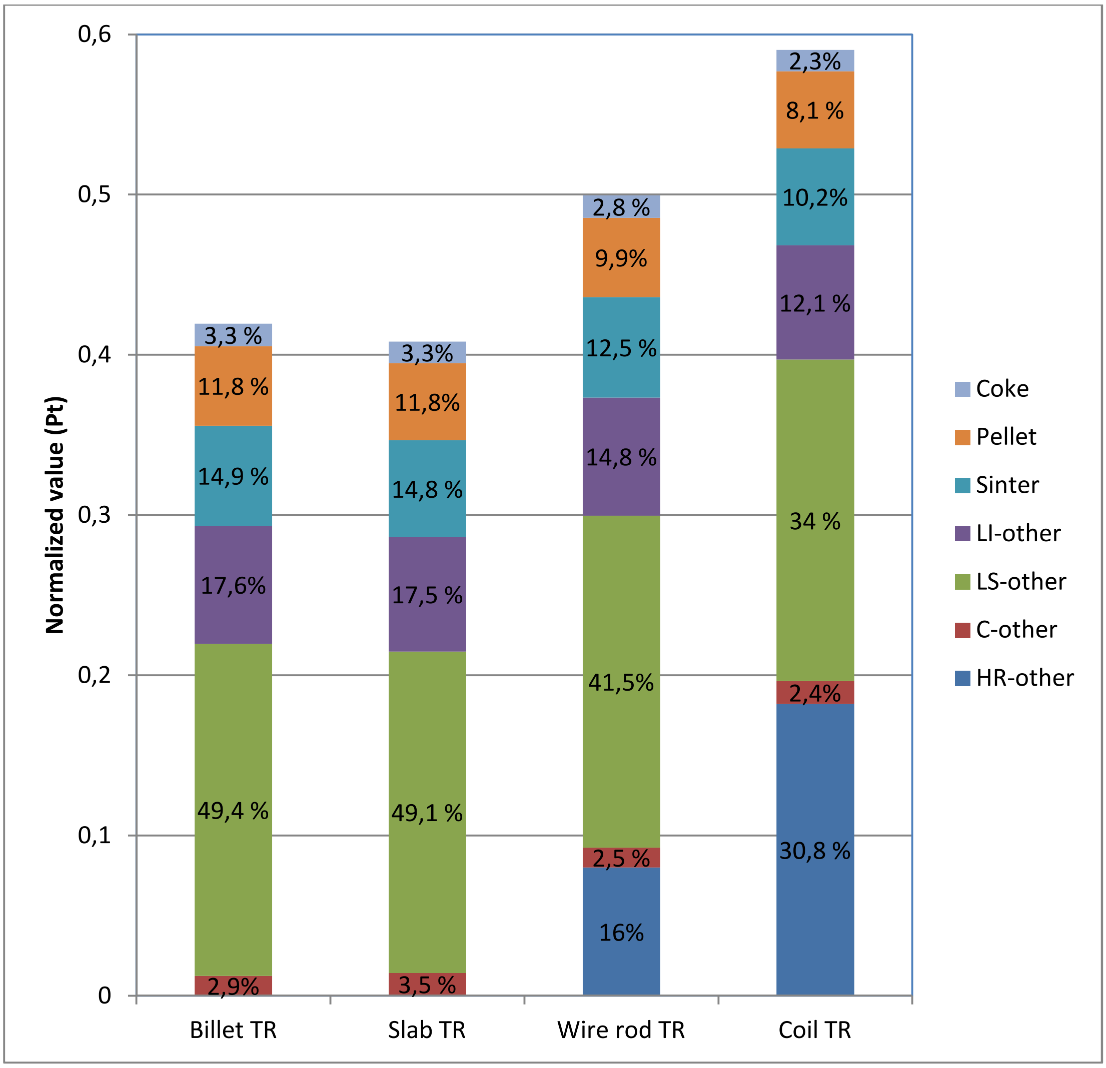



Figure 28. Contributions of processes to ‘Respiratory Inorganics’ impact category

The contributors of ‘Global Warming’ impact category are presented in Figure 29. This figure shows that for both semi-finished and finished products, liquid steel production excluding the contribution of liquid iron showed the highest impact as in the case of ‘Respiratory Inorganics’. And, the second highest environmental impact is resulted from liquid iron production. In order to decrease the environmental impacts in the category of ‘Global Warming’, it is beneficial to reduce the impacts of liquid steel and liquid iron production processes especially carbon dioxide emissions.

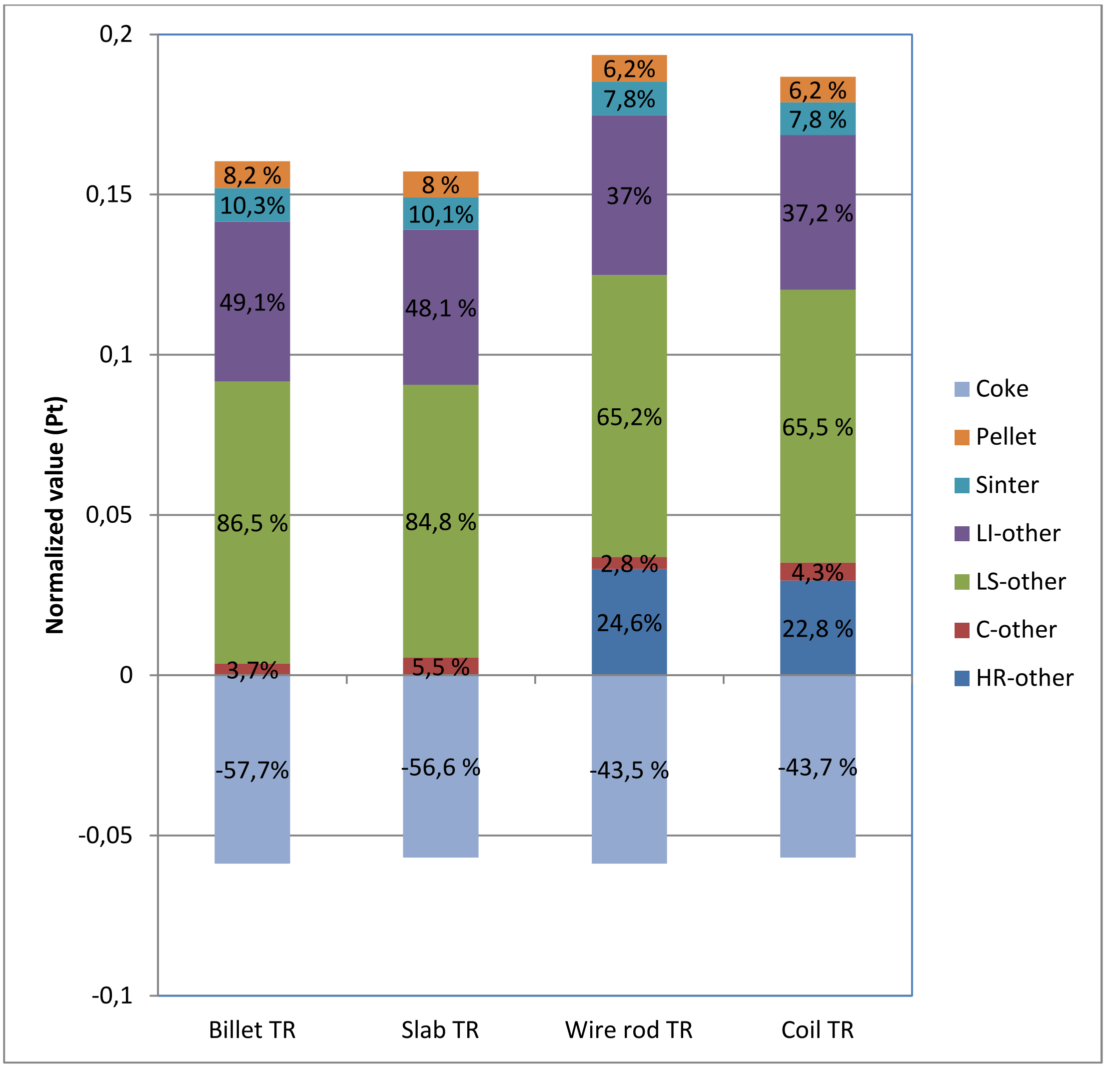



Figure 29. Contributions of processes to ‘Global Warming’ impact category

In investment planning stage aiming to reduce the total environmental impacts, it will be effective to give the priority to the impact category having the largest contribution to the total environmental impact. For all final products, the environmental impact of ‘Respiratory Inorganics’ catgory is very high when compared to the other impact categories. Thus, giving importance to this category is beneficial especially to liquid steel production and hot rolling processes for finished products and to liquid steel production and liquid iron production processes for semi-finished products. It is recommended that second-ranked investment area is the ‘Global Warming’ impact category to reduce the total environmental impact. In this category, liquid steel and liquid iron productions become prominent.

# CHAPTER 7

# SUMMARY AND CONCLUSION

The results obtained from the LCA study conducted for integrated iron and steel industry in Turkey are summarized in Table 24. This table presents the results for the products of sub-processes and the final products, in terms of impact categories in a comparative way.

Table 24. Summary of the normalized impact assessment results

| Process | Product | Impact on Human Health | Impact on Ecosystem Quality | Impact on Climate Change | Impact on Resources | Total Environmental Impact (Single Score) |
|---|---|---|---|---|---|---|
| | | (Pt) | (Pt) | (Pt) | (Pt) | (Pt) |
| Coke making | Coke | 1,46E-01 | 2,1E-02 | -6,13E-02 | 1,09E-01 | 2,15E-01 |
| Sintering | Sinter | 3,51E-01 | 1,06E-02 | 5,87E-02 | 1,65E-02 | 4,37E-01 |
| Blast Furnace Process | Liquid iron | 2,70E-01 | 1,00E-02 | 1,35E-02 | 7,30E-03 | 3,00E-01 |
| Basic Oxygen Furnace Process | Liquid steel | 4,10E-01 | 1,57E-02 | 9,49E-02 | 4,14E-02 | 5,62E-01 |
| Casting | Billet | 4,35E-01 | 1,67E-02 | 1,02E-01 | 4,33E-02 | 5,97E-01 |
| | Slab | 4,24E-01 | 1,63E-02 | 1,00E-01 | 4,32E-02 | 5,84E-01 |
| Hot Rolling | Wire rod | 5,15E-01 | 1,94E-02 | 1,35E-01 | 5,91E-02 | 7,29E-01 |
| | Coil | 6,06E-01 | 2,18E-02 | 1,30E-01 | 5,66E-02 | 8,15E-01 |

Based on the results summarized in Table 24, following conclusions can be drawn:

- Among the sub-processes applied, basic oxygen furnace process shows the highest total environmental impact when assessed for its product of liquid steel.

- Liquid steel shows the highest impact in the category of ‘Human Health’ and ‘Climate Change’ followed by sinter among the products of sub-processes.
- Coke has the priority causing depletion of non-renewable energy sources categorized under ‘Resources’.
- Coke has a negative contribution in the category of ‘Climate Change’ because the production of coke oven gas avoids the external energy consumption and so the impact on ‘Climate Change’ is lowered. Furthermore, the environmental impact of liquid iron on ‘Climate Change’ is also further lowered by means of the blast furnace gas recycling.
- The comparison of final products reveals that hot rolled coil has the highest total environmental impact followed by wire rod, billet and slab.
- Slab shows lower environmental impacts than billet and this is explained by the allocation percentages. Similarly, the allocation percentages have a significant influence on liquid iron.

Furthermore, hot rolling of casting products corresponds to approximately 24% of the total environmental impacts of the full production cycle of one ton of product. It is also concluded that the allocation percentages of the products have a significant influence on the impact assessment results.

To conclude, integrated iron and steel products have impacts mainly on ‘Respiratory Inorganics’ and ‘Global Warming’ impact categories and it is recommended the facility giving the priority to those impact categories in investment planning stage for environmental impact reduction. In ‘Respiratory Inorganics’ impact category, the prior processes are liquid steel and hot rolling processes for finished products and liquid steel and liquid iron production processes for semi-finished products. It is beneficial to use effective dust collection methods to decrease the particulate emissions. In ‘Global Warming’ impact category, liquid steel and liquid iron production processes become prominent and carbon dioxide emission reduction is recommended to the facility.

# CHAPTER 8

# RECOMMENDATIONS

In addition to the above mentioned conclusions, the assessments performed in this thesis were mainly based on assumptions and these assumptions can affect the accuracy of the results. As can be concluded from this study that impact assessment results are sensitive to some parameters; such as allocation percentages and the characterization, damage, normalization factors of impact assessment methods. Thus, different allocation percentages and different impact assessment methods using different factors will change the impact assessment results. When the results of the study are used, this aspect should be taken into consideration.

Moreover, there may be uncertainties in the results due to the assumptions. It is necessary to conduct an uncertainty analysis. The software has the ability of conducting uncertainty analysis. However, this analysis cannot assess the uncertainty of inventory data collected from the facility. Therefore, the results of the uncertainty analysis conducted by the software are thought to be inadequate. Conducting a comprehensive uncertainty analysis is required an extensive study, so it could not be covered in the present study due to time limitations. In further studies, uncertainty analysis should be conducted in order to ensure the accuracy of the data.

# REFERENCES


[1] European Confederation of Iron and Steel Industries, website: http://www.eurofer.org/, August 2010.

[2] T.C. Sanayi ve Ticaret Bakanlığı, *Demir Çelik Sektörü Raporu*, Sanayi Genel Müdürlüğü, Sektörel Raporlar ve Analizler Serisi, 2010

[3] World Steel Association, website: www.worldsteel.org, August 2010.

[4] Demir Çelik Üreticileri Derneği (DÇÜD) web-site: http://www.dcud.org.tr/dcs.aspx, September 2011.

[5] Gielen, D., and Moriguchi, Y., *$CO_2$ in the iron and steel industry: an analysis of Japanese emission reduction potentials*, Energy Policy 30, 849–863, 2002.

[6] Ministry of Energy and Natural Resources of Turkey, web-site: http://www.enerji.gov.tr/duyurular/2009_yili_genel_enerji_dengesi.pdf, August 2011.

[7] Nicholas, M.J., Clift, R., Azapagicl, A., Walker, F.C. and Porter, D.E., *Determination of `Best Available Techniques' For Integrated Pollution Prevention and Control: A Life Cycle Approach*, Institution of Chemical Engineers, Trans IChemE, 78, Part B, 2000.

[8] Directive *2008/98/EC* of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives, OJ L 312, 22.11.2008, p. 3.

[9] Seppala, J., Koskela, S., Melanen, M. and Palperi, M., *The Finnish metals industry and the environment,* Resources, Conservation and Recycling, 35, 61–76, 2002

[10] Norgate, T.E., Jahanshahi and S., Rankin, W.J., *Assessing the environmental impact of metal production processes*, Journal of Cleaner Production, 15, 838-848, 2007.

[11] Pizzol, M., Christensen, P., Schmidt, J. and Thomsen, M., *Impacts of "metals" on human health: a comparison between nine different*

*methodologies for Life Cycle Impact Assessment (LCIA)*, Journal of Cleaner Production, 19, 646-656, 2011.

[12] Tongpool, R., Jirajariyavech, A., Yuvaniyama, C. and Mungcharoen, T., *Analysis of steel production in Thailand: Environmental impacts and solutions*, Energy, 35, 4192-4200, 2010.

[13] Burchart-Korol, D., *Evaluation of Environmental Impacts in Iron-Making Based on Life Cycle Assessment,* International Metallurgical and Materials Conference , 2011

[14] Burchart-Korol, D., *Significance of Environmental Life Cycle Assessment (LCA) Method in the Iron and Steel Industry*, Metalurgija 50, 3, 205-208, 2011.

[15] Huang, Z., Ding, X., Sun, H., and Liu, S., *Identification of main influencing factors of life cycle $CO_2$ emissions from the integrated steel works using sensitivity analysis*, Journal of Cleaner Production 18, 1052–1058, 2010.

[16] Caneghem, J.V., Vermeulen, I., Block, C., Cramm, P., Mortier R. and Vandecasteele C., *Abiotic depletion due to resource consumption in a steelwork assessed by five different methods*, Resources, Conservation and Recycling, 54, 1067–1073, 2010.

[17] Lee, K.M. and Park P.J., *Estimation of the environmental credit for the recycling of granulated blast furnace slag based on LCA Resources*, Conservation and Recycling, 44, 139–151, 2005.

[18] Birat, J.P., *The sustainability footprint of steelmaking by-products*, Steel Times International, September 2011.

[19] Li, G., Nie, Z., Zhou, H., Di, X., Liu, Y. and Zuo, T., *An accumulative model for the comparative life cycle assessment case study: iron and steel process*, International Journal of Life Cycle Assessment, 7, 4, 225 – 229, 2002.

[20] Curran, M. A., Notten, P., Chayer, J. A., and Cicas G., *Summary of global life cycle inventory data resources*, SETAC/UNEP Life Cycle Initiative, Task Force 1: Database Registry, 2006.

[21] Ertem, M.E., Sen,S., Akar, G., Pamukcu, C., *Specific Energy Consumption Analysis of Turkish Integrated Steel Plants and Sustainable*

*Energy Management in ERDEMIR*, Energy Sources, Part A, 32:931–941, 2010.

[22] Kakkar, M. and Maudgal, S., *Life Cycle Assessment - An Effective Tool for Cleaner Production in the Steel Sector*, Sustainable Development Solutions for Asia and the Pacific, Sustainable Development Papers, 2008

[23] Yellishetty, M., Ranjith, P.G. and Tharumarajah, A., *Iron ore and steel production trends and material flows in the world: Is this really sustainable?*, Resources, Conservation and Recycling, 54, 1084-1094, 2010.

[24] Mirgaux, O., Ablitzer, D., and Iosif, A.M., *How physical modelling can improve Life Cycle Inventory accuracy and allow predictive LCA: an application to the steel industry*, Revue de Metallurgie, 106, 12, 579 – 584, 2009.

[25] Keoleian, G. A. and Menerey, D., *Life Cycle Design Guidance Manual, Report EPA 600/R-92/226,* US EPA, Cincinnati, Ohio, 1993.

[26] Curran, M., A., *Scientific Applications International Corporation's report on Life Cycle Assessment: Principles and Practice,* National Risk Management Research Laboratory Office of Research and Development U.S. EPA, May 2006.

[27] Rebitzer, G., Ekvall, T., Frischknecht, R., Hunkeler, D., Norris, G., Rydberg, T., Schmidg, W.-P., Suh, S., Weidema, B.P. and Pennington, D.W., *Life cycle assessment Part 1: Framework, goal and scope definition, inventory analysis, and applications,* Environment International, 2003.

[28] *ISO 14040 Environmental management - Life cycle assessment - Principles and framework*, International Organization for Standardization, second edition, 2006.

[29] URL 1: *International Organization for Standardization (ISO) web-site:* http://www.iso.org/iso/iso_catalogue/catalogue_ics/catalogue_detail_ics.htm?csnumber=23154, September 2011.

[30] Sonnemann G., Castells F., Schihmacher M., *Integrated Life Cycle Risk Assessment for Industrial Processes*, Lewis Publishers, 2003.

[31] ISO 14041, *Environmental management - Life cycle assessment - Goal and scope definition and inventory analysis*, International Organization for Standardization, first edition, 1998.

[32] ISO 14042, *Environmental management - Life cycle assessment - Life cycle impact assessment,* International Organization for Standardization, first edition, 2000.

[33] Udo de Haes, H.A., Jolliet, O., Finnveden, G., Hauschild, M., Krewitt, W. and Müller-Wenk, R., *Best Available Practice Regarding Impact Categories and Category Indicators in Life Cycle Impact Assessment*, SETAC-Europe: Second Working Group on LCIA (WIA-2), 1999.

[34] Goedkoop, M.J., Heijungs, R., Struis, J., Huppes, G. and Meent, D., *Combined Midpoint/endpoint impact assessment*, Product Ecology Consultants, 2002.

[35] Goedkoop, M., Schryver, A.D. and Oele, M., *Introduction to LCA with SimaPro 7*, Product Ecology Consultants, 2008.

[36] Consoli, F, Allen, D., Boustead, I., Fava, W., Franklin W., Jensen, A. A., Oude, N., Parrish, R., Perriman, R., Postlethwaite, D, Quay, B., Seguin, J., and Vigon B., *Guidelines for Life Cycle Assessment - A Code of Practice*, Society of Environmental Toxicology and Chemistry, Sesimbra/Portugal SETAC workshop report, SETAC press, Pensacola, FL, 1993.

[37] Lindfors, L.G., Christiansen, K., Hoffman, L., Virtanen, Y., Juntilla, V., Hanssen, O., J., Ronning, A., Ekvall, T., and Finnveden, G. (1995), *Nordic Guidelines on Life Cycle Assessment*, Nord: 20, Nordic Council of Ministers, Copenhagen, 1995.

[38] ISO 14043, *Environmental management - Life cycle assessment - Life cycle interpretation,* International Organization for Standardization, first edition, 2000.

[39] Guinee J. B., Goree, M., Heijungs, R., Huppes, G., Kleijn, R. & A. De Koning., *An Operational Guide to the ISO Standards, Final Report. The Netherlands: Ministry of Housing, Spatial Planning and the Environment (VROM) and the Centre for Environmental Studies*, Leiden University. 2001.

[40] Russell, C. and Vaughan W. J., *Steel Production: Processes, Products and Residuals*, 1976.

[41] European Commission, Integrated Pollution Prevention and Control, *Reference Document on Best Available Techniques in the Iron and Steel Production*, December 2001.

[42] European Commission, Integrated Pollution Prevention and Control, *Draft Reference Document on Best Available Techniques in the Iron and Steel Production,* July 2009.

[43] *Profile of the Iron and Steel Industry*, EPA Office of Compliance Sector Notebook Project, EPA/310-R-95-005, 1999

[44] Long, F.J. *The production of iron and steel*, St Martin's Press Inc., New York, 1963.

[45] *Demir Çelik A.Ş. Emisyon Raporu*, Türkiye Bilimsel ve Teknolojik Araştırma Kurumu, Marmara Araştırma Merkezi, Çevre Enstitüsü, 2010.

[46] European Commission, Integrated Pollution Prevention and Control, *Reference Document on Best Available Techniques in the Ferrous Metal Processing Industry*, December 2001.

[47] UNEP SETAC Life Cycle Initiative website: http://jp1.estis.net/sites/lcinit/default.asp?site=lcinit&page_id=11A26B55-8A61-4FDA-AE7F-47C13119E384, August 2011.

[48] American Iron and Steel Institute, website: www.steel.org, August 2010.

[49] Sonverdi, E., Yildirim, G., Özmen, A., and Aydoğan, Y., *ERDEMİR'de yaşam boyu değerlendirme (Lca) çalışması*, II. Ulusal Demir-Çelik Sempozyumu ve Sergisi Bildiriler Kitabı, 2003.

[50] Price, E., *Global Stainless Steel Life Cycle Inventory*, International Iron & Steel Institute, International Stainless Steel Forum, BSSA Conference, Sheffield, UK, 2003.

[51] Ultra low $CO_2$ steelmaking, ULCOS Project, web-site: http://www.ulcos.org/en/, July 2011.

[52] *Elektrik Üretim Sektör Raporu*, Elektrik Üretim Anonim Şirketi, 2009.

[53] Elektirk İşleri Etüt İdaresi, web-site: www.eie.gov.tr/duyurular/EV/EV_kanunu/cevrim_katsayilari.xls, August 2011.

## APPENDIX A

## FLOW CHART OF PRODUCTION AT INTEGRATED IRON AND STEEL PLANT

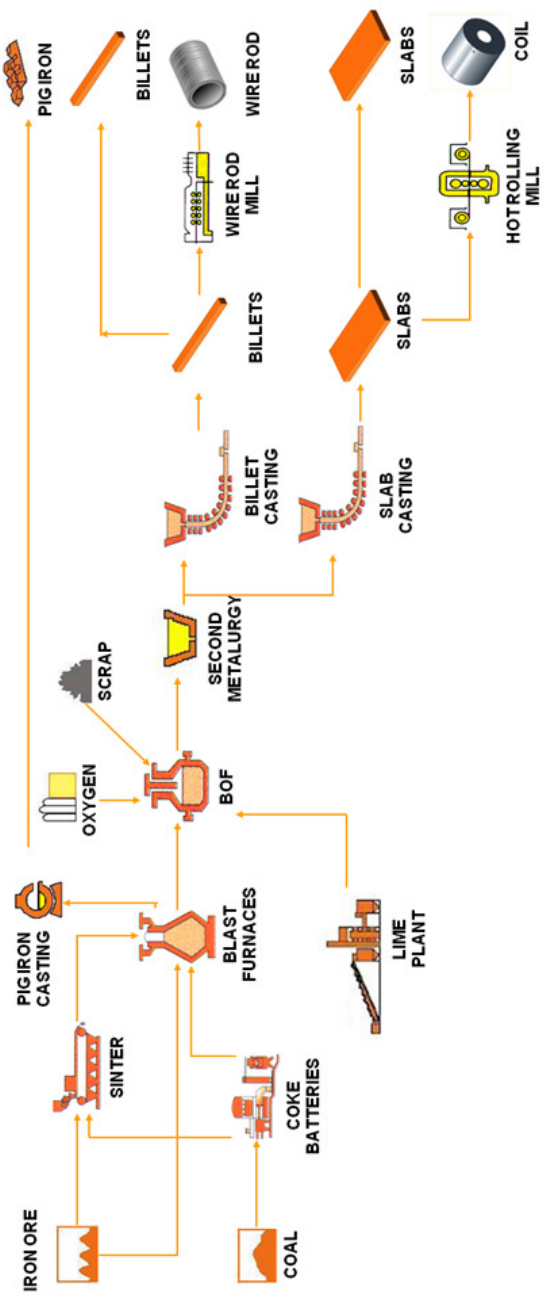



Figure 30. Flow chart of production at integrated iron and steel plant

# APPENDIX B

# PROCESSES APPLIED IN THE FACILITY

The facility is an integrated steel facility in Turkey that produces both flat and long products. Production process in the facility consists of several sub-process; coke making, sintering, iron-making (blast furnaces), steelmaking (basic oxygen furnaces), continuous casting and rolling. The products of the facility are billet, wire rod, slab, coil and a variety of by-products. Billets and slabs are produced via continuous casting of liquid steel from blast furnaces. Billets and slabs are semi-finished products used in manufacturing of hot rolled products, wire rod and coil respectively. Along with steel production process, by-products are produced. These by-products are granulated BF slag, coke, crude benzene (light oil), ammonium sulfate (fertilizer), and tar. Details of sub-processes were presented afterwards. Besides production process covering sub-processes, utility services were available in the facility. These utility services were energy and water facilities and mechanical workshop.

## B.1. Coke making

The main purpose of coke oven plant is to produce metallurgical coke which is a need for blast furnaces. Coke oven plant in the facility consists of coal preparation, batteries and by-products units as presented in Figure 5. The functions of metallurgical coke in the blast furnace are procurement of gas and liquid permeability, providing the necessary heat for reactions, and it's reducing features.

The main input of coke making process is hard coal to produce coke via pyrolysis. Sulfuric acid, sodium hydroxide and wash oil were utilized during the formation of by-products in coke oven gas cleaning unit. Waters used in coke making process are wet quenching water, steam, cleaning water and pump cooling water. Quenching water input is the amount of water added during the wet quenching instead of water loss as water vapour into the atmosphere. Energy used in combustion chamber is coke oven gas and natural gas, in the same time fusi, the mixture of tar and coal dust from by-product formation, is an input to coke batteries as a fuel and also an output of coke oven gas cleaning unit. Electricity is used to provide the energy required for machineries. The outputs from the system are coke produced from hard coal, coke oven gas produced while coking in coke batteries. The other outputs are benzene, tar, ammonium sulfate as by-products. Steam is produced while dry coke quenching. The wastes produced are biological treatment sludge formed during treatment of ammonia water in coke oven gas cleaning unit, and steam wasted from wet coke quenching process. The main emissions from the system are carbon dioxide, carbon monoxide, sulfur dioxide, nitric oxide, nitrogen dioxide and dust.

The intention of coal preparation plant is stocking, stock taking, crushing, preparing, blending, weighing and charging of foreign-sourced hard coal having different properties. Hard coals used in coke plants are brought from USA, Australia, Canada, Indonesia, and Zonguldak. Hard coals are sent to the crusher with the help of conveyor belt. Coal sent to crushers, having maximum size of 50 mm, is crushed to be under 3 mm. After the crushed coal is stocked in silos, coals blended in different characteristics are sent to 3 coal towers located above coke batteries.

In addition, the integrated iron and steel production process requires large amounts of energy and stores large amounts of energy as well. Some of the energy is produced in batteries during the coke production. Manufacture of coke is distillation of coal blends in the airless environment in refractor built coke cabins. Coke batteries consist of a combination of a certain number of coke cabins. Heat required for coking of hard coal is obtained through burning of coke oven gas and natural gas in heating cabins.

Coke oven gas is very valuable due to its high calorific value (approximately 4400 kcal/$m^3$) and the by-products produced during cleaning of coke oven gas. Coke oven gas content is as follows:

Table 25. Content of coke oven gas

| Components | Percentages (%) |
|---|---|
| $CO$ | 6 |
| $CO_2$ | 3 |
| $H_2$ | 60 |
| $N_2$ | 6 |
| $CH_4$ | 20 |

Two different quenching methods which are coke wet quenching and coke dry quenching were applied for coke produced in batteries. In wet quenching, water input is the amount of water added instead of water loss as water vapour into the atmosphere. In dry system, coke is quenched via circulation gas (75% of the nitrogen-carbon-carbon-hydrogen-oxygen) until it is cooled at 150-200 °C, and the temperature of circulation gas is 800 °C. Steam is obtained by using excess heat in circulation gas (420 °C., 39 atmospheres, 25 ton/hour).

Quenched coke was sent to the manipulation unit. In coke manipulation unit, coke is classified by grain thickness. According to grain thickness, broken coke is divided into three. 0-10 mm coke (coke breeze) is sent to sintering, 10-25mm nut coke and the 25-60 mm metallurgical coke are sent to the blast furnaces.

Crude coke oven gas, evolved while coking in coke batteries, is cleaned in coke by-product unit, and during cleaning of gas, tar, benzene and ammonium sulfate are derived. After deriving the by-products cleaned coke oven gas is sent to gasometers in energy facility to balance the pressure and to be stored, and to be used as fuel in different units of the facilities of the plant. Ammonium sulfate is sold to the domestic market for use as fertilizer in agriculture. Benzene as a fuel and input in the chemical plants is sold abroad.

Ammonia water is sprayed on the coke oven gas from coke batteries; thus the temperature coke oven gas is reduced. Meanwhile, tar and steam, in the coke oven gas resulting from the humidity of the coal, condenses and passes through the liquid phase. Then, coke oven gas is separated from the mixture of tar and ammonia water in the separator unit. The mixture of tar and ammonia water is sent to decanter and separated by the difference of specific gravity. Tar is sent to tar storage tank to be sold, and ammonia water is sent to gas cleaning unit for re-cooling. The mixture of tar and coal dust at the bottom due to its specific gravity is called fusi in the field. Fusi is sent to the batteries to be burned.

Coke oven gas from separator is sent to the fertilizer plant. Ammonia in the coke oven gas is converted to the fertilizer (ammonium sulfate) by spraying acid solution on it. The reaction here is as follows:

$$2NH_{3(gas)} + H_2SO_{4\,(liquid)} \rightarrow (NH_4)_2SO_4 \text{ (fertilizer)} + \text{heat}$$

Finally, benzene in the coke oven gas is kept by benzene wash oil. Then, a mixture of benzene and oil are separated by distillation method. Benzene is sent to storage tanks to be sold, clean wash oil is used again.

There is a steady increase in the amount of gas cleaning water (ammonia water) arising from humidity available in hard coal. Therefore, excessive ammonia water is withdrawn from the system continuously and sent to biological treatment plant. The amount of ammonia in the water is trying to keep constant in the system because the more ammonia leads to the formation of corrosive salt ($NH_4Cl$, $NH_4SCN$, $(NH_4)$ $2SO_4$).

The amount of wastewater involves cleaning water and pump cooling water, steam used during the separation of benzene and oil, and ammonia waste water from humidity of the coal, are also included. Total amount of wastewater was calculated approximately from the water flow rate coming to the wastewater treatment plant.

### B.2. Sintering

Sintering is partial melting and bringing into ingots of powdered iron ore, coke breeze and alkalinity adjusting materials, and the product obtained is called sinter. The main three purposes for sintering are: (1) loading and unloading during transport from the mine the ore into powder, that was caused by blockages in powder form to be blast furnaces; brought to a certain size to be permeable; (2) excess sulfur, arsenic and moisture in the ore will lead to breakage in finished steel, thus vaporized during sintering; (3) since giving iron ore directly to blast furnaces will reduces efficiency, the actual blending of raw materials are turned into semi-finished products called sinter.

Sintering unit can be thought as a recycling unit of the facility, there are many inputs from different units of the facility. The inputs of sintering process are iron ore with the additives of limestone, lime, dolomite, dunite and magnesite. In addition, the wastes are utilized from different units of the facility. These wastes are sinter dust, pellet dust, iron ore dust, basic oxygen furnace slag, iron bearing flue dust from dry gas cleaning, iron bearing sludge from wet gas cleaning, and mill scales from rolling. The purpose of using basic oxygen furnace slag in sinter not blast furnace slag is that the iron content of basic oxygen furnace slag is higher than that in blast furnace slag. In the facility, a mixture of mill scale, flue dust, lime and gas cleaning sludge called 'wastes' from prior years is added to the blend. Energy used in the unit is electricity required for machineries and coke oven gas and coke breeze for ignition of sinter blend. The product is sinter and the wastes are sinter dust, multicyclone sludge from dust collecting system. Finally the main air emissions are carbon monoxide, sulfur dioxide, nitric oxide, nitrogen dioxide, hydrogen chloride, hydrogen fluoride, dioxin, furan, and dust.

In preparing the blend material for sintering, limestone, magnesium oxide (MgO) bearing raw materials (dolomite, dunite, magnesite) is used as additives. To this mixture, the sintered powder earned in the system and for burning purposes anthracite powder and coke breeze is added. As grain size and moisture content of the blend increases, coke addition is prompted. The most important thing is to set the degree of acidity and alkalinity. The acidic minerals in the ore are $SiO_2$ and $Al_2O_3$, alkaline minerals are CaO, MgO, and CuO. Elements in the composition of the ore such as sulfur and arsenic are burned and vaporized as oxides during sintering. Na2O, K2O remain in the ore, and vaporized in blast furnaces at 900-1000 °C. Sinter blend have a thickness of approximately 380 mm. Sintering begins with ignition of sinter blend with coke oven gas (1100 ° -1200 ° C) while passing through the furnace. Owing to the high temperature, a hard and a porous structure is obtained.

Chemical properties of sinter are as follows:

- Sinter bearing high degree of CaO is not used hot to avoid fragmentation,
- Alkaline (1.4-1.5) sinter provides coke consumption since it is easy to reduce,
- If alkalinity value is 1:20 to 1:25, physical strength is in the minimum,
- The higher the softening temperature of sintering, the better the gas permeability of furnace,
- FeO should be 10% maximum (Increases fayalite formation and the coke consumption)
- Alkaline and sulfur must be minimum in sinter.

The ore by rail and sea is drained to the main stock area. In the area four stacker-reclaimer, in blending area one stacker and one reclaimer are available. The iron ore from main stock area is broken in the crushing buildings and turned into dust. Broken ores above 7 mm sometimes sent as a piece of ore to the blast furnaces. Broken ores less than 7 mm are stocked out in blending area. The ore blending area is the area where the ore for sintering, piece of ore, limestone, dolomite, quartzite, manganese for blast furnace and basic oxygen furnace are stocked. After the obtained sinter is sieved and weighed, it is charged into the blast furnace.

The dust during sinter breaking, sieving and transport process is kept by electromagnetic methods with 5 electro filter. 0-250 micron size dust particles are kept by plate-type electrostatic precipitator. Dusts is sent to dosing unit and in blended again.

### B.3. Blast Furnaces

A blast furnace is a heating process where solid metal in the form of pieces of iron ore, sinter and pellet turned into liquid iron. 3 blast furnaces – one new, two old- are in operation, and the 4th blast furnace is under construction.

The inputs of blast furnaces are sinter, pellet, iron ore, coke, and pulverized coal with the additives of limestone, dolomite, manganese ore, and quartzite. Energy utilized in the unit is natural gas, coke oven gas, blast furnace gas, electricity, steam, oxygen, air, and nitrogen. Coke oven gas is used for cleaning of slag channels and heating of stoves. Blast furnace gas is also used for heating of stoves. Nitrogen is used during transmission of pulverized coal from pulverized coal injection unit into the blast furnace, and air is used for combustion in stoves. The water used in the unit is gas cleaning water and cooling water. The outputs of the unit are liquid iron as product and blast furnace gas as by-product. The wastes are flue dust, gas cleaning sludge, and wastewater from gas cleaning unit and liquid slag, scale and scrap. The main emissions from the system are carbon monoxide, sulfur dioxide, nitric oxide, nitrogen dioxide and dust.

Blast furnaces takes combustion air from a turbo blower unit connected to energy facilities. Increasing pressure of the air absorbed from the suction chimneys above the blower are sent to blast furnace stoves. There are a total of 6 turbo-blowers. Blast furnace stove aims to heat the cold compressed air from turbo blower and sends to blast furnaces. Stoves are heated by blast furnace gas and coke oven gas. Hot air from stoves (900-1000 $^{O}$C) is routed to furnaces by means of tuyeres. The furnace starts to work by giving hot air.

Bunkers are used to stock material needed by blast furnace and to screen the material in unwanted sizes affecting permeability. After weighed materials are charged into the furnace, moisture of material flies and the temperature increases when moving down. As a result of increasing temperature materials heats up and reacts. At the level of tuyere, at 2000 °C the pig iron and slag dropwise goes down into the reservoir. In the meantime, pulverized coal is injected into tuyeres. Reduced pig iron, irreducible other metal oxides and coke ash accumulate in a reservoir creating slag. Pig iron in the reservoir is send to the pig pots; slag is send to the slag pots.

Slightly reduced elements in blast furnaces like manganese and silisium are included in the structure of liquid iron. Also impurities in reduced iron are kept in the slag. As a result, due to density differences liquid iron is collected at the bottom of the furnace, the slag is collected on the top. The majority of liquid iron separated from slag is sent to basic oxygen furnace to produce steel and the remaining part is sent to the pig machine to produce and sold pig iron. And, blast furnaces gas having a calorific value of 880 kcal/$m^3$ is subjected to the treatment to be used as a fuel. The gas treatment unit consists of dry cleaning and wet cleaning parts. Firstly, BF gas is sent to dust collection system, and then fine particles are turned into sludge by spraying water on it. Held dust and sludge is sent to the sinter. The content of produced blast furnaces gas is presented in Table 26.

.

Table 26. Content of blast furnace gas

| **Components** | **Percentages (%)** |
|---|---|
| CO | 26 |
| $CO_2$ | 18 |
| $H_2$ | 6 |
| $N_2$ | 50 |
| $CH_4$ | 0 |

Liquid iron is shaped into ingots of various weights in pig machine. Lime from the lime calcining plants is mixed with water and poured over the pig ingots.

Slag consisting of not reduced oxides and coke ash at 1450 °C is moved to slag granulation plant. In slag granulation plant, while the evacuation of hot slag 7-8 atm pressure water is sprayed to granulate slag. Granulated slag as raw material for cement production sold in the domestic and foreign markets, and slag cannot be granulated is sent to the waste area.

Scales solidified and stuck in the pots are cleaned by means of hammer blows. Meanwhile shell lime is sprayed to ease this operation.

### B.4. Basic Oxygen Furnace

Liquid iron produced in blast furnaces is converted to liquid steel in 3 Basic Oxygen converters of Basic Oxygen Furnace (BOF) unit. Basic Oxygen Furnace gas (BOF gas) cleaning unit is Venturi Wet Washing System.

The main input to basic oxygen furnace is liquid steel which is the product of blast furnace. The other metallic inputs to convertor are steel scrap, pig iron dust, desulphurization scale and iron ore. The other inputs to converter are magnesite, fluorite, coke, the mixture of anthracite (%50) and pulverized coal (%50), FeSi, lime and oxygen. Pot inputs are FeMn, FeSi, SiMn, coke breeze, coke, Al, FeCr, FeMo, FeV, fluorite, and calcium aluminate. Energy used in the unit is natural gas, coke oven gas, electricity and steam. The water used in the unit is gas cleaning water and cooling water. The outputs of the unit are liquid steel as product and basic oxygen furnace gas as by-product. The wastes are converter slag, desulphurization slag, gas cleaning sludge, and wastewater from gas cleaning unit. The main emissions from the system are carbon monoxide, sulfur dioxide, nitric oxide, nitrogen dioxide and dust.

Liquid crude iron produced in blast furnaces is moved to BOF unit with torpedoes, and in drain pit iron is charged from torpedoes to charging pots. Liquid iron transferred to charging pots is moved to sulfur removal stations. Desulfurization process is done by insufflations of oiled lime powder and magnesium and nitrogen as carrier gas from nozzles to charging pots. The amount of use is automatically calculated by taking into account the initial sulfur content of liquid iron and the required sulfur content at the end of the sulfur removal process. After sulfur removal process is completed; the slag formed on top of the pots is moved to slag pots via deslagging machine.

Before liquid iron charging, scrap is charged to the converter. Scrap allocated according to their quality in scrap preparation plant is charged to converter by weighing the desired amounts. Charged scrap to the converter is approximately 15-20 %.

Steel production process begins by making the charge of liquid iron to converter after scrap charge. One of the most important materials used in the steel production in converter is oxygen. Converter reaction is an exothermic reaction. Since high heat comes out during oxygen blowing on mine at 1300 °C, heat balance is set by scrap charge. 99.5% pure oxygen produced in air separation unit (oxygen production plant), is blown with immersion of nozzles up to a certain depth of hot metal and scrap bath.

Besides the production of liquid steel, slag and waste gas is formed. The removal of unwanted elements is provided by charging slag forming materials (calcined lime, dolomite and Ferro-alloys) to the liquid steel. Due to differences in specific gravity, liquid steel is located at the bottom and slag on the upper part of the converter. Slag in converter is sent to the slag pool for evacuation. After the iron bearing material in BOF slag is taken, the rest of is stocked.

During the burning of carbon in iron by blowing oxygen, the CO and $CO_2$ gases are generated. Waste gas generated during steel production process is sent to store of basic oxygen furnace gas (BOF gas) through pipelines and then, used as a fuel in boilers of power plants. Since complete combustion cannot be achieved in boiler system, the amount of CO is higher than the amount of $CO_2$. 60- 65 % gas released during Oxygen blowing is CO gas. If the ratio of CO gas formed during the oxygen blowing is up to 30%, it is burned in stacks; if the ratio is above 30%, the gas is collected on the gas holder of converter. The content of basic oxygen furnace gas is given in Table 27. In converter boilers steam flow of 30 tons/hour is generated. Steam produced is used for process and heating in various parts of the plant and.

Table 27. Content of basic oxygen furnace gas

| Components | Percentages (%) |
|---|---|
| CO | 72,5 |
| $CO_2$ | 16,2 |
| $H_2$ | 3,3 |
| $N_2$ + Ar | 2,7 |
| Other | 5,3 |

The liquid steel taken to casting pots is transferred to ladle metallurgy stations. Ladle metallurgy stations provide control of temperature in liquid steel, alloying, and refining in the pots. It also ensures time compliance with the converter and continuous casting machines, and thus plays a role in increasing the efficiency of steel production. 3 units are old and 2 new lime kiln. The new lime kiln calcination process is made using 40-80 mm size limestone; the produced lime is dimensioned and then transported.

### B.5. Continuous Casting

Casting is a shaping process where liquid steel is poured on the mould. As a result of casting process semi-finished product occurs. In the facility continuous casting is done. Liquid steel is continuously cast into semi-finished products. The casting material is named according to its shape. The thin and long semi-finished product is named billet and flat semi-finished product is named slab.

The basic input to continuous casting is liquid steel. The necessary energy is met from natural gas, LPG, coke oven gas, blast furnace gas, electricity, oxygen, nitrogen and argon. Water consumed is pure and cooling water. The outputs are billet and slab, and losses of them. The billet and slab losses are resent to basic oxygen furnaces. The main emissions from the system are carbon monoxide, sulfur dioxide, nitric oxide, nitrogen dioxide and dust.

There exist two rolling mills in the facility, wire rod and coil rolling mill. Hot rolling is applied in both of them.

The most basic of waste from continuous casting and rolling mills is the mill scale the oxide layer formed on the surface of product. Pressurized water is sprayed on the surface of semi-finished and finished product for cooling and cleaning purposes. During this process, oxide layer is mixed with a little oil from cleaning machines while water flow to the pit. Here, the heavy rough mill scale sinks to the bottom and oil is get to the top. The thin mill scales not separated from oil suspense. Mill scale collected from the bottom and sent to the sintering after drying. Oil collected and sent to the oil firing plants.

Fine mill scale is sent to radial tanks. Here, fine mill scale separated from water is belt filtered and sent to sintering. Clean water is cooled and resent to cooling towers to be used as the cooling water.

### B.6. Hot Rolling

**Wire Rod Mill**

The annual capacity of wire rod mill in the facility is 500.000 tones. The semi-finished products -billets- from continuous casting are primarily heated up to annealing temperature (1050-1300$^o$C) depending on the amount of carbon in steel. After cleaning the mill scales on the billet, it is passed through rollers. The billet having a cross-sectional area of 130x130 mm$^2$ is rolled to produce wire rod in 5.5-16 mm diameter weighing approximately 1.5 tons.

Together with billet input, the inputs to the system are generally energy, which are natural gas, electricity and oxygen. Cooling water is used for cooling and cleaning purposes. The outputs are mill scales, losses of wire rod and emissions. Mill scales are sent to sintering and wire rod losses sent to basic oxygen furnaces. The main emissions from the system are carbon monoxide, sulfur dioxide, nitric oxide, nitrogen dioxide and dust.

**Coil Mill**

Shaping slabs heated to the temperature of rolling is called hot rolling. Hot rolling mill process in the facility is semi-continuous having annual capacity of 3,500,000 tons. 225 mm thick slabs are annealed in slab reheating furnace at about 1250 $^0$C temperature and send to a line for rolling. After tip and tail is cut, then thinned slab is sent to strip rolling. The hot-rolled strip having its final thickness is cooled and turned into hot rolled coil by coilers.

The main input is slab, and the energy inputs are is coke oven gas, electricity, oxygen and nitrogen. During annealing process of slabs, oxide layer is formed on the surface as an output. The oxide layer called mill scale is rinsed with water up to 220 bar pressure. Water used for cooling and cleaning purposes is cooling water. Mill scales are sent to sintering and coil losses sent to basic oxygen furnaces. The main emissions from the system are carbon monoxide, sulfur dioxide, nitric oxide, nitrogen dioxide and dust.

### B.7. Utility services

**Energy Facilities**

The organization purpose and functions of energy facilities include;

- production of energy to interconnected system
- procurement of pressurized air for blast furnaces
- supply of distilled water, hot water and steam for the units of the facility

Energy Facility is comprised of 6 main divisions including boiler, turbo generator, turbo blower, waste heat, and oxygen plants.

*Boilers:* Boiler was formed to acquire steam at 100 Atm. Pressure and 540 °C temperature. Each of five boilers has a capacity of 220 tons/hour. Blast furnace gas, coke oven gas and natural gas are used as fuel.

*Turbo Generator:* There are 5 generators driven by steam obtained from boilers, 2 of which have a capacity of 25 MV, 3 having a capacity of 55 MV. Decreasing the pressure and the temperatures of steam obtained from boilers is sent to various parts of the plant through pipes.

*Turbo Blower:* There are 6 turbo blowers to produce compressed air. Generated compressed air used in the units that are listed below:

- Basic Oxygen Furnaces (converter blowing, continuous casting shears, tundish and ladle cooling)
- Rolling Mill (shear and oven cooling)
- Blast Furnaces (belt tracking, the opening of the oven mouth, cleaning, tuyere, casting hall)
- Coke Making (coal flow, coal silos above the battery)

*Oxygen Plants:* This unit meets the required oxygen, nitrogen and argon of basic oxygen furnace, continuous casting, blast furnaces, rolling mill, coke ovens and other units. Oxygen and nitrogen are produced from the air in the atmosphere. Facility consisting of 5 blocks consumes 17,500 kwh of electricity per hour to produce 18,000 $m^3$ of oxygen and 6,000 $m^3$ of nitrogen gas per hour.

*Waste Heat Unit:* Hot water from power station is passed through deaerators BOF converter. Steam obtained from boilers is taken to accumulators. Here, after passing through steam regulators sent to 10 atm steam station.

**Water Facility**

*Pure water:* This unit meets the needs of pure water in the Power Plant and Boilers in the field. Water directly taken from stream or coming from water purification systems is gradually passed through several filters to treat the water for the foreign matters and hardness of it. Also subjected to chemical reactions in different systems and turned into pure water to prevent calcification in the pipes.

*Service water:* Service water is used in different units of the facility for cooling purposes.

*Sea water:* Sea water is used for heat transfer in turbo blowers and in electricity generation.

**Mechanical Workshop**

Directorate of Mechanical and Auxiliary Workshop is responsible for repair and manufacturing of machine parts during production, maintenance and repair, revision and modernizations. Mechanical and auxiliary workshops consist of the following workshops:

*Manufacturing workshops* performs the production and repair of spare parts.

*Machinery workshop* contains lathes, horizontal drilling machines, submerged arc welding machines, planer, trolley, milling, gear grinding machines and presses.

*Hot forging workshop* contains drop hammers and annealing furnaces.

*Steel construction workshop* contains transporters, steel structures, pressure vessels necessary for the maintenance and repair different units of the facility.

# APPENDIX C

## LIST OF ASSUMPTIONS

1. The selected facility is considered as a representative sample of Turkish integrated iron and steel industry in terms of manufacturing technologies and production capacity.
2. The inputs and outputs of facility together with the amounts belonging to 2009 are assumed to represent the average values for Turkey.
3. Assumptions made in inventory analysis;
   a. In input and output analysis, for all production process average amounts belonging to 2009 are used except emission values. Since there is a not continuous measurement in flue gases, the average of three months' measurements are used.
   b. In coke making process, the amount of treatment sludge is not known, and it is considered negligible.
   c. In casting process, since the basic oxygen furnace and casting units were evaluated together, air emissions from casting were also evaluated under basic oxygen furnaces. Emissions from casting unit are not known separately except for carbon dioxide.
   d. The amount of processed water is not available, therefore the amount is assumed to be one $m^3$ for one m3 of water processing for all types of water; pure water, service water and sea water.
4. Assumptions made during data integration to SimaPro;
   a. Mass allocation was used for products and co-products calculated with their mass percentages, only energy allocation was made for energy facilities. This method is assumed to reflect the allocation of impacts to the products and co-products.

**b.** A few of the data were taken from the databases and it is assumed that these data represent the data belonging to Turkey.

  **i.** The data not specific to country were directly taken from the database. These are magnesite, fluorspar, ferrosilicat, ferromanganese, ferrochromium, aluminium, oil, quartzite and air.

  **ii.** Country-specific data were selected from the database according to the suitability to the country conditions such as geographical similarities. These are iron ore, scrap, dolomite, sodium hydroxide, sulfuric acid, lime, limestone, LPG, natural gas and anthracite coal.

  **iii.** Some of the country specific data were adapted to Turkey, such as electricity and hard coal. While adapting the electricity, natural gas, domestic coal, and hydraulic sources generation were taken as 55%, 25% and 20% respectively. For transportation, approximate distances were calculated by means of Google maps. For very long intercontinental distances, only sea routes are taken into consideration due to the negligible distances of land routes.

**c.** Avoided products are taken as electricity.

**d.** Some inputs were not available in databases of the software and there was not sufficient information to define the materials. In such cases, inputs having similar characteristics were used.

  **i.** Dunit is defined as dolomite

  **ii.** Pellet is defined as sinter

  **iii.** Pellet dust is defined as sinter dust

  **iv.** Coke breeze was defined as coke

  **v.** Pulverized coal is defined as pulverized lignite

  **vi.** Iron dust is defined as iron ore

  **vii.** Mill scale input is assumed to be 50% of wire rod mill scale and 50% of coil mill scale

  **viii.** The gas cleaning sludge is taken as 50% blast furnace gas cleaning sludge and 50% basic oxygen furnace gas cleaning sludge

e. The density of produced gases is taken from literature.

   i. The density of coke oven gas is taken as 0,490 $Kg/m^3$.

   ii. The density of blast furnace gas is taken as 1,290 $Kg/m^3$.

   iii. The density of basic oxygen furnace gas is taken as 1,429 $Kg/m^3$.

5. Characterization, damage assessment and normalization factors of IMPACT 2002+ method are taken from software as developed by the authors.

## APPENDIX D

## THE SCREENSHOT OF PROCESSES IN SIMAPRO

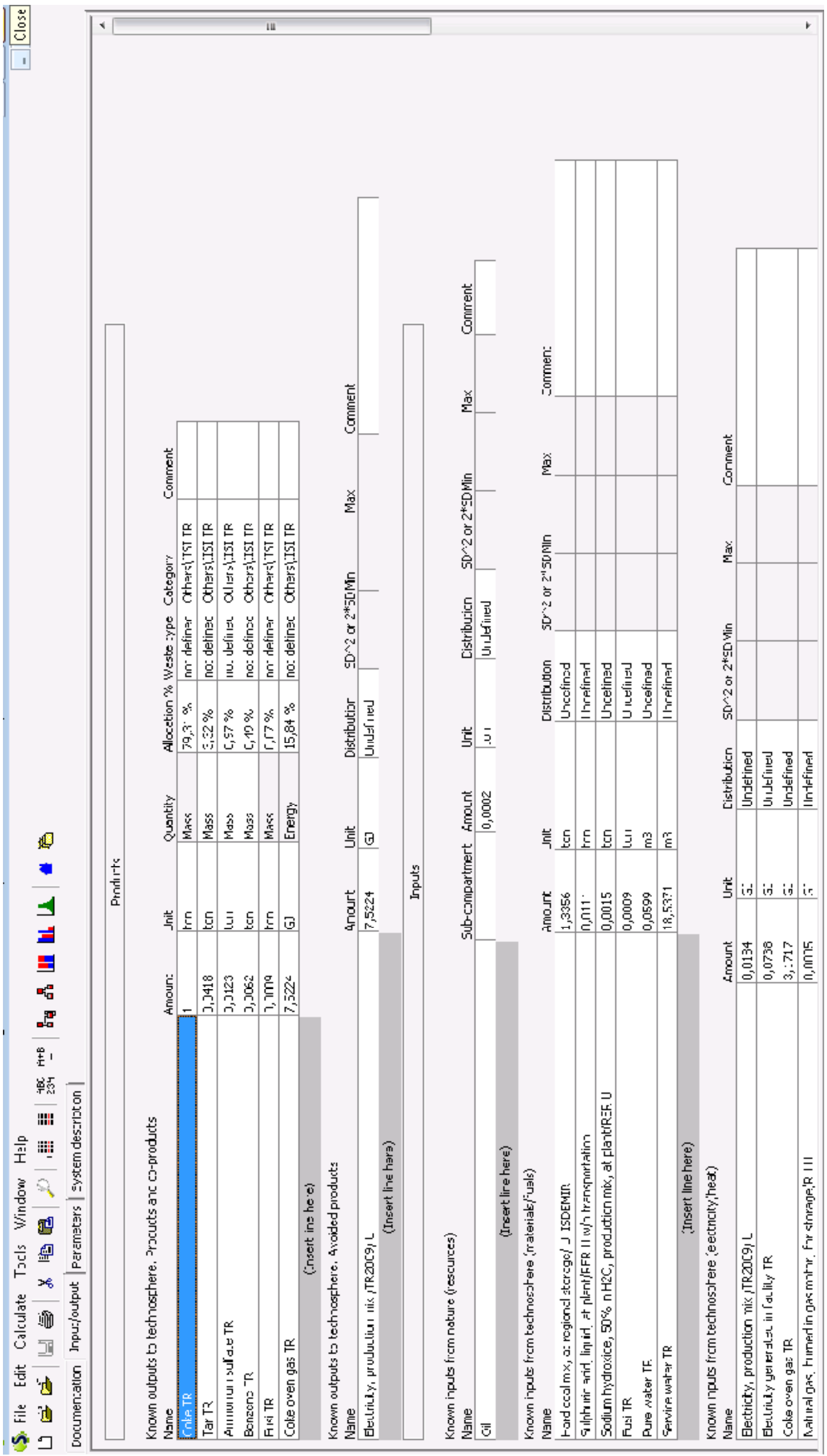


Figure 31. The screenshot of the coke making process in SimaPro

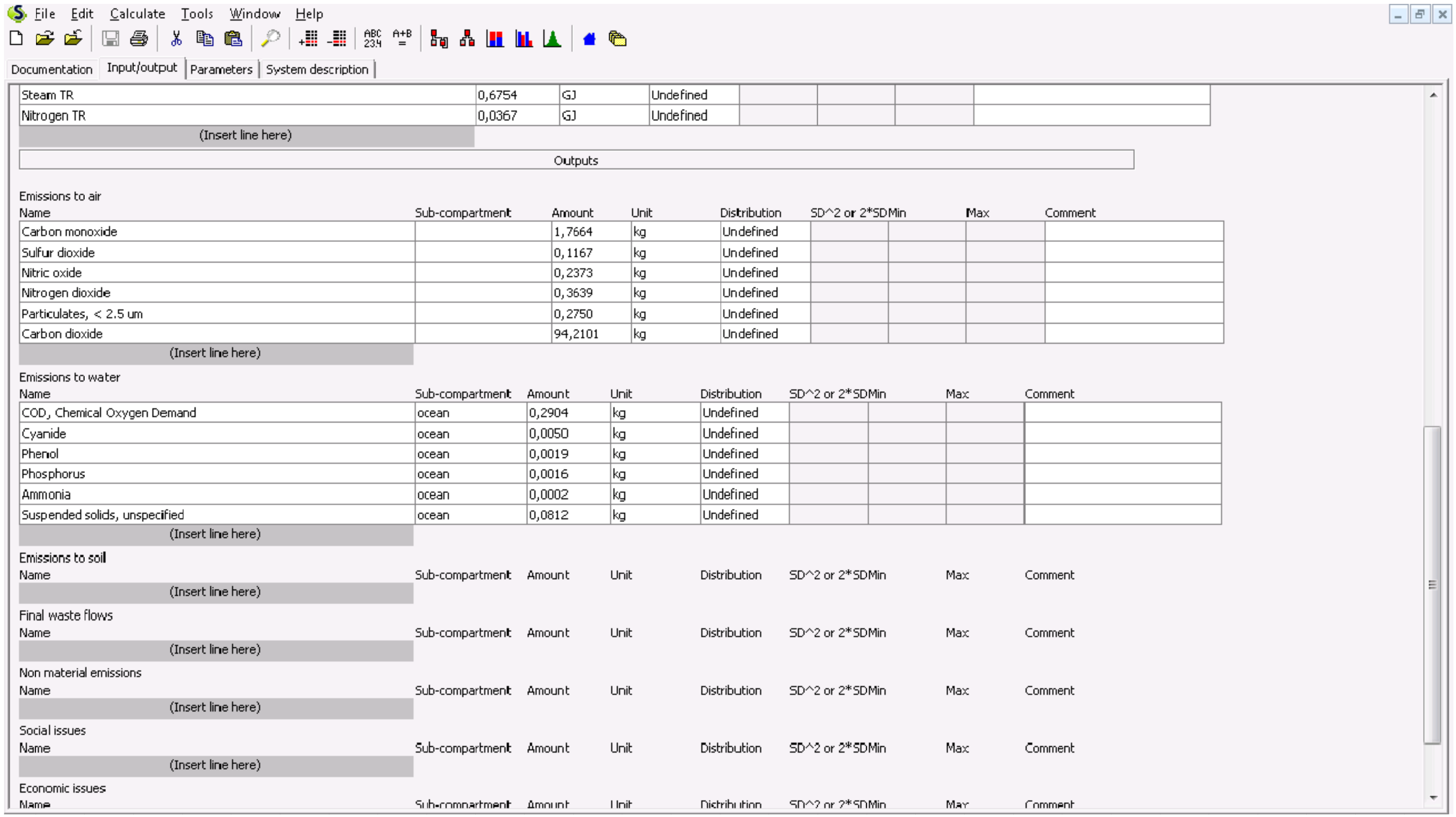



Figure 31. The screenshot of the coke making process in SimaPro - continued

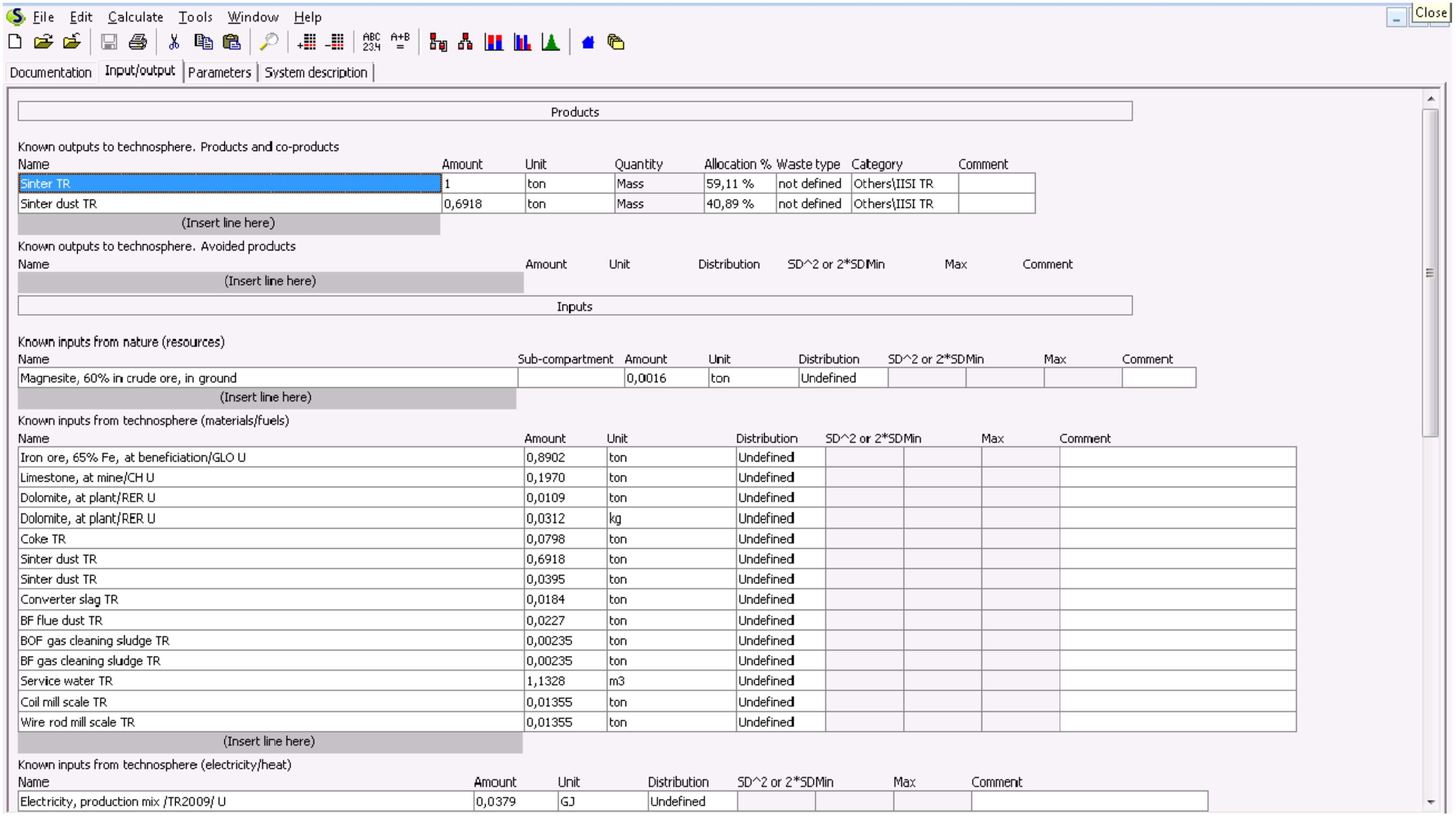



Figure 32. The screenshot of the sintering process in SimaPro

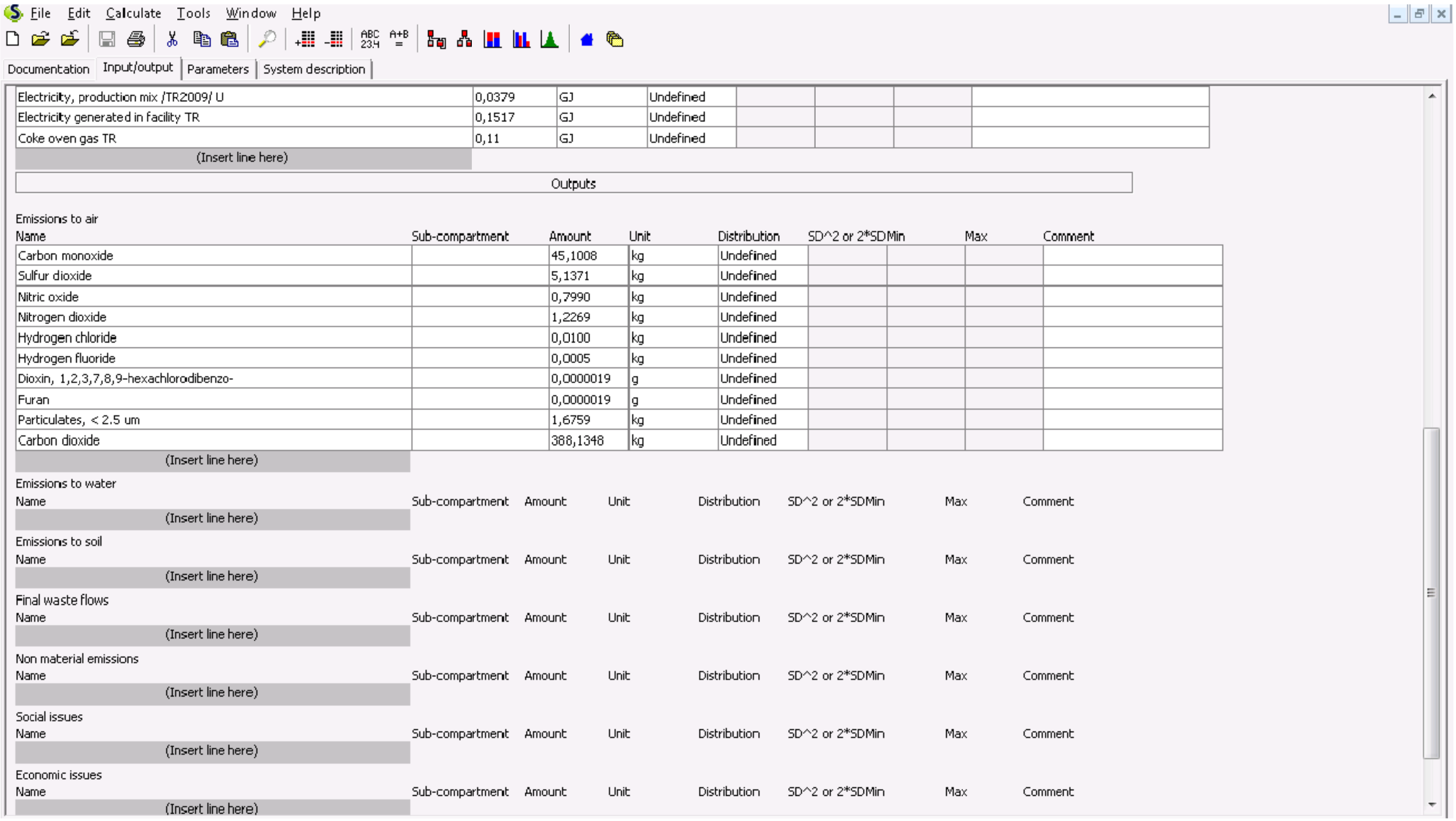



Figure 32. The screenshot of the sintering process in SimaPro - continued

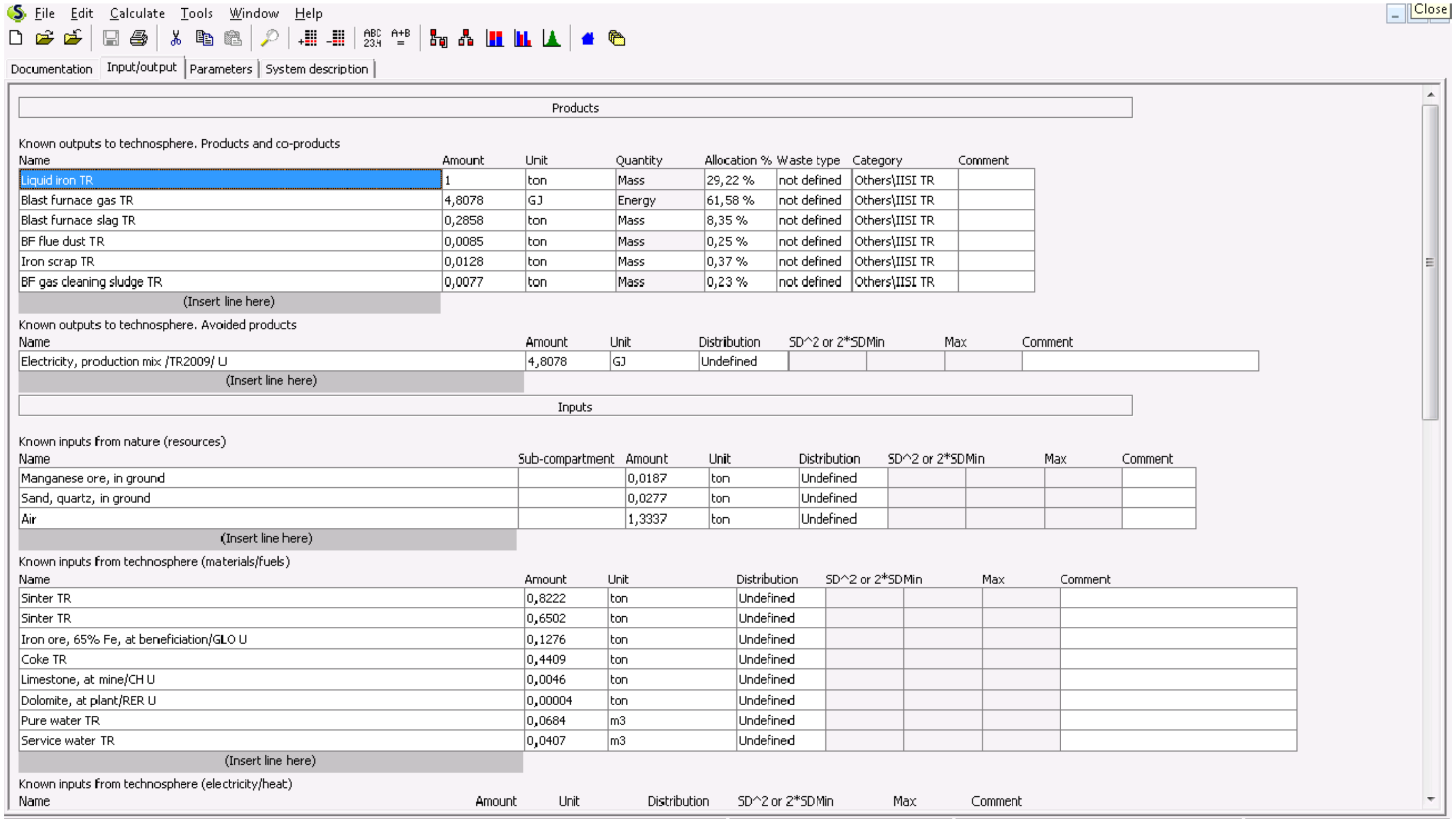



Figure 33. The screenshot of the blast furnace process in SimaPro

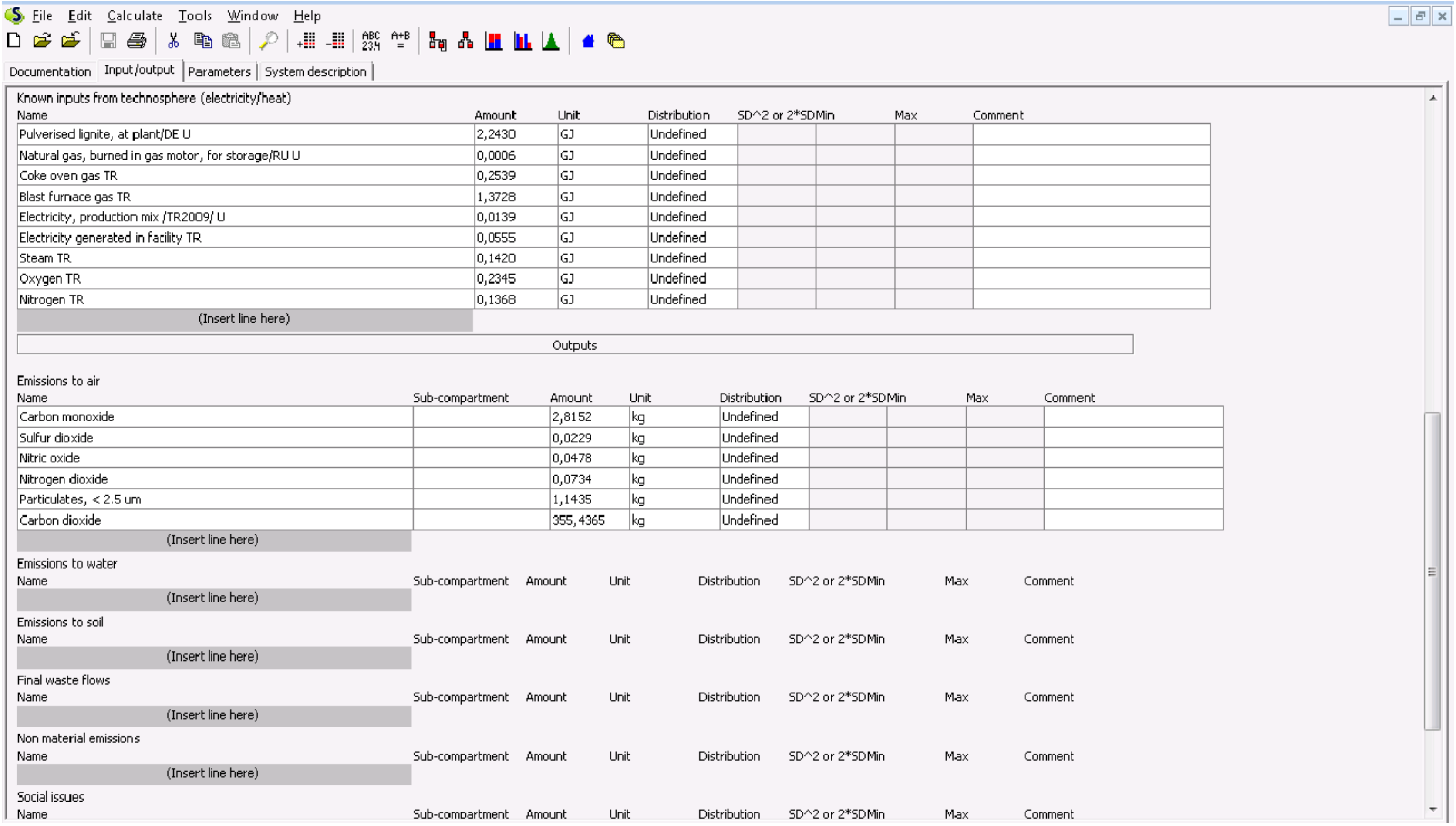



Figure 33. The screenshot of the blast furnace process in SimaPro - continued

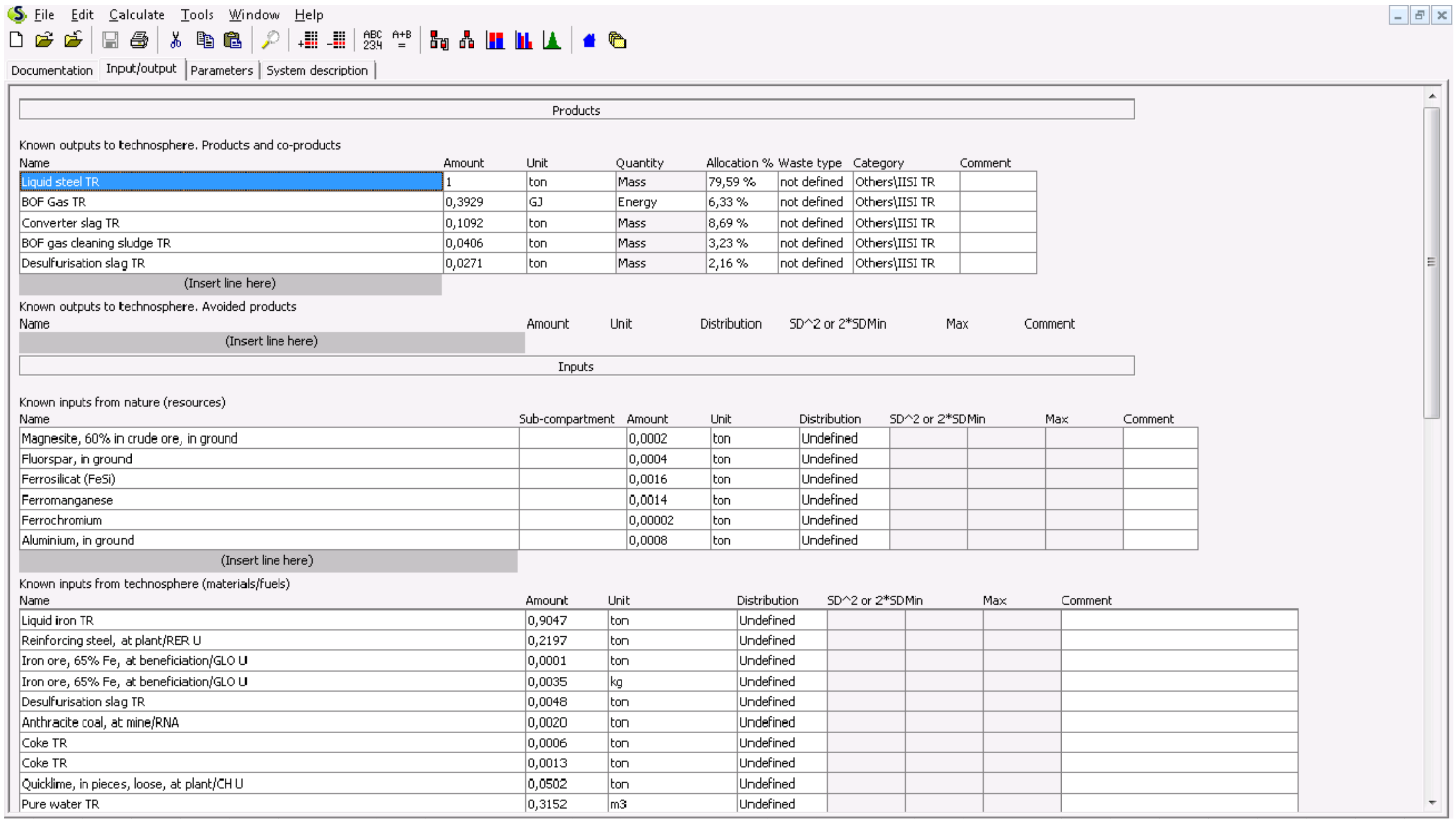



Figure 34. The screenshot of the basic oxygen furnace process in SimaPro

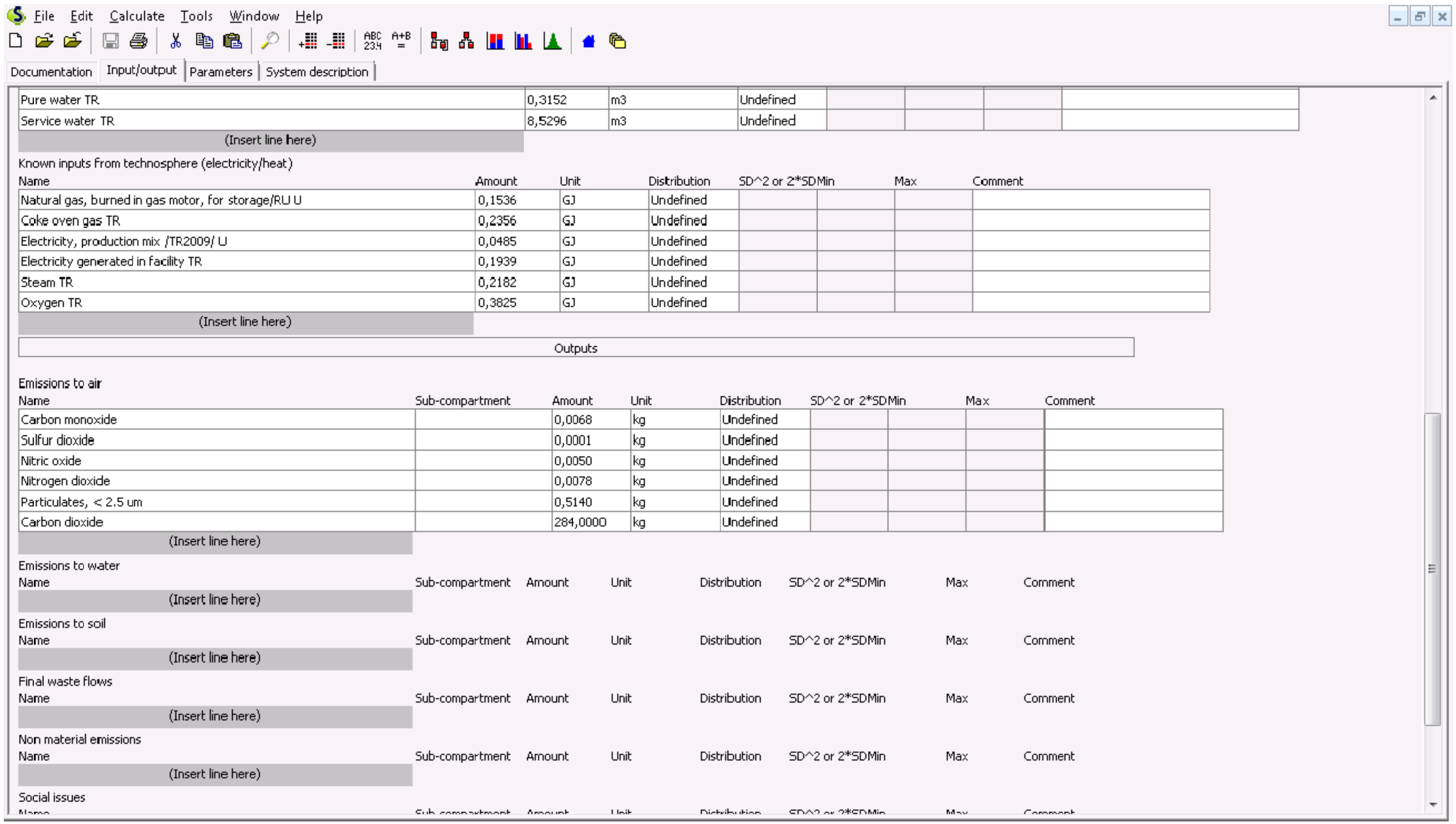



Figure 34. The screenshot of the basic oxygen furnace process in SimaPro - continued

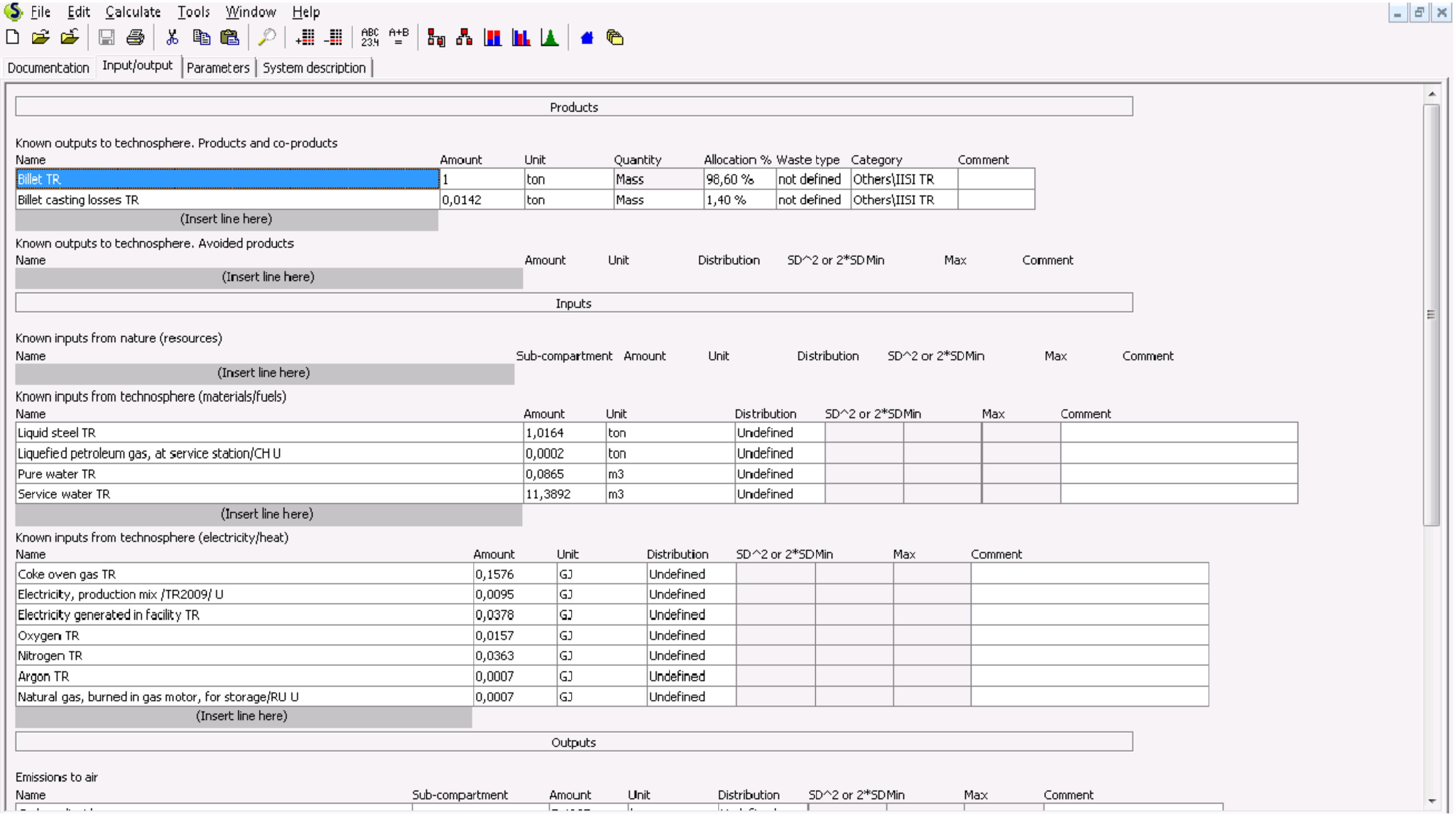



Figure 35. The screenshot of the billet casting process in SimaPro

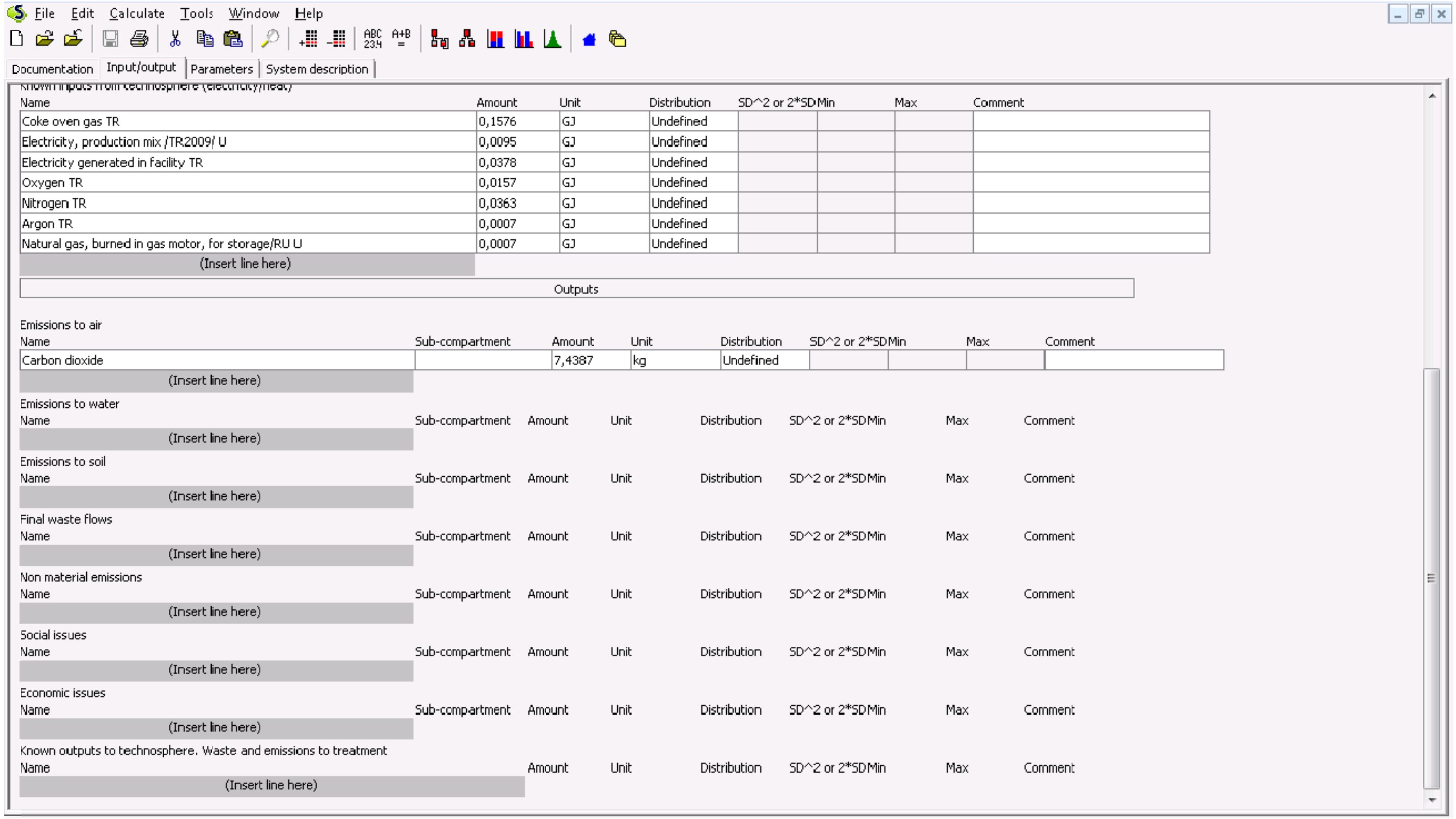
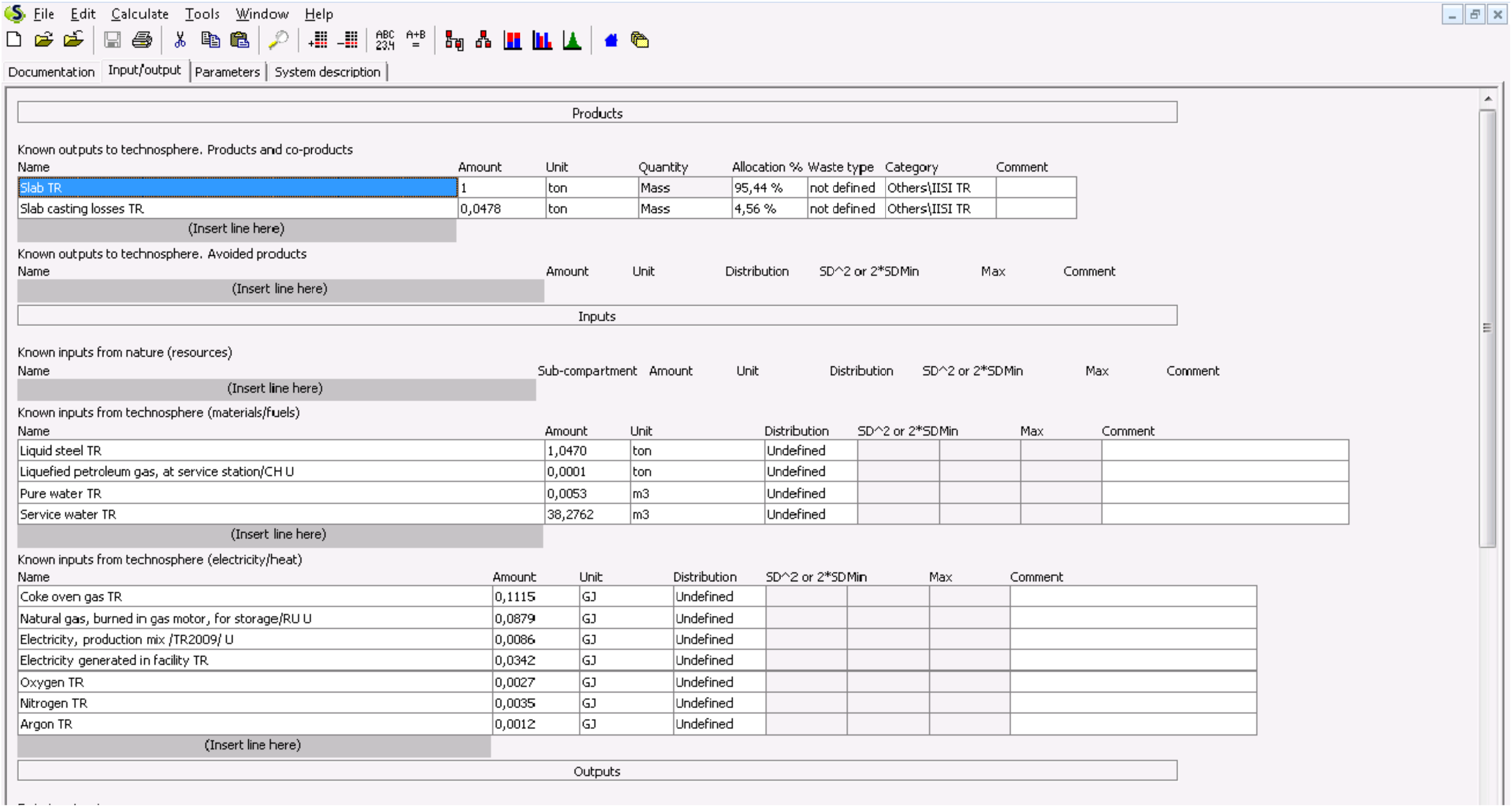



Figure 35. The screenshot of the billet casting process in SimaPro - continued



File Edit Calculate Tools Window Help

Documentation | Input/output | Parameters | System description

Products

Known outputs to technosphere. Products and co-products

| Name | Amount | Unit | Quantity | Allocation % | Waste type | Category | Comment |
|---|---|---|---|---|---|---|---|
| Slab TR | 1 | ton | Mass | 95,44 % | not defined | Others\IISI TR | |
| Slab casting losses TR | 0,0478 | ton | Mass | 4,56 % | not defined | Others\IISI TR | |
| (Insert line here) | | | | | | | |

Known outputs to technosphere. Avoided products

| Name | Amount | Unit | Distribution | SD^2 or 2*SDMin | Max | Comment |
|---|---|---|---|---|---|---|
| (Insert line here) | | | | | | |

Inputs

Known inputs from nature (resources)

| Name | Sub-compartment | Amount | Unit | Distribution | SD^2 or 2*SDMin | Max | Comment |
|---|---|---|---|---|---|---|---|
| (Insert line here) | | | | | | | |

Known inputs from technosphere (materials/fuels)

| Name | Amount | Unit | Distribution | SD^2 or 2*SDMin | Max | Comment |
|---|---|---|---|---|---|---|
| Liquid steel TR | 1,0470 | ton | Undefined | | | |
| Liquefied petroleum gas, at service station/CH U | 0,0001 | ton | Undefined | | | |
| Pure water TR | 0,0053 | m3 | Undefined | | | |
| Service water TR | 38,2762 | m3 | Undefined | | | |
| (Insert line here) | | | | | | |

Known inputs from technosphere (electricity/heat)

| Name | Amount | Unit | Distribution | SD^2 or 2*SDMin | Max | Comment |
|---|---|---|---|---|---|---|
| Coke oven gas TR | 0,1115 | GJ | Undefined | | | |
| Natural gas, burned in gas motor, for storage/RU U | 0,0879 | GJ | Undefined | | | |
| Electricity, production mix /TR2009/ U | 0,0086 | GJ | Undefined | | | |
| Electricity generated in facility TR | 0,0342 | GJ | Undefined | | | |
| Oxygen TR | 0,0027 | GJ | Undefined | | | |
| Nitrogen TR | 0,0035 | GJ | Undefined | | | |
| Argon TR | 0,0012 | GJ | Undefined | | | |
| (Insert line here) | | | | | | |

Outputs

Figure 36. The screenshot of the slab casting process in SimaPro

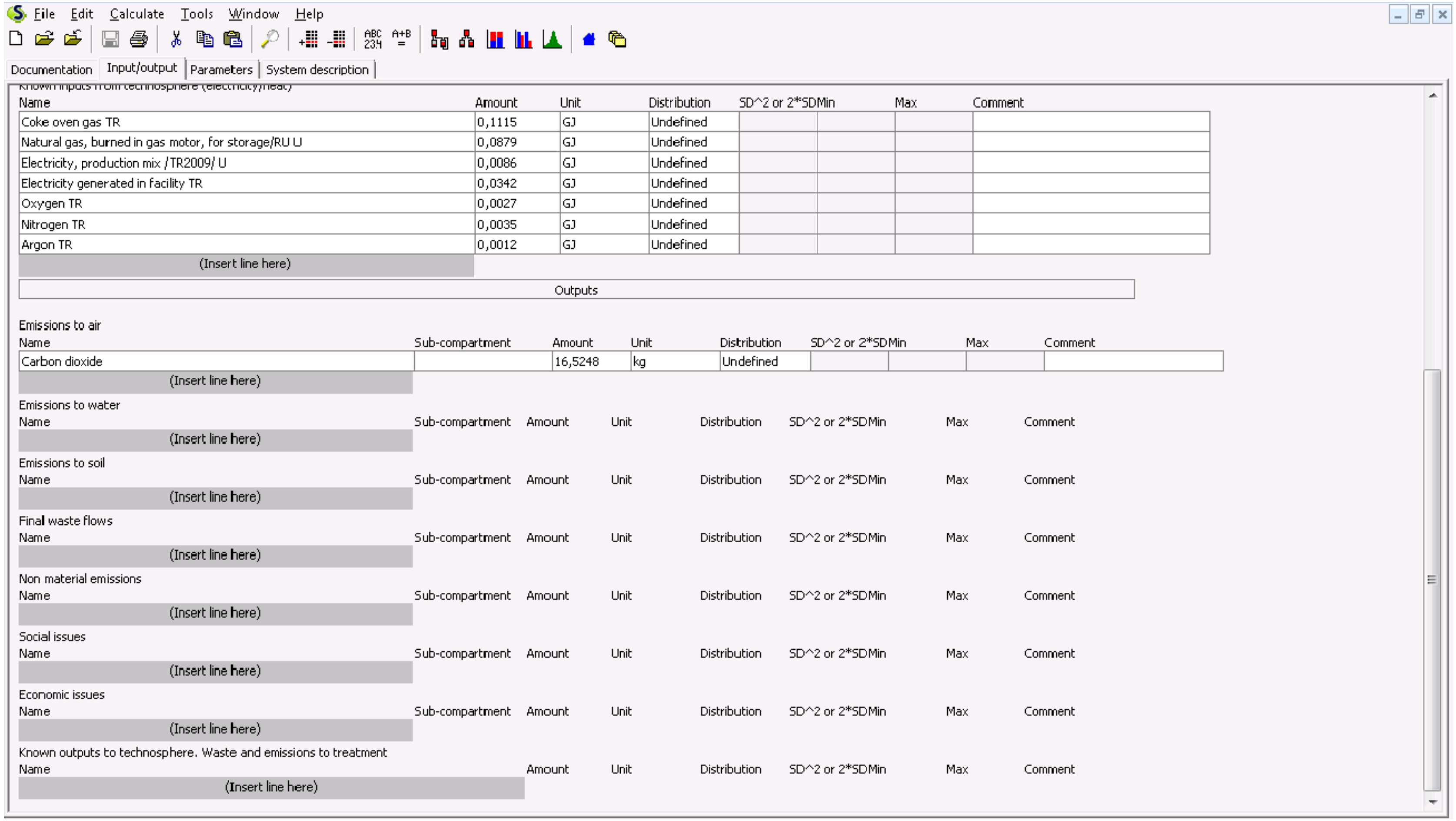



Figure 36. The screenshot of the slab casting process in SimaPro - continued

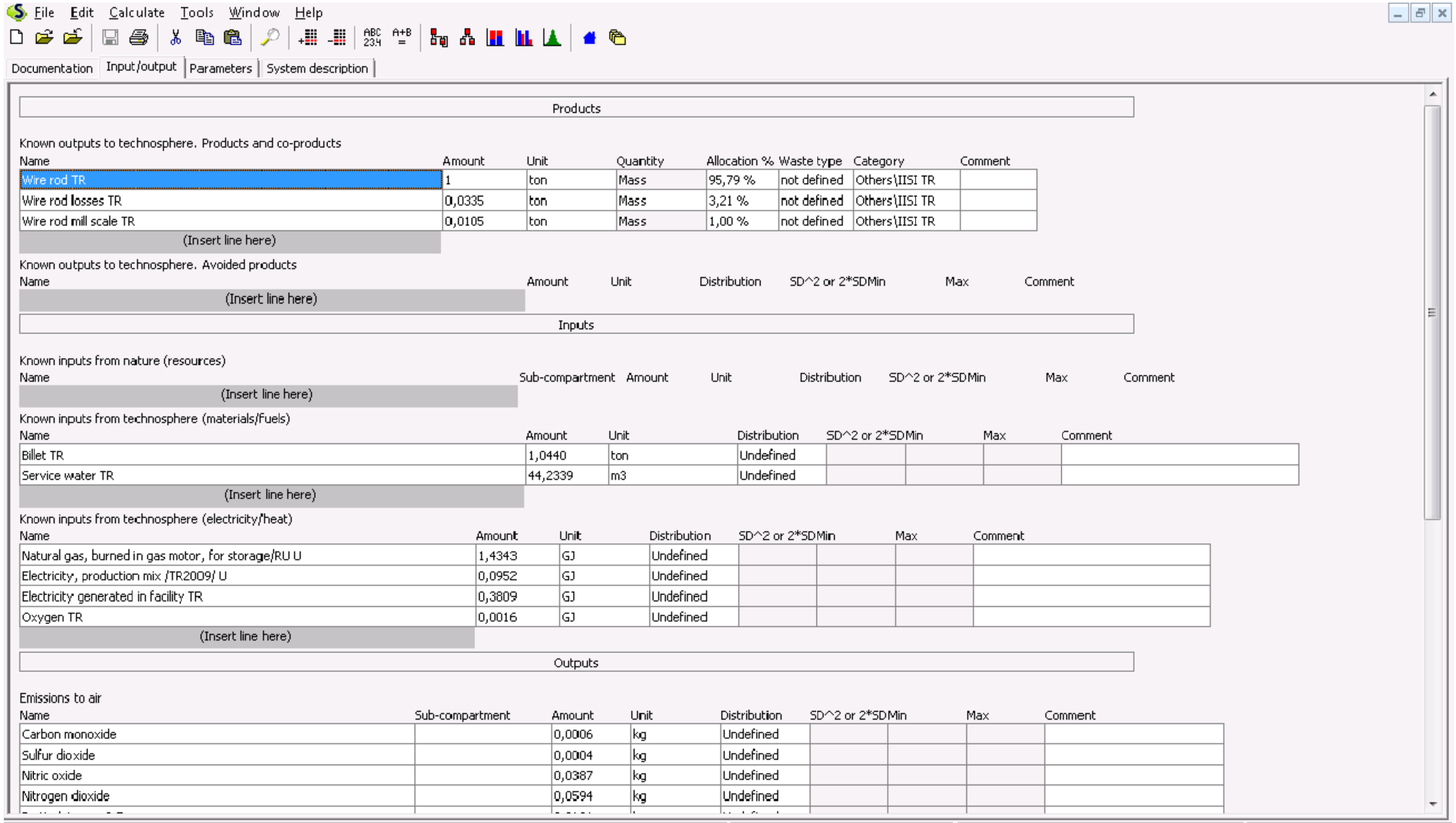



Figure 37. The screenshot of the wire rod hot rolling process in SimaPro

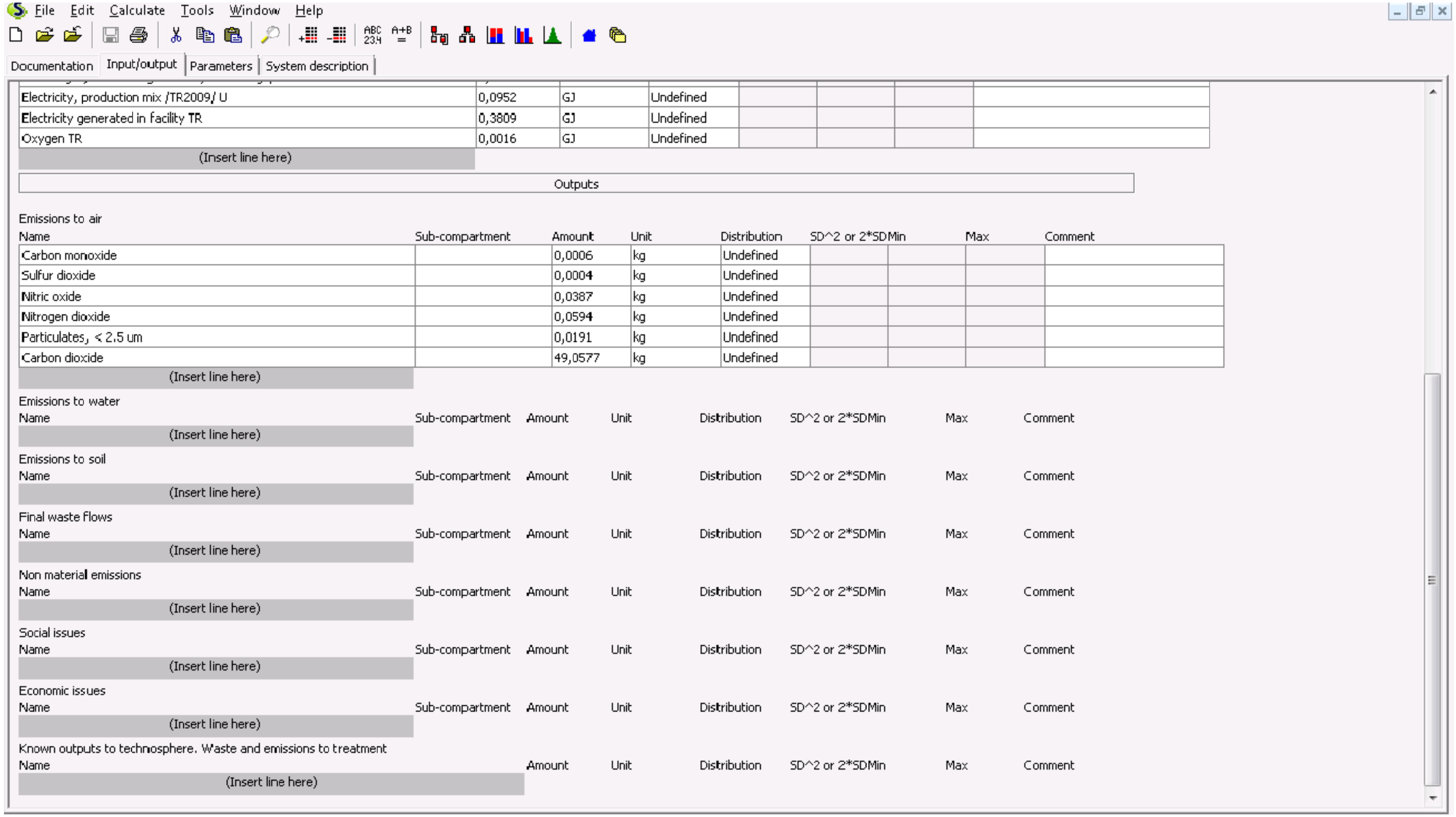



Figure 37. The screenshot of the wire rod hot rolling process in SimaPro - continued

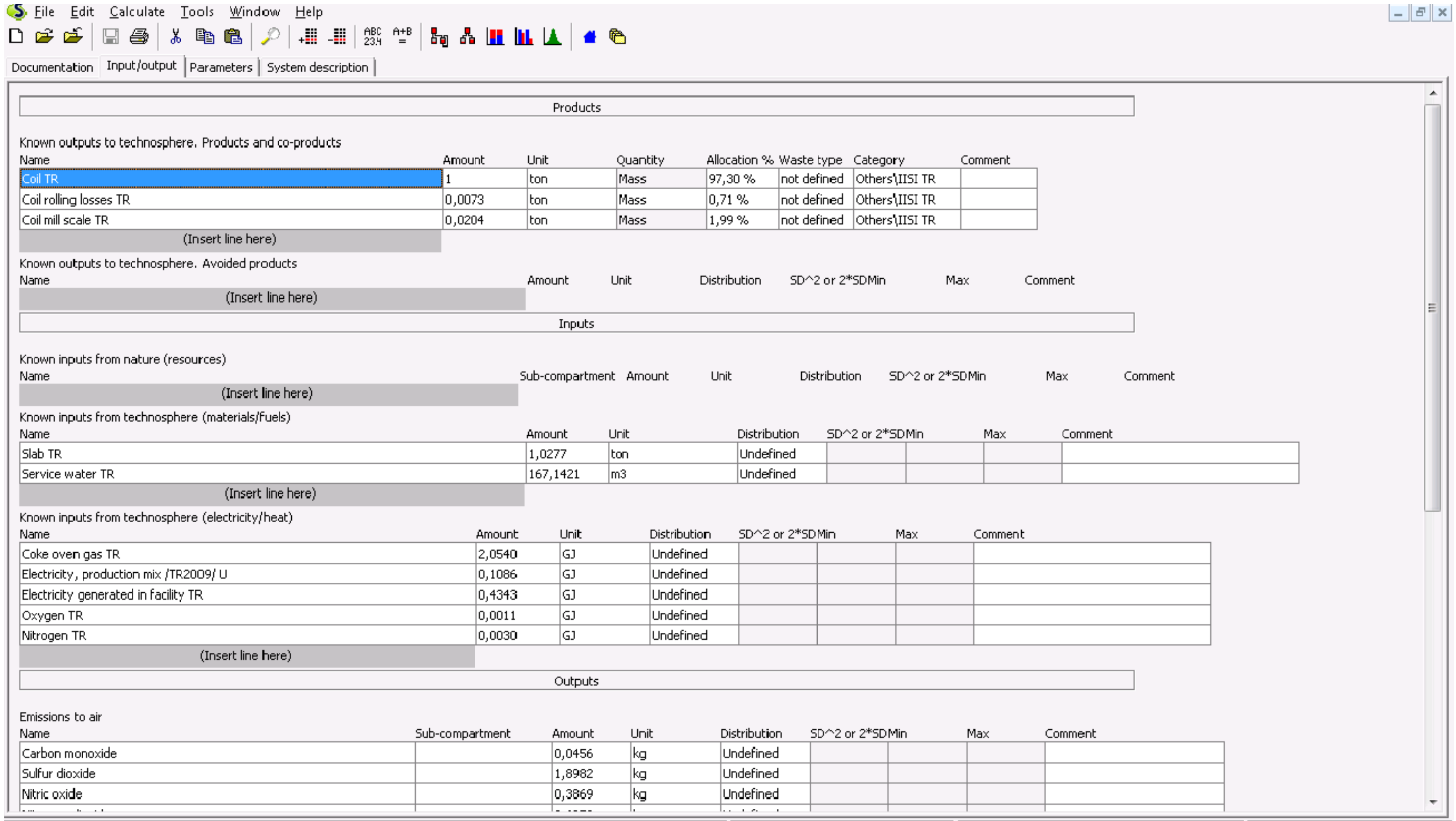



Figure 38. The screenshot of the coil hot rolling process in SimaPro

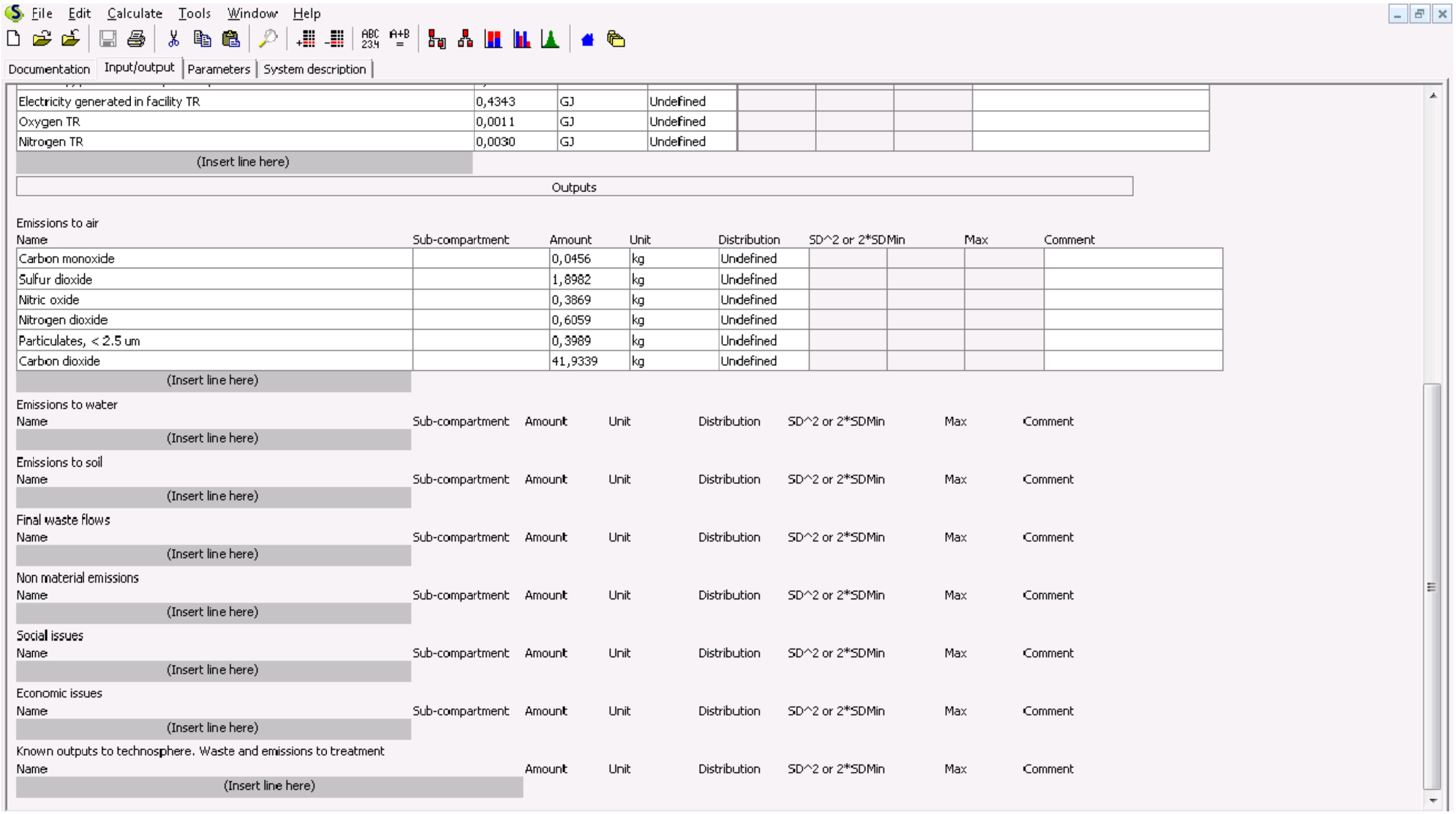



Figure 38. The screenshot of the coil hot rolling process in SimaPro - continued

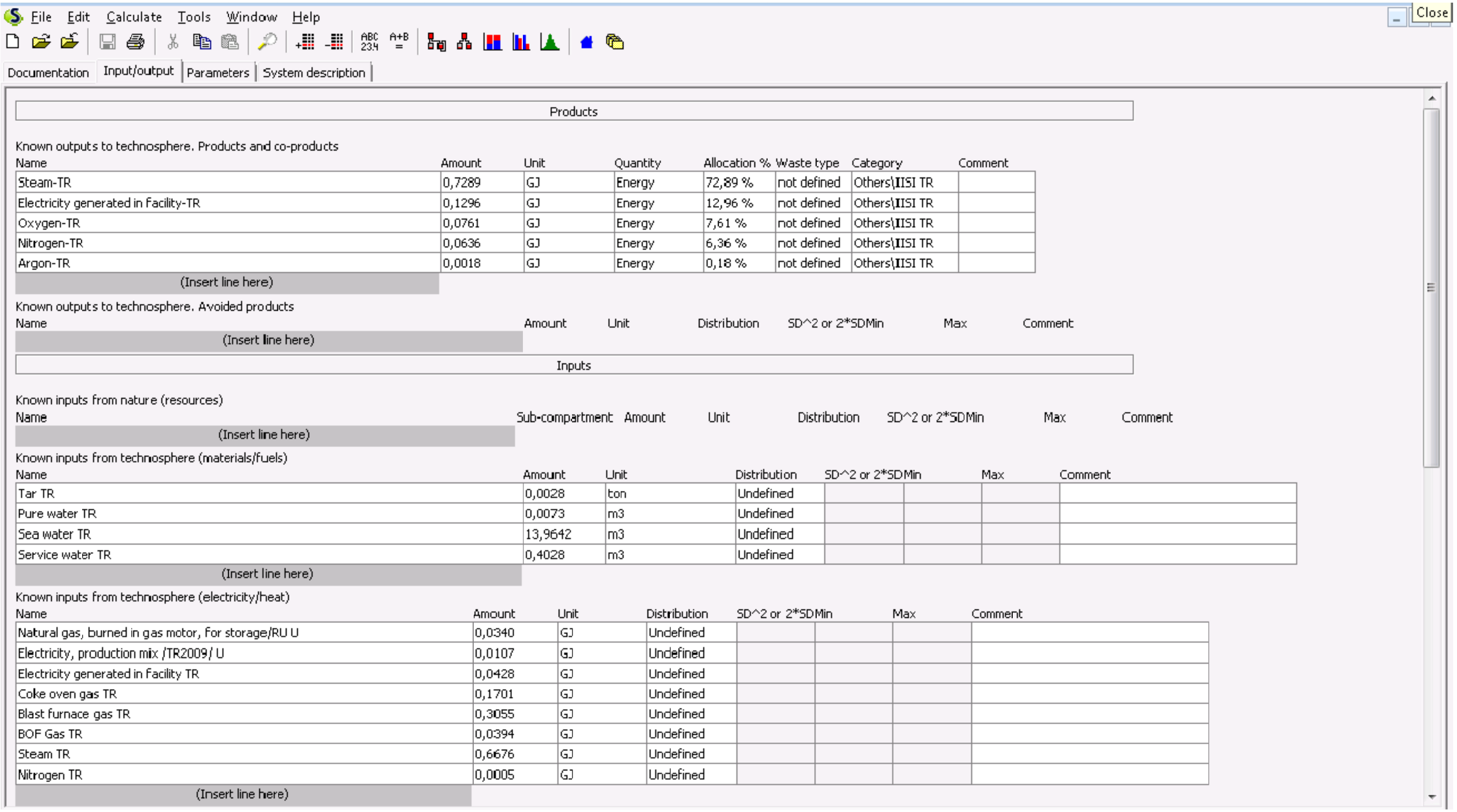



Figure 39. The screenshot of the energy facilities in SimaPro

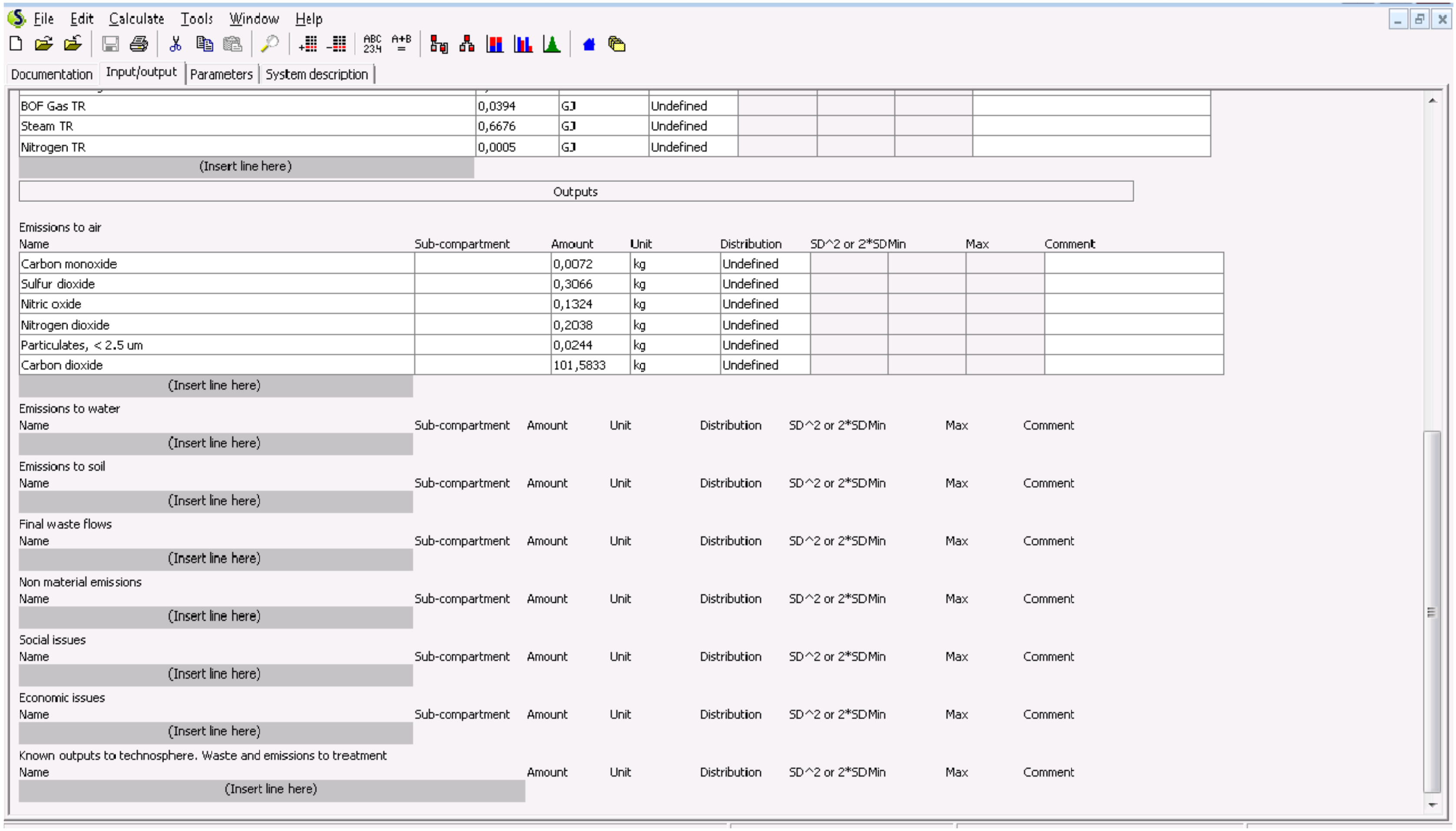



Figure 39. The screenshot of the energy facilities in SimaPro - continued

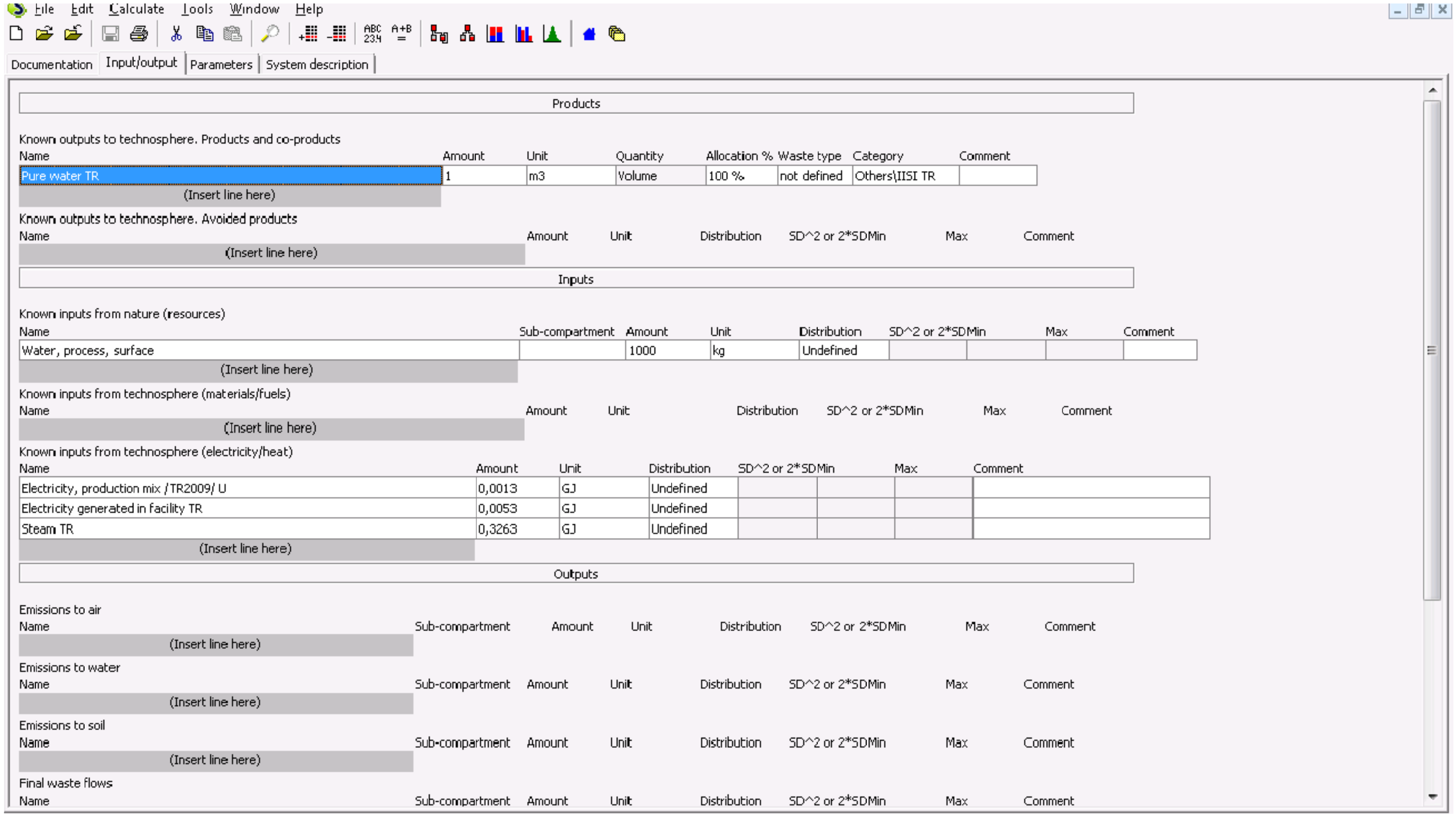



Figure 40. The screenshot of the pure water facility in SimaPro

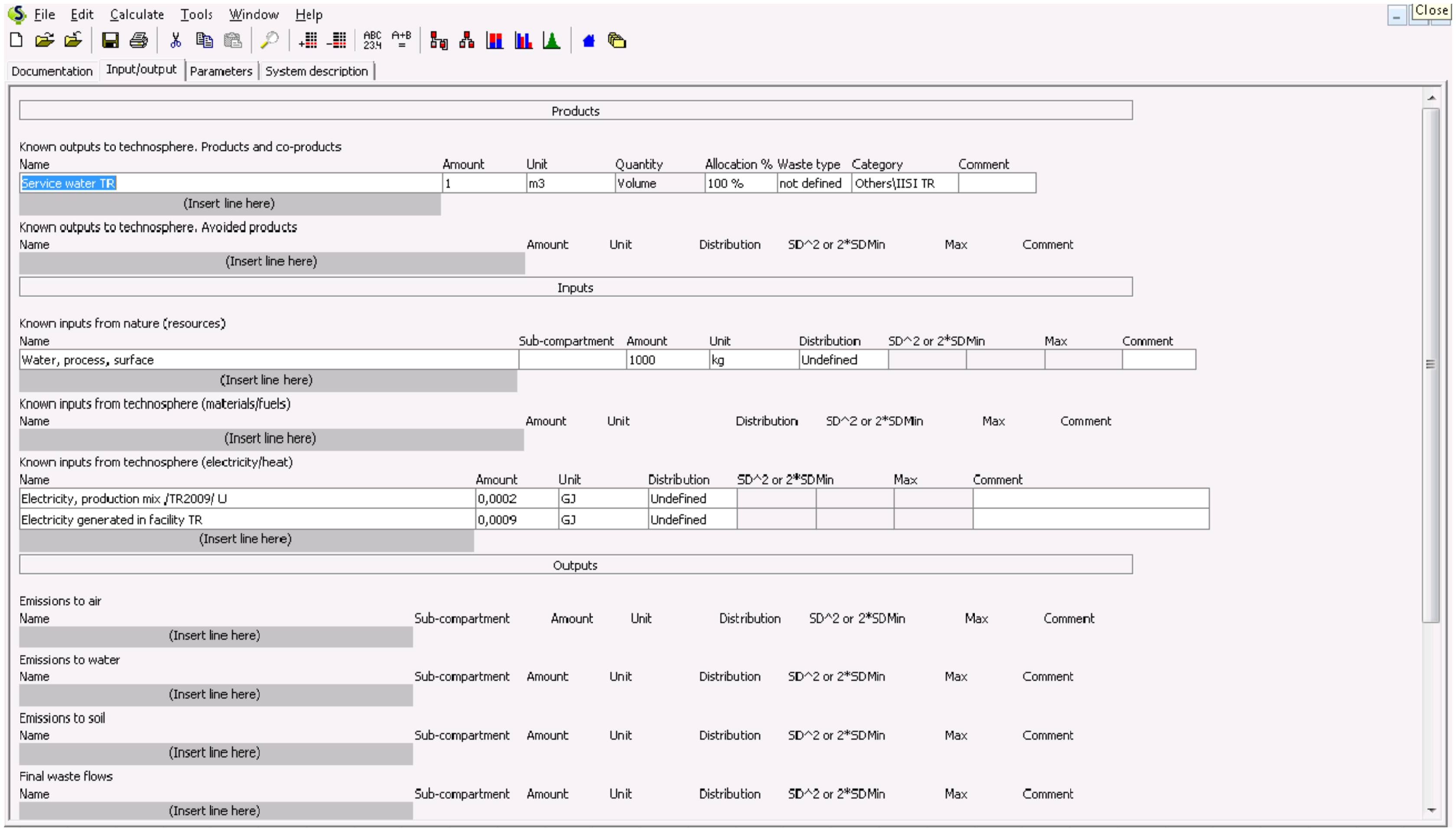



Figure 41. The screenshot of the service water facility in SimaPro

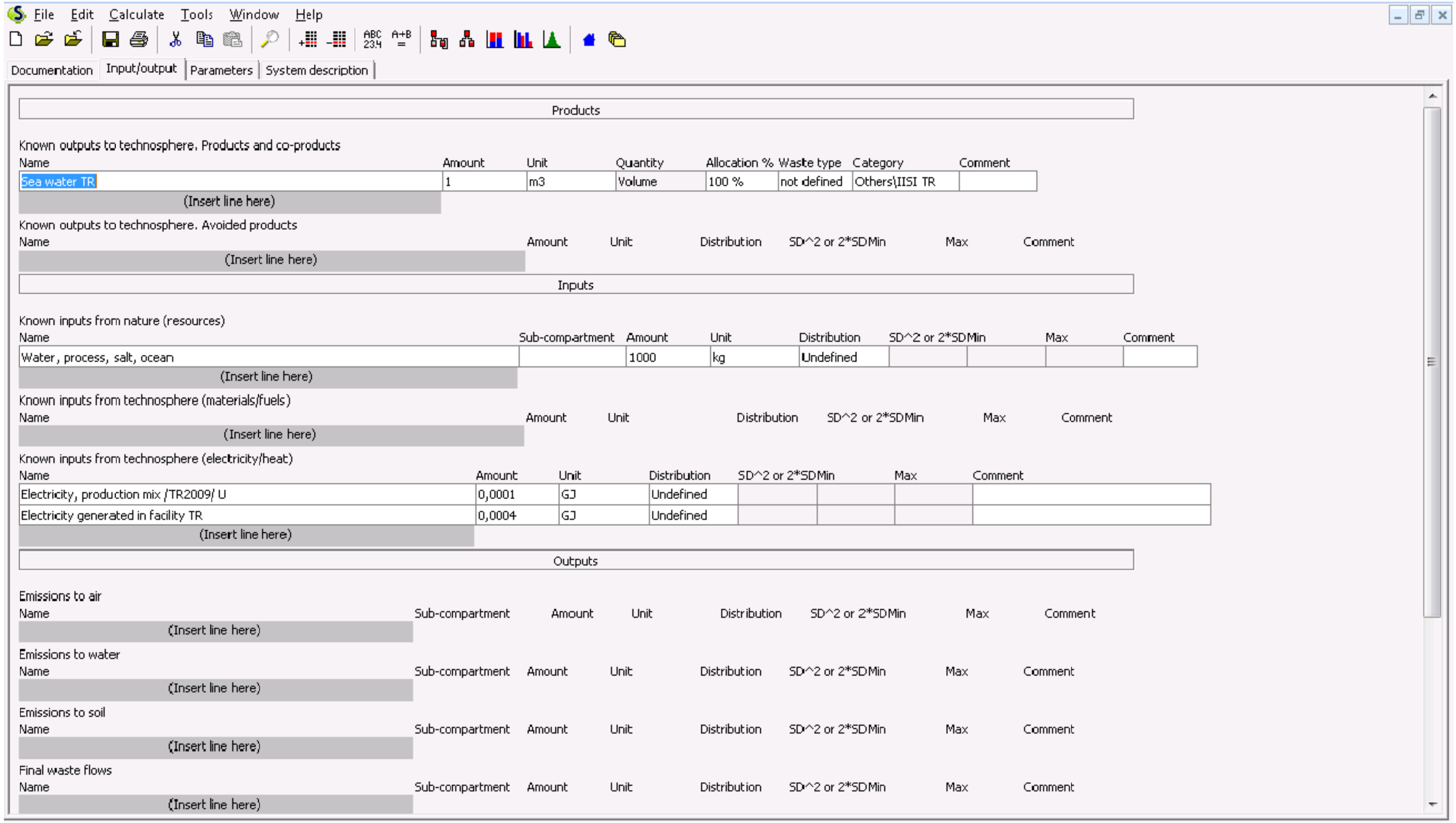



Figure 42. The screenshot of the sea water facility in SimaPro

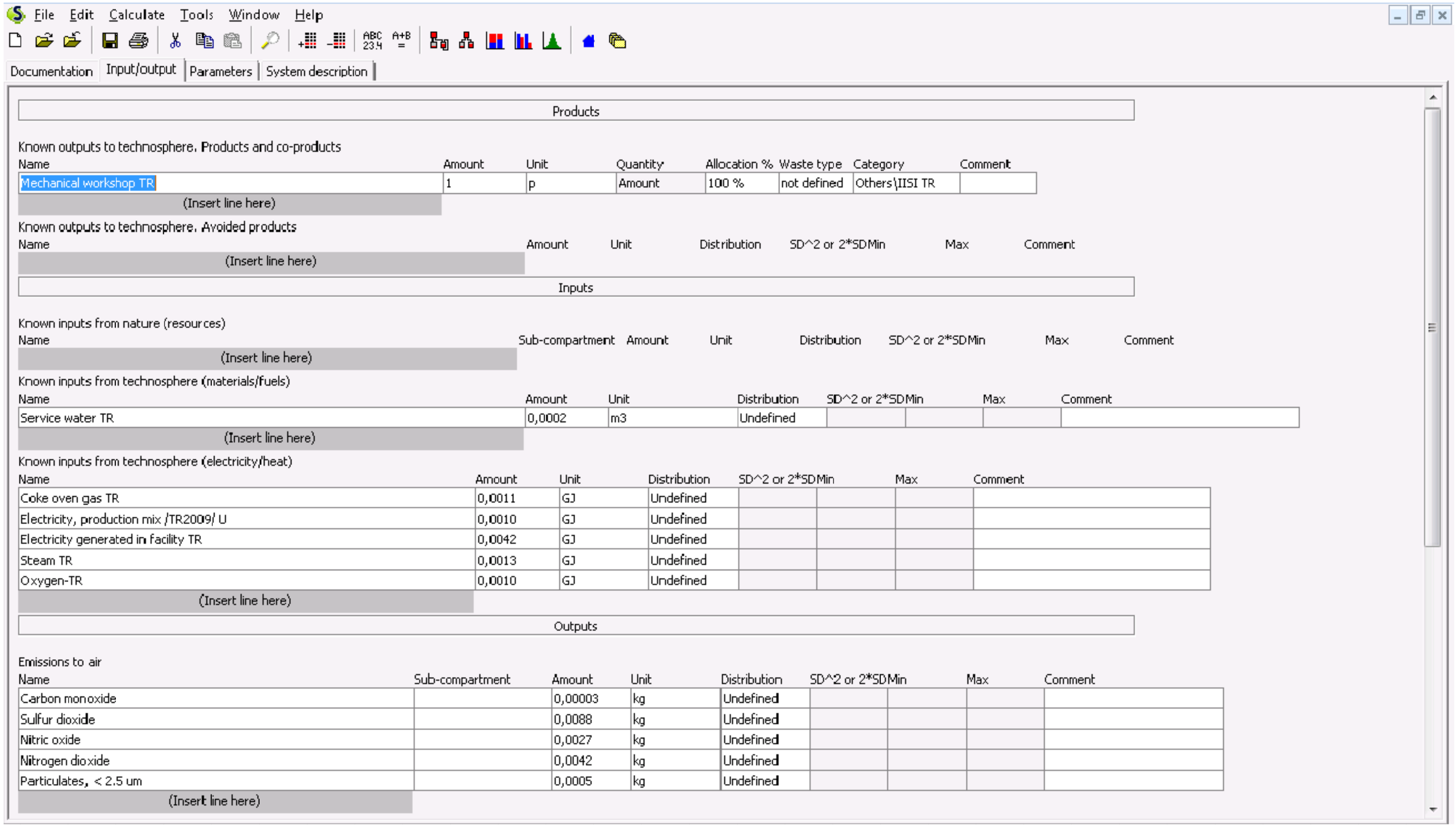



Figure 43. The screenshot of the mechanical workshop in SimaPro

# APPENDIX E

## A SAMPLE CALCULATION FOR HYDROCARBON (AIR) IN COKE MAKING PROCESS

Table 28. A sample calculation for hydrocarbon (air) in coke making process

| | Characterisation Factor | Unit | Damage Factor | Unit | Normalisation Factor | Unit |
|---|---|---|---|---|---|---|
| **Carcinogens** | 3,54E+03 | kg $C_2H_3Cl$ eq/kg | 2,80E-06 | DALY/kg $C_2H_3Cl$ eq | 141 | 1/DALY |
| **Non-carcinogens** | 5,29E-04 | kg $C_2H_3Cl$ eq/kg | 2,80E-06 | DALY/kg $C_2H_3Cl$ eq | | |
| **Respiratory Inorganics** | - | kg PM 2,5 eq/kg | 7,00E-04 | DALY/kg PM2,5 | | |
| **Ionizing Radiation** | - | Bq C-14eq/Bq | 2,10E-10 | DALY/Bq C-14 eq | | |
| **Ozone Layer Depletion** | - | kg CFC-14 eq/kg | 1,05E-03 | DALY/kg CFC-11 eq | | |
| **Respiratory Organics** | 9,86E-01 | kg $C_2H_4$ eq/kg | 2,13E-06 | DALY/kg $CH_4$ eq | | |
| | **Calculated Characterisation Amount** | **Unit** | **Calculated Damage Amount** | **Unit** | **Calculated Normalized Amount** | **Unit** |
| | **Inventory Amount (239,66515 mg) * Characterisation Factor** | | **Calculated Characterisation Amount * Damage Factor** | | **Calculated Damage Amount *** | |
| **Carcinogens** | 8,48E-01 | kg $C_2H_3Cl$ eq | 2,37E-06 | DALY | 3,35E-04 | Pt |
| **Non-carcinogens** | 1,27E-07 | kg $C_2H_3Cl$ eq | 3,55E-13 | DALY | 5,01E-11 | Pt |
| **Respiratory Inorganics** | - | kg PM 2,5 eq | - | DALY | - | Pt |
| **Ionizing Radiation** | - | Bq C-14eq | - | DALY | - | Pt |
| **Ozone Layer Depletion** | - | kg CFC-14 eq | - | DALY | - | Pt |
| **Respiratory Organics** | 2,36E-04 | kg $C_2H_4$ eq | 5,03E-10 | DALY | 7,10E-08 | Pt |

# APPENDIX F

## CALCULATION PROCEDURE OF PROCESS CONTRIBUTIONS TO TOTAL ENVIRONMENTAL IMPACT

Table 29. Calculation procedure of process contributions to total environmental impact

| **Process** | **Amount of product used for production of 1 ton of finished** | **Impact of 1 ton of product (Pt)** | **Allocation percentage of product** | **Total environmental impact of product** | |
|---|---|---|---|---|---|
| **Finished product** | A1 | B1 | C1 | A1*B1 | =D1 |
| **Semi-finished product** | A2 | B2 | C2 | A2*B2*C1 | =D2 |
| **Liquid steel** | A3 | B3 | C3 | A3*B3*C2*C1 | =D3 |
| **Liquid iron** | A4 | B4 | C4 | A4*B4*C3*C2*C1 | =D4 |
| **Sinter** | A5 | B5 | - | A5*B5*C4*C3*C2*C1 | =D5 |
| **Pellet** | A6 | B6 | - | A6*B6*C4*C3*C2*C1 | =D6 |
| **Coke** | A7 | B7 | - | A7*B7*C4*C3*C2*C1 | =D7 |
| | **Contributions of processes (Pt)** | | | | |
| **HR-other** | Impact of hot rolling minus that of casting | | | D1-D2 | |
| **C-other** | Impact of casting minus that of liquid steel | | | D2-D3 | |
| **LS-other** | Impact of liquid steel minus that of liquid iron | | | D3-D4 | |
| **LI-other** | Impact of liquid iron minus sinter, pellet and coke | | | D4-D5-D6-D7 | |
| **Sinter** | Impact of sinter | | | D5 | |
| **Pellet** | Impact of pellet | | | D6 | |
| **Coke** | Impact of coke | | | D7 | |

## APPENDIX G

## NORMALIZED IMPACT ASSESSMENT RESULTS PER MID-POINT AND END-POINT IMPACT CATEGORIES

Table 30. Normalized impact assessment results for 1 ton of coke

| End-point impact category | | | Mid-point impact category | | |
|---|---|---|---|---|---|
| | **Pt** | **%** | | **Pt** | **%** |
| **Human Health** | 1,46E-01 | 67,84 | **Carcinogens** | 3,62E-04 | 0,17 |
| | | | **Non-carcinogens** | 1,22E-04 | 0,06 |
| | | | **Respiratory inorganics** | 1,45E-01 | 67,60 |
| | | | **Ionizing radiation** | 7,44E-06 | 0,00 |
| | | | **Ozone layer depletion** | 7,46E-07 | 0,00 |
| | | | **Respiratory organics** | 1,45E-05 | 0,01 |
| **Ecosystem Quality** | 2,1E-02 | 9,75 | **Aquatic ecotoxicity** | 4,75E-04 | 0,22 |
| | | | **Terrestrial ecotoxicity** | 1,85E-02 | 8,58 |
| | | | **Terrestrial acid/nutri** | 1,98E-03 | 0,92 |
| | | | **Land occupation** | 5,29E-05 | 0,02 |
| | | | **Aquatic acidification** | 0,0E+00 | 0,00 |
| | | | **Aquatic eutrophication** | 0,0E+00 | 0,00 |
| **Climate Change** | -6,13E-02 | -28,48 | **Global warming** | -6,13E-02 | -28,48 |
| **Resources** | 1,09E-01 | 50,90 | **Non-renewable energy** | 1,09E-01 | 50,86 |
| | | | **Mineral extraction** | 8,51E-05 | 0,04 |
| **Total** | 2,15E-01 | 100,00 | **Total** | 2,15E-01 | 100,00 |

Table 31. Normalized impact assessment results for 1 ton of sinter

| End-point impact category | | | Mid-point impact category | | |
|---|---|---|---|---|---|
| | **Pt** | **%** | | **Pt** | **%** |
| **Human Health** | 3,51E-01 | 80,38 | **Carcinogens** | 6,11E-04 | 0,14 |
| | | | **Non-carcinogens** | 6,78E-04 | 0,16 |
| | | | **Respiratory inorganics** | 3,50E-01 | 80,08 |
| | | | **Ionizing radiation** | 1,38E-05 | 0,00 |
| | | | **Ozone layer depletion** | 3,21E-07 | 0,00 |
| | | | **Respiratory organics** | 9,97E-06 | 0,00 |

Table 31. Normalized impact assessment results for 1 ton of sinter - continued

| End-point impact category | | | Mid-point impact category | | |
|---|---|---|---|---|---|
| | **Pt** | **%** | | **Pt** | **%** |
| **Ecosystem Quality** | 1,06E-02 | 2,42 | **Aquatic ecotoxicity** | 2,35E-04 | 0,05 |
| | | | **Terrestrial ecotoxicity** | 8,09E-03 | 1,85 |
| | | | **Terrestrial acid/nutri** | 2,24E-03 | 0,51 |
| | | | **Land occupation** | 9,74E-06 | 0,00 |
| | | | **Aquatic acidification** | 0,00E+00 | 0,00 |
| | | | **Aquatic eutrophication** | 0,00E+00 | 0,00 |
| **Climate Change** | 5,87E-02 | 13,44 | **Global warming** | 5,87E-02 | 13,44 |
| **Resources** | 1,65E-02 | 3,77 | **Non-renewable energy** | 1,62E-02 | 3,70 |
| | | | **Mineral extraction** | 2,92E-04 | 0,07 |
| **Total** | 4,37E-01 | 100,00 | **Total** | 4,37E-01 | 100,00 |

Table 32. Normalized impact assessment results for 1 ton of liquid iron

| End-point impact category | | | Mid-point impact category | | |
|---|---|---|---|---|---|
| | **Pt** | **%** | | **Pt** | **%** |
| **Human Health** | 2,70E-01 | 89,74 | **Carcinogens** | 3,88E-04 | 0,13 |
| | | | **Non-carcinogens** | 3,02E-04 | 0,10 |
| | | | **Respiratory inorganics** | 2,69E-01 | 89,51 |
| | | | **Ionizing radiation** | 2,63E-06 | 0,00 |
| | | | **Ozone layer depletion** | -3,30E-07 | 0,00 |
| | | | **Respiratory organics** | -1,06E-06 | 0,00 |
| **Ecosystem Quality** | 1,00E-02 | 3,33 | **Aquatic ecotoxicity** | 2,28E-04 | 0,08 |
| | | | **Terrestrial ecotoxicity** | 8,14E-03 | 2,71 |
| | | | **Terrestrial acid/nutri** | 1,64E-03 | 0,55 |
| | | | **Land occupation** | 1,46E-05 | 0,00 |
| | | | **Aquatic acidification** | 0,00E+00 | 0,00 |
| | | | **Aquatic eutrophication** | 0,00E+00 | 0,00 |
| **Climate Change** | 1,35E-02 | 4,50 | **Global warming** | 1,35E-02 | 4,50 |
| **Resources** | 7,30E-03 | 2,43 | **Non-renewable energy** | 7,09E-03 | 2,36 |
| | | | **Mineral extraction** | 2,07E-04 | 0,07 |
| **Total** | 3,00E-01 | 100,00 | **Total** | 3,00E-01 | 100,00 |

Table 33. Normalized impact assessment results for 1 ton of liquid steel

| End-point impact category | | | Mid-point impact category | | |
|---|---|---|---|---|---|
| | **Pt** | **%** | | **Pt** | **%** |
| **Human Health** | 4,10E-01 | 72,93 | **Carcinogens** | 8,86E-03 | 1,58 |
| | | | **Non-carcinogens** | 6,40E-03 | 1,14 |
| | | | **Respiratory inorganics** | 3,94E-01 | 70,20 |
| | | | **Ionizing radiation** | 4,99E-05 | 0,01 |
| | | | **Ozone layer depletion** | 1,59E-06 | 0,00 |
| | | | **Respiratory organics** | 2,78E-05 | 0,00 |
| **Ecosystem Quality** | 1,57E-02 | 2,80 | **Aquatic ecotoxicity** | 3,43E-04 | 0,06 |
| | | | **Terrestrial ecotoxicity** | 1,27E-02 | 2,27 |
| | | | **Terrestrial acid/nutri** | 2,63E-03 | 0,47 |
| | | | **Land occupation** | 3,18E-05 | 0,01 |
| | | | **Aquatic acidification** | 0,00E+00 | 0,00 |
| | | | **Aquatic eutrophication** | 0,00E+00 | 0,00 |
| **Climate Change** | 9,49E-02 | 16,90 | **Global warming** | 9,49E-02 | 16,90 |
| **Resources** | 4,14E-02 | 7,36 | **Non-renewable energy** | 4,09E-02 | 7,29 |
| | | | **Mineral extraction** | 4,23E-04 | 0,08 |
| **Total** | 5,62E-01 | 100,00 | **Total** | 5,62E-01 | 100,00 |

Table 34. Normalized impact assessment results for 1 ton of billet

| End-point impact category | | | Mid-point impact category | | |
|---|---|---|---|---|---|
| | **Pt** | **%** | | **Pt** | **%** |
| **Human Health** | 4,35E-01 | 72,89 | **Carcinogens** | 8,93E-03 | 1,50 |
| | | | **Non-carcinogens** | 6,46E-03 | 1,08 |
| | | | **Respiratory inorganics** | 4,19E-01 | 70,30 |
| | | | **Ionizing radiation** | 5,05E-05 | 0,01 |
| | | | **Ozone layer depletion** | 1,61E-06 | 0,00 |
| | | | **Respiratory organics** | 2,83E-05 | 0,00 |
| **Ecosystem Quality** | 1,67E-02 | 2,80 | **Aquatic ecotoxicity** | 3,62E-04 | 0,06 |
| | | | **Terrestrial ecotoxicity** | 1,34E-02 | 2,25 |
| | | | **Terrestrial acid/nutri** | 2,85E-03 | 0,48 |
| | | | **Land occupation** | 3,33E-05 | 0,01 |
| | | | **Aquatic acidification** | 0,00E+00 | 0,00 |
| | | | **Aquatic eutrophication** | 0,00E+00 | 0,00 |
| **Climate Change** | 1,02E-01 | 17,04 | **Global warming** | 1,02E-01 | 17,04 |
| **Resources** | 4,33E-02 | 7,27 | **Non-renewable energy** | 4,29E-02 | 7,19 |
| | | | **Mineral extraction** | 4,39E-04 | 0,07 |
| **Total** | 5,97E-01 | 100,00 | **Total** | 5,97E-01 | 100,00 |

Table 35. Normalized impact assessment results for 1 ton of slab

| End-point impact category | | | Mid-point impact category | | |
|---|---|---|---|---|---|
| | Pt | % | | Pt | % |
| **Human Health** | 4,24E-01 | 72,59 | **Carcinogens** | 8,88E-03 | 1,52 |
| | | | **Non-carcinogens** | 6,42E-03 | 1,10 |
| | | | **Respiratory inorganics** | 4,08E-01 | 69,96 |
| | | | **Ionizing radiation** | 5,02E-05 | 0,01 |
| | | | **Ozone layer depletion** | 1,60E-06 | 0,00 |
| | | | **Respiratory organics** | 2,87E-05 | 0,00 |
| **Ecosystem Quality** | 1,63E-02 | 2,79 | **Aquatic ecotoxicity** | 3,54E-04 | 0,06 |
| | | | **Terrestrial ecotoxicity** | 1,31E-02 | 2,25 |
| | | | **Terrestrial acid/nutri** | 2,75E-03 | 0,47 |
| | | | **Land occupation** | 3,26E-05 | 0,01 |
| | | | **Aquatic acidification** | 0,00E+00 | 0,00 |
| | | | **Aquatic eutrophication** | 0,00E+00 | 0,00 |
| **Climate Change** | 1,00E-01 | 17,21 | **Global warming** | 1,00E-01 | 17,21 |
| **Resources** | 4,32E-02 | 7,41 | **Non-renewable energy** | 4,28E-02 | 7,34 |
| | | | **Mineral extraction** | 4,31E-04 | 0,07 |
| **Total** | 5,84E-01 | 100,00 | **Total** | 5,84E-01 | 100,00 |

Table 36. Normalized impact assessment results for 1 ton of wire rod

| End-point impact category | | | Mid-point impact category | | |
|---|---|---|---|---|---|
| | Pt | % | | Pt | % |
| **Human Health** | 5,15E-01 | 70,72 | **Carcinogens** | 9,12E-03 | 1,25 |
| | | | **Non-carcinogens** | 6,60E-03 | 0,91 |
| | | | **Respiratory inorganics** | 4,99E-01 | 68,55 |
| | | | **Ionizing radiation** | 5,22E-05 | 0,01 |
| | | | **Ozone layer depletion** | 1,61E-06 | 0,00 |
| | | | **Respiratory organics** | 3,91E-05 | 0,01 |
| **Ecosystem Quality** | 1,94E-02 | 2,66 | **Aquatic ecotoxicity** | 4,15E-04 | 0,06 |
| | | | **Terrestrial ecotoxicity** | 1,54E-02 | 2,11 |
| | | | **Terrestrial acid/nutri** | 3,58E-03 | 0,49 |
| | | | **Land occupation** | 3,71E-05 | 0,01 |
| | | | **Aquatic acidification** | 0,00E+00 | 0,00 |
| | | | **Aquatic eutrophication** | 0,00E+00 | 0,00 |
| **Climate Change** | 1,35E-01 | 18,51 | **Global warming** | 1,35E-01 | 18,51 |
| **Resources** | 5,91E-02 | 8,11 | **Non-renewable energy** | 5,86E-02 | 8,04 |
| | | | **Mineral extraction** | 4,84E-04 | 0,07 |
| **Total** | 7,29E-01 | 100,00 | **Total** | 7,29E-01 | 100,00 |

Table 37. Normalized impact assessment results for 1 ton of coil

| End-point impact category | | | Mid-point impact category | | |
|---|---|---|---|---|---|
| | **Pt** | **%** | | **Pt** | **%** |
| **Human Health** | 6,06E-01 | 74,42 | **Carcinogens** | 9,16E-03 | 1,12 |
| | | | **Non-carcinogens** | 6,63E-03 | 0,81 |
| | | | **Respiratory inorganics** | 5,90E-01 | 72,47 |
| | | | **Ionizing radiation** | 5,29E-05 | 0,01 |
| | | | **Ozone layer depletion** | 1,64E-06 | 0,00 |
| | | | **Respiratory organics** | 3,12E-05 | 0,00 |
| **Ecosystem Quality** | 2,18E-02 | 2,67 | **Aquatic ecotoxicity** | 4,54E-04 | 0,06 |
| | | | **Terrestrial ecotoxicity** | 1,68E-02 | 2,07 |
| | | | **Terrestrial acid/nutri** | 4,42E-03 | 0,54 |
| | | | **Land occupation** | 4,08E-05 | 0,01 |
| | | | **Aquatic acidification** | 0,00E+00 | 0,00 |
| | | | **Aquatic eutrophication** | 0,00E+00 | 0,00 |
| **Climate Change** | 1,30E-01 | 15,97 | **Global warming** | 1,30E-01 | 15,97 |
| **Resources** | 5,66E-02 | 6,95 | **Non-renewable energy** | 5,61E-02 | 6,89 |
| | | | **Mineral extraction** | 5,00E-04 | 0,06 |
| **Total** | 8,15E-01 | 100 | **Total** | 8,15E-01 | 100,00 |

# APPENDIX H

## CONTRIBUTION OF INPUTS AND OUTPUTS TO END-POINT IMPACT CATEGORIES

Table 38. Contribution of inputs and outputs to end-point impact categories for 1 ton of coke production

| Inputs/Outputs | Human Health | | Ecosystem Quality | | Climate Change | | Resources | | Single Score | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Pt | % | Pt | % | Pt | % | Pt | % | Pt | % |
| **Emission contribution** | 2,96E-02 | 20,37 | 2,48E-04 | 1,19 | 7,77E-03 | -12,83 | 0,00E+00 | 0,00 | 3,76E-02 | 17,58 |
| **Electricity, production mix /TR2009/ U** | -7,45E-02 | -51,28 | -1,71E-03 | -8,19 | -1,15E-01 | 189,87 | -1,01E-01 | -93,21 | -2,92E-01 | -136,58 |
| **Natural gas, burned in gas motor, for storage/RU U** | 3,51E-07 | 0,00 | 5,92E-09 | 0,00 | 2,35E-06 | 0,00 | 2,99E-06 | 0,00 | 5,70E-06 | 0,00 |
| **Sodium hydroxide, 50% in H2O, production mix, at plant/RER U** | 8,71E-05 | 0,06 | 8,60E-06 | 0,04 | 1,17E-04 | -0,19 | 1,56E-04 | 0,14 | 3,69E-04 | 0,17 |
| **Fusi TR** | 1,02E-04 | 0,07 | 1,47E-05 | 0,07 | -4,29E-05 | 0,07 | 7,66E-05 | 0,07 | 1,50E-04 | 0,07 |
| **Electricity, production mix /TR2009/** | 1,82E-04 | 0,13 | 4,18E-06 | 0,02 | 2,82E-04 | -0,47 | 2,46E-04 | 0,23 | 7,14E-04 | 0,33 |
| **Sulphuric acid, liquid, at plant/RER U w/o transportation** | 9,45E-04 | 0,65 | 1,16E-05 | 0,06 | 6,57E-05 | -0,11 | 7,10E-05 | 0,07 | 1,09E-03 | 0,51 |
| **Service water TR** | 2,48E-03 | 1,71 | 8,61E-05 | 0,41 | 6,59E-04 | -1,09 | 1,70E-04 | 0,16 | 3,40E-03 | 1,59 |
| **Pure water TR** | 2,91E-03 | 2,00 | 1,02E-04 | 0,49 | 7,18E-04 | -1,19 | 1,44E-04 | 0,13 | 3,87E-03 | 1,81 |
| **Nitrogen TR** | 5,38E-03 | 3,70 | 1,88E-04 | 0,90 | 1,32E-03 | -2,18 | 2,65E-04 | 0,24 | 7,15E-03 | 3,34 |
| **Coke oven gas TR** | 9,09E-03 | 6,26 | 1,31E-03 | 6,27 | -3,82E-03 | 6,31 | 6,82E-03 | 6,29 | 1,34E-02 | 6,26 |
| **Electricity generated in facility TR** | 1,08E-02 | 7,43 | 3,77E-04 | 1,80 | 2,66E-03 | -4,39 | 5,33E-04 | 0,49 | 1,44E-02 | 6,72 |
| **Hard coal mix, at regional storage/ U** | 5,92E-02 | 40,75 | 1,68E-02 | 80,42 | 2,03E-02 | -33,52 | 1,96E-01 | 180,89 | 2,92E-01 | 136,62 |
| **Steam TR** | 9,90E-02 | 68,15 | 3,45E-03 | 16,51 | 2,44E-02 | -40,28 | 4,87E-03 | 4,49 | 1,32E-01 | 61,57 |
| **Total** | 1,45E-01 | 100,00 | 2,09E-02 | 100,00 | -6,06E-02 | 100,00 | 1,08E-01 | 100,00 | 2,14E-01 | 100,00 |

Table 39. Contribution of inputs and outputs to end-point impact categories for 1 ton of sinter production

| Inputs/Outputs | Human Health | | Ecosystem Quality | | Climate Change | | Resources | | Single Score | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Pt | % | Pt | % | Pt | % | Pt | % | Pt | % |
| **Emission contribution** | 1,47E-01 | 50,00 | 8,63E-04 | 9,76 | 2,83E-02 | 57,61 | 0,00E+00 | 0,00 | 1,76E-01 | 48,17 |
| **Wire rod mill scale TR** | 4,22E-03 | 1,44 | 1,59E-04 | 1,80 | 1,10E-03 | 2,24 | 4,83E-04 | 3,51 | 5,96E-03 | 1,63 |
| **Sinter dust TR** | 4,75E-03 | 1,62 | 1,43E-04 | 1,62 | 7,93E-04 | 1,61 | 2,22E-04 | 1,61 | 5,91E-03 | 1,62 |
| **Sinter dust TR (Pellet dust)** | 8,31E-02 | 28,26 | 2,50E-03 | 28,27 | 1,39E-02 | 28,30 | 3,89E-03 | 28,29 | 1,03E-01 | 28,27 |
| **Service water TR** | 1,17E-04 | 0,04 | 4,05E-06 | 0,05 | 3,10E-05 | 0,06 | 8,00E-06 | 0,06 | 1,60E-04 | 0,04 |
| **Limestone, at mine/CH U** | 2,00E-04 | 0,07 | 1,08E-04 | 1,22 | 2,12E-05 | 0,04 | 2,04E-05 | 0,15 | 3,50E-04 | 0,10 |
| **Iron ore, 65% Fe, at beneficiation/GLO U** | 1,56E-02 | 5,31 | 2,87E-03 | 32,45 | 9,14E-04 | 1,86 | 1,25E-03 | 9,09 | 2,06E-02 | 5,64 |
| **Electricity, production mix /TR2009/ U** | 2,89E-04 | 0,10 | 6,64E-06 | 0,08 | 4,48E-04 | 0,91 | 3,90E-04 | 2,84 | 1,13E-03 | 0,31 |
| **Electricity generated in facility TR** | 1,71E-02 | 5,82 | 5,98E-04 | 6,76 | 4,22E-03 | 8,59 | 8,43E-04 | 6,13 | 2,28E-02 | 6,22 |
| **Dolomite, at plant/RER U** | 6,13E-08 | 0,00 | 1,99E-08 | 0,00 | 5,08E-08 | 0,00 | 6,19E-08 | 0,00 | 1,94E-07 | 0,00 |
| **Dolomite, at plant/RER U (Dunit)** | 2,14E-05 | 0,01 | 6,94E-06 | 0,08 | 1,77E-05 | 0,04 | 2,16E-05 | 0,16 | 6,76E-05 | 0,02 |
| **Converter slag TR** | 4,57E-03 | 1,55 | 1,76E-04 | 1,99 | 1,06E-03 | 2,16 | 4,61E-04 | 3,35 | 6,27E-03 | 1,71 |
| **Coke TR** | 7,11E-03 | 2,42 | 1,02E-03 | 11,53 | -2,99E-03 | -6,09 | 5,34E-03 | 38,84 | 1,05E-02 | 2,87 |
| **Coke oven gas TR** | 2,43E-04 | 0,08 | 3,49E-05 | 0,39 | -1,02E-04 | -0,21 | 1,82E-04 | 1,32 | 3,58E-04 | 0,10 |
| **Coil mill scale TR** | 5,00E-03 | 1,70 | 1,80E-04 | 2,04 | 1,07E-03 | 2,18 | 4,67E-04 | 3,40 | 6,72E-03 | 1,84 |
| **BOF gas cleaning sludge TR** | 5,87E-04 | 0,20 | 2,26E-05 | 0,26 | 1,36E-04 | 0,28 | 5,93E-05 | 0,43 | 8,05E-04 | 0,22 |
| **BF gas cleaning sludge TR** | 3,95E-04 | 0,13 | 1,47E-05 | 0,17 | 1,98E-05 | 0,04 | 1,07E-05 | 0,08 | 4,40E-04 | 0,12 |
| **BF flue dust TR** | 3,72E-03 | 1,27 | 1,38E-04 | 1,56 | 1,86E-04 | 0,38 | 1,01E-04 | 0,73 | 4,15E-03 | 1,13 |
| **Total** | 2,94E-01 | 100,00 | 8,84E-03 | 100,00 | 4,91E-02 | 100,00 | 1,37E-02 | 100,00 | 3,66E-01 | 100,00 |

Table 40. Contribution of inputs and outputs to end-point impact categories for 1 ton of liquid iron production

| Inputs/Outputs | Human Health | | Ecosystem Quality | | Climate Change | | Resources | | Single Score | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Pt | % | Pt | % | Pt | % | Pt | % | Pt | % |
| **Emission contribution** | 3,43E-02 | 13,14 | 1,88E-05 | 0,19 | 1,08E-02 | 86,81 | 5,17E-06 | 0,07 | 4,51E-02 | 15,55 |
| **Blast furnace gas TR** | 3,96E-02 | 15,17 | 1,47E-03 | 15,11 | 1,98E-03 | 15,92 | 1,07E-03 | 15,24 | 4,41E-02 | 15,20 |
| **Coke oven gas TR** | 2,73E-04 | 0,10 | 3,93E-05 | 0,40 | -1,15E-04 | -0,92 | 2,05E-04 | 2,92 | 4,02E-04 | 0,14 |
| **Coke TR** | 1,92E-02 | 7,36 | 2,75E-03 | 28,27 | -8,05E-03 | -64,71 | 1,44E-02 | 205,03 | 2,83E-02 | 9,75 |
| **Dolomite, at plant/RER U** | 3,83E-08 | 0,00 | 1,24E-08 | 0,00 | 3,17E-08 | 0,00 | 3,87E-08 | 0,00 | 1,21E-07 | 0,00 |
| **Electricity generated in facility TR** | 3,05E-03 | 1,17 | 1,07E-04 | 1,10 | 7,52E-04 | 6,04 | 1,50E-04 | 2,14 | 4,06E-03 | 1,40 |
| **Electricity, production mix /TR2009/ U** | 5,17E-05 | 0,02 | 1,19E-06 | 0,01 | 8,01E-05 | 0,64 | 6,98E-05 | 0,99 | 2,03E-04 | 0,07 |
| **Electricity, production mix /TR2009/ U (Avoided product)** | -1,79E-02 | -6,86 | -4,11E-04 | -4,22 | -2,77E-02 | -222,65 | -2,41E-02 | -343,15 | -7,01E-02 | -24,16 |
| **Iron ore, 65% Fe, at beneficiation/GLO U** | 1,09E-03 | 0,42 | 2,00E-04 | 2,06 | 6,39E-05 | 0,51 | 8,76E-05 | 1,25 | 1,44E-03 | 0,50 |
| **Limestone, at mine/CH U** | 2,28E-06 | 0,00 | 1,23E-06 | 0,01 | 2,41E-07 | 0,00 | 2,32E-07 | 0,00 | 3,98E-06 | 0,00 |
| **Natural gas, burned in gas motor, for storage/RU U** | 1,58E-07 | 0,00 | 2,67E-09 | 0,00 | 1,06E-06 | 0,01 | 1,35E-06 | 0,02 | 2,57E-06 | 0,00 |
| **Nitrogen TR** | 7,53E-03 | 2,88 | 2,63E-04 | 2,70 | 1,85E-03 | 14,87 | 3,71E-04 | 5,28 | 1,00E-02 | 3,45 |
| **Oxygen TR** | 1,29E-02 | 4,94 | 4,50E-04 | 4,63 | 3,18E-03 | 25,56 | 6,36E-04 | 9,06 | 1,72E-02 | 5,91 |
| **Pulverised lignite, at plant/DE U** | 2,75E-03 | 1,05 | 3,19E-05 | 0,33 | 2,47E-03 | 19,85 | 6,69E-03 | 95,26 | 1,19E-02 | 4,11 |
| **Pure water TR** | 1,25E-03 | 0,48 | 4,36E-05 | 0,45 | 3,08E-04 | 2,48 | 6,19E-05 | 0,88 | 1,66E-03 | 0,57 |
| **Service water TR** | 2,05E-06 | 0,00 | 7,10E-08 | 0,00 | 5,43E-07 | 0,00 | 1,40E-07 | 0,00 | 2,80E-06 | 0,00 |
| **Sinter TR** | 8,33E-02 | 31,91 | 2,51E-03 | 25,80 | 1,39E-02 | 111,73 | 3,90E-03 | 55,53 | 1,04E-01 | 35,70 |
| **Sinter TR (Pellet)** | 6,58E-02 | 25,21 | 1,98E-03 | 20,35 | 1,10E-02 | 88,42 | 3,09E-03 | 44,00 | 8,19E-02 | 28,21 |
| **Steam TR** | 7,82E-03 | 3,00 | 2,73E-04 | 2,81 | 1,92E-03 | 15,43 | 3,85E-04 | 5,48 | 1,04E-02 | 3,58 |
| **Total** | 2,61E-01 | 100,00 | 9,73E-03 | 100,00 | 1,24E-02 | 100,00 | 7,02E-03 | 100,00 | 2,90E-01 | 100,00 |

Table 41. Contribution of inputs and outputs to end-point impact categories for 1 ton of liquid steel production

| Inputs/Outputs | Human Health | | Ecosystem Quality | | Climate Change | | Resources | | Single Score | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Pt | % | Pt | % | Pt | % | Pt | % | Pt | % |
| **Emission contribution** | 4,10E-02 | 10,01 | 5,20E-06 | 0,03 | 2,31E-02 | 24,12 | 1,01E-05 | 0,02 | 6,41E-02 | 11,39 |
| **Anthracite coal, at mine/RNA** | 1,28E-04 | 0,03 | 3,49E-06 | 0,02 | 8,69E-05 | 0,09 | 4,19E-04 | 1,01 | 6,37E-04 | 0,11 |
| **Coke oven gas TR** | 6,85E-04 | 0,17 | 9,85E-05 | 0,62 | -2,88E-04 | -0,30 | 5,14E-04 | 1,24 | 1,01E-03 | 0,18 |
| **Coke TR** | 1,53E-04 | 0,04 | 2,19E-05 | 0,14 | -2,96E-05 | -0,03 | 1,15E-04 | 0,28 | 2,60E-04 | 0,05 |
| **Coke TR** | 7,05E-05 | 0,02 | 1,01E-05 | 0,06 | -6,41E-05 | -0,07 | 5,29E-05 | 0,13 | 6,94E-05 | 0,01 |
| **Desulfurisation slag TR** | 1,58E-03 | 0,39 | 6,07E-05 | 0,38 | 3,66E-04 | 0,38 | 1,59E-04 | 0,38 | 2,17E-03 | 0,38 |
| **Electricity generated in facility TR** | 2,88E-02 | 7,03 | 1,01E-03 | 6,40 | 7,10E-03 | 7,41 | 1,42E-03 | 3,42 | 3,83E-02 | 6,81 |
| **Electricity, production mix /TR2009/ U** | 4,87E-04 | 0,12 | 1,12E-05 | 0,07 | 7,55E-04 | 0,79 | 6,58E-04 | 1,58 | 1,91E-03 | 0,34 |
| **Iron ore, 65% Fe, at beneficiation/GLO U** | 2,30E-06 | 0,00 | 4,24E-07 | 0,00 | 1,35E-07 | 0,00 | 1,85E-07 | 0,00 | 3,04E-06 | 0,00 |
| **Iron ore, 65% Fe, at beneficiation/GLO U (Iron ore dust)** | 8,06E-08 | 0,00 | 1,48E-08 | 0,00 | 4,73E-09 | 0,00 | 6,49E-09 | 0,00 | 1,07E-07 | 0,00 |
| **Liquid iron TR** | 1,92E-01 | 46,86 | 7,15E-03 | 45,33 | 9,64E-03 | 10,07 | 5,21E-03 | 12,54 | 2,14E-01 | 38,02 |
| **Natural gas, burned in gas motor, for storage/RU U** | 1,09E-04 | 0,03 | 1,85E-06 | 0,01 | 7,32E-04 | 0,76 | 9,32E-04 | 2,24 | 1,77E-03 | 0,32 |
| **Oxygen TR** | 5,69E-02 | 13,89 | 1,98E-03 | 12,55 | 1,40E-02 | 14,62 | 2,80E-03 | 6,74 | 7,57E-02 | 13,45 |
| **Pure water TR** | 1,55E-02 | 3,78 | 5,42E-04 | 3,44 | 3,83E-03 | 4,00 | 7,71E-04 | 1,86 | 2,06E-02 | 3,67 |
| **Quicklime, in pieces, loose, at plant/CH U** | 6,35E-04 | 0,15 | 7,71E-05 | 0,49 | 3,95E-03 | 4,12 | 1,42E-03 | 3,42 | 6,08E-03 | 1,08 |
| **Reinforcing steel, at plant/RER U** | 3,81E-02 | 9,30 | 3,63E-03 | 23,01 | 2,43E-02 | 25,37 | 2,54E-02 | 61,12 | 9,14E-02 | 16,24 |
| **Service water TR** | 1,16E-03 | 0,28 | 4,02E-05 | 0,25 | 3,08E-04 | 0,32 | 7,93E-05 | 0,19 | 1,59E-03 | 0,28 |
| **Steam TR** | 3,24E-02 | 7,91 | 1,13E-03 | 7,16 | 7,99E-03 | 8,34 | 1,60E-03 | 3,85 | 4,31E-02 | 7,66 |
| **Total** | 4,10E-01 | 100,00 | 1,58E-02 | 100,00 | 9,58E-02 | 100,00 | 4,16E-02 | 100,00 | 5,63E-01 | 100,00 |

Table 42. Contribution of inputs and outputs to end-point impact categories for 1 ton of billet production

| Inputs/Outputs | Human Health | | Ecosystem Quality | | Climate Change | | Resources | | Single Score | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Pt | % | Pt | % | Pt | % | Pt | % | Pt | % |
| **Emission contribution** | 0,00E+00 | 0,00 | 0,00E+00 | 0,00 | 7,45E-04 | 0,74 | 0,00E+00 | 0,00 | 7,45E-04 | 0,13 |
| **Argon TR** | 1,28E-04 | 0,03 | 4,47E-06 | 0,03 | 3,16E-05 | 0,03 | 6,31E-06 | 0,01 | 1,70E-04 | 0,03 |
| **Coke oven gas TR** | 5,65E-04 | 0,13 | 8,12E-05 | 0,49 | -2,37E-04 | -0,23 | 4,24E-04 | 0,98 | 8,33E-04 | 0,14 |
| **Electricity generated in facility TR** | 6,93E-03 | 1,60 | 2,42E-04 | 1,46 | 1,71E-03 | 1,69 | 3,41E-04 | 0,79 | 9,22E-03 | 1,55 |
| **Electricity, production mix /TR2009/ U** | 1,18E-04 | 0,03 | 2,70E-06 | 0,02 | 1,82E-04 | 0,18 | 1,59E-04 | 0,37 | 4,62E-04 | 0,08 |
| **Liquefied petroleum gas, at service station/CH U** | 1,08E-05 | 0,00 | 3,67E-07 | 0,00 | 1,12E-05 | 0,01 | 7,17E-05 | 0,17 | 9,41E-05 | 0,02 |
| **Liquid steel TR** | 4,08E-01 | 94,35 | 1,57E-02 | 94,51 | 9,46E-02 | 93,48 | 4,12E-02 | 95,66 | 5,60E-01 | 94,30 |
| **Natural gas, burned in gas motor, for storage/RU U** | 6,13E-07 | 0,00 | 1,04E-08 | 0,00 | 4,11E-06 | 0,00 | 5,23E-06 | 0,01 | 9,96E-06 | 0,00 |
| **Nitrogen TR** | 6,65E-03 | 1,54 | 2,32E-04 | 1,40 | 1,64E-03 | 1,62 | 3,27E-04 | 0,76 | 8,85E-03 | 1,49 |
| **Oxygen TR** | 2,88E-03 | 0,67 | 1,00E-04 | 0,60 | 7,08E-04 | 0,70 | 1,42E-04 | 0,33 | 3,83E-03 | 0,65 |
| **Pure water TR** | 5,26E-03 | 1,22 | 1,83E-04 | 1,10 | 1,30E-03 | 1,28 | 2,61E-04 | 0,61 | 7,00E-03 | 1,18 |
| **Service water TR** | 1,91E-03 | 0,44 | 6,61E-05 | 0,40 | 5,06E-04 | 0,50 | 1,30E-04 | 0,30 | 2,61E-03 | 0,44 |
| **Total** | 4,32E-01 | 100,00 | 1,66E-02 | 100,00 | 1,01E-01 | 100,00 | 4,31E-02 | 100,00 | 5,93E-01 | 100,00 |

Table 43. Contribution of inputs and outputs to end-point impact categories for 1 ton of slab production

| Inputs/Outputs | Human Health | | Ecosystem Quality | | Climate Change | | Resources | | Single Score | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Pt | % | Pt | % | Pt | % | Pt | % | Pt | % |
| **Emission contribution** | 0,00E+00 | 0,00 | 0,00E+00 | 0,00 | 1,60E-03 | 1,60 | 0,00E+00 | 0,00 | 1,60E-03 | 0,28 |
| **Argon TR** | 2,13E-04 | 0,05 | 7,42E-06 | 0,05 | 5,24E-05 | 0,05 | 1,05E-05 | 0,02 | 2,83E-04 | 0,05 |
| **Coke oven gas TR** | 3,87E-04 | 0,09 | 5,56E-05 | 0,34 | -1,62E-04 | -0,16 | 2,90E-04 | 0,67 | 5,71E-04 | 0,10 |
| **Electricity generated in facility TR** | 6,06E-03 | 1,44 | 2,12E-04 | 1,31 | 1,49E-03 | 1,49 | 2,99E-04 | 0,70 | 8,06E-03 | 1,39 |
| **Electricity, production mix /TR2009/ U** | 1,03E-04 | 0,02 | 2,37E-06 | 0,01 | 1,60E-04 | 0,16 | 1,39E-04 | 0,32 | 4,04E-04 | 0,07 |
| **Liquefied petroleum gas, at service station/CH U** | 5,24E-06 | 0,00 | 1,78E-07 | 0,00 | 5,40E-06 | 0,01 | 3,47E-05 | 0,08 | 4,55E-05 | 0,01 |
| **Liquid steel TR** | 4,07E-01 | 96,57 | 1,57E-02 | 96,66 | 9,43E-02 | 94,35 | 4,11E-02 | 95,57 | 5,58E-01 | 96,12 |
| **Natural gas, burned in gas motor, for storage/RU U** | 7,46E-05 | 0,02 | 1,26E-06 | 0,01 | 5,00E-04 | 0,50 | 6,36E-04 | 1,48 | 1,21E-03 | 0,21 |
| **Nitrogen TR** | 6,21E-04 | 0,15 | 2,17E-05 | 0,13 | 1,53E-04 | 0,15 | 3,06E-05 | 0,07 | 8,26E-04 | 0,14 |
| **Oxygen TR** | 4,79E-04 | 0,11 | 1,67E-05 | 0,10 | 1,18E-04 | 0,12 | 2,36E-05 | 0,05 | 6,37E-04 | 0,11 |
| **Pure water TR** | 3,12E-04 | 0,07 | 1,09E-05 | 0,07 | 7,69E-05 | 0,08 | 1,55E-05 | 0,04 | 4,15E-04 | 0,07 |
| **Service water TR** | 6,20E-03 | 1,47 | 2,15E-04 | 1,32 | 1,65E-03 | 1,65 | 4,24E-04 | 0,99 | 8,49E-03 | 1,46 |
| **Total** | 4,21E-01 | 100,00 | 1,62E-02 | 100,00 | 9,99E-02 | 100,00 | 4,30E-02 | 100,00 | 5,81E-01 | 100,00 |

Table 44. Contribution of inputs and outputs to end-point impact categories for 1 ton of wire rod production

| Inputs/Outputs | Human Health | | Ecosystem Quality | | Climate Change | | Resources | | Single Score | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Pt | % | Pt | % | Pt | % | Pt | % | Pt | % |
| **Emission contribution** | 3,24E-03 | 0,63 | 4,75E-05 | 0,25 | 4,75E-03 | 3,54 | 0,00E+00 | 0,00 | 8,04E-03 | 1,11 |
| **Billet TR** | 4,32E-01 | 84,31 | 1,66E-02 | 86,00 | 1,01E-01 | 75,25 | 4,31E-02 | 73,22 | 5,93E-01 | 81,77 |
| **Electricity generated in facility TR** | 6,74E-02 | 13,15 | 2,35E-03 | 12,17 | 1,66E-02 | 12,37 | 3,32E-03 | 5,64 | 8,97E-02 | 12,37 |
| **Electricity, production mix /TR2009/ U** | 1,14E-03 | 0,22 | 2,61E-05 | 0,14 | 1,76E-03 | 1,31 | 1,54E-03 | 2,62 | 4,47E-03 | 0,62 |
| **Natural gas, burned in gas motor, for storage/RU U** | 1,21E-03 | 0,24 | 2,05E-05 | 0,11 | 8,14E-03 | 6,06 | 1,04E-02 | 17,67 | 1,98E-02 | 2,73 |
| **Oxygen TR** | 2,83E-04 | 0,06 | 9,88E-06 | 0,05 | 6,97E-05 | 0,05 | 1,39E-05 | 0,02 | 3,76E-04 | 0,05 |
| **Service water TR** | 7,15E-03 | 1,40 | 2,48E-04 | 1,28 | 1,90E-03 | 1,42 | 4,90E-04 | 0,83 | 9,79E-03 | 1,35 |
| **Total** | 5,12E-01 | 100,00 | 1,93E-02 | 100,00 | 1,34E-01 | 100,00 | 5,89E-02 | 100,00 | 7,25E-01 | 100,00 |

Table 45. Contribution of inputs and outputs to end-point impact categories for 1 ton of coil production

| Inputs/Outputs | Human Health | | Ecosystem Quality | | Climate Change | | Resources | | Single Score | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Pt | % | Pt | % | Pt | % | Pt | % | Pt | % |
| **Emission contribution** | 6,72E-02 | 11,14 | 6,27E-04 | 2,90 | 4,13E-03 | 3,18 | 0,00E+00 | 0,00 | 7,20E-02 | 8,88 |
| **Coke oven gas TR** | 7,23E-03 | 1,20 | 1,04E-03 | 4,82 | -3,03E-03 | -2,34 | 5,42E-03 | 9,69 | 1,07E-02 | 1,32 |
| **Electricity generated in facility TR** | 7,81E-02 | 12,95 | 2,72E-03 | 12,59 | 1,92E-02 | 14,80 | 3,84E-03 | 6,86 | 1,04E-01 | 12,82 |
| **Electricity, production mix /TR2009/ U** | 1,32E-03 | 0,22 | 3,03E-05 | 0,14 | 2,04E-03 | 1,57 | 1,78E-03 | 3,18 | 5,17E-03 | 0,64 |
| **Nitrogen TR** | 5,39E-04 | 0,09 | 1,88E-05 | 0,09 | 1,33E-04 | 0,10 | 2,66E-05 | 0,05 | 7,17E-04 | 0,09 |
| **Oxygen TR** | 1,98E-04 | 0,03 | 6,90E-06 | 0,03 | 4,87E-05 | 0,04 | 9,74E-06 | 0,02 | 2,63E-04 | 0,03 |
| **Service water TR** | 2,74E-02 | 4,54 | 9,53E-04 | 4,41 | 7,29E-03 | 5,62 | 1,88E-03 | 3,36 | 3,75E-02 | 4,63 |
| **Slab TR** | 4,21E-01 | 69,82 | 1,62E-02 | 75,01 | 9,99E-02 | 77,02 | 4,30E-02 | 76,85 | 5,80E-01 | 71,60 |
| **Total** | 6,03E-01 | 100,00 | 2,16E-02 | 100, 00 | 1,30E-01 | 100,00 | 5,60E-02 | 100,00 | 8,10E-01 | 100,00 |

# APPENDIX I

## CONTRIBUTION OF INPUTS AND OUTPUTS TO MID-POINT IMPACT CATEGORIES

Table 46. Contribution of inputs and outputs to mid-point impact categories for 1 ton of coke production

| | Carcinogens (kg $C_2H_3Cl$ eq) | | Non-carcinogens (kg $C_2H_3Cl$ eq) | | Respiratory Inorganics (kg PM2.5 eq) | | Ionizing Radiation (Bq C-14 eq) | | Ozone Layer Depletion (kg CFC-11 eq) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Amount** | **%** | **Amount** | **%** | **Amount** | **%** | **Amount** | **%** | **Amount** | **%** |
| **Emission Contribution** | 0,00E+00 | 0,00 | 0,00E+00 | 0,00 | 3,00E-01 | 20,45 | 0,00E+00 | 0,00 | 5,01E-06 | 50,21 |
| **Coke oven gas TR** | 5,72E-02 | 6,26 | 1,93E-02 | 6,28 | 9,18E-02 | 6,26 | 1,57E+01 | 6,41 | 3,14E-07 | 3,15 |
| **Electricity generated in facility TR** | 6,54E-02 | 7,15 | 4,87E-02 | 15,84 | 1,09E-01 | 7,43 | 6,00E+00 | 2,45 | -3,07E-08 | -0,31 |
| **Electricity, production mix /TR2009/ U** | 1,91E-03 | 0,21 | 3,67E-03 | 1,19 | 1,82E-03 | 0,12 | 2,32E+00 | 0,95 | 3,61E-08 | 0,36 |
| **Electricity, production mix /TR2009/ U (avoided product)** | -7,80E-01 | -85,31 | -1,50E+00 | -487,78 | -7,45E-01 | -50,79 | -9,50E+02 | -387,97 | -1,48E-05 | -148,31 |
| **Fusi TR** | 6,42E-04 | 0,07 | 2,17E-04 | 0,07 | 1,03E-03 | 0,07 | 1,76E-01 | 0,07 | 3,52E-09 | 0,04 |
| **Hard coal mix, at regional storage/** | 9,00E-01 | 98,44 | 1,23E+00 | 399,98 | 5,90E-01 | 40,23 | 1,07E+03 | 436,97 | 1,96E-05 | 196,41 |
| **Natural gas, burned in gas motor, for storage/RU U** | 1,29E-07 | 0,00 | 5,02E-07 | 0,00 | 3,52E-06 | 0,00 | 5,11E-04 | 0,00 | 5,62E-12 | 0,00 |
| **Nitrogen TR** | 3,25E-02 | 3,55 | 2,42E-02 | 7,87 | 5,43E-02 | 3,70 | 2,98E+00 | 1,22 | -1,53E-08 | -0,15 |
| **Pure water TR** | 1,76E-02 | 1,92 | 1,31E-02 | 4,26 | 2,94E-02 | 2,00 | 1,62E+00 | 0,66 | -8,11E-09 | -0,08 |
| **Service water TR** | 1,52E-02 | 1,66 | 1,17E-02 | 3,80 | 2,50E-02 | 1,70 | 1,82E+00 | 0,74 | 3,37E-10 | 0,00 |
| **Sodium hydroxide, 50% in H2O, production mix, at** | 3,65E-03 | 0,40 | 8,90E-03 | 2,89 | 8,21E-04 | 0,06 | 3,55E+01 | 14,50 | 7,20E-08 | 0,72 |
| **Steam TR** | 5,99E-01 | 65,51 | 4,46E-01 | 145,03 | 9,99E-01 | 68,11 | 5,49E+01 | 22,42 | -2,81E-07 | -2,82 |
| **Sulphuric acid, liquid, at plant/RER U w/o** | 1,20E-03 | 0,13 | 1,73E-03 | 0,56 | 9,56E-03 | 0,65 | 3,85E+00 | 1,57 | 7,82E-08 | 0,78 |
| **Total** | 9,14E-01 | 100,00 | 3,08E-01 | 100,00 | 1,47E+00 | 100,00 | 2,45E+02 | 100,00 | 9,98E-06 | 100,00 |

Table 46. Contribution of inputs and outputs to mid-point impact categories for 1 ton of coke production-continued 2

| Inputs/Outputs | Respiratory Organics (kg $C_2H_4$ eq) | | Aquatic Ecotoxicity (kg TEG water) | | Terrestrial Ecotoxicity (kg TEG soil) | | Terrestrial Acidifcation/Nitrification (kg $SO_2$ eq) | | Land Occupation ($m^2$org.arable) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Amount | % | Amount | % | Amount | % | Amount | % | Amount | % |
| **Emission Contribution** | 0,00E+00 | 0,00 | 0,00E+00 | 0,00 | 0,00E+00 | 0,00 | 3,27E+00 | 12,55 | 0,00E+00 | 0,00 |
| **Coke oven gas TR** | 2,91E-03 | 6,29 | 8,07E+03 | 6,25 | 1,99E+03 | 6,25 | 1,63E+00 | 6,25 | 4,14E-02 | 6,25 |
| **Electricity generated in facility TR** | 3,33E-04 | 0,72 | 2,08E+03 | 1,61 | 4,77E+02 | 1,50 | 1,23E+00 | 4,72 | 6,80E-03 | 1,03 |
| **Electricity, production mix /TR2009/ U** | 2,67E-04 | 0,58 | 1,05E+01 | 0,01 | 3,65E+00 | 0,01 | 2,68E-02 | 0,10 | 9,96E-05 | 0,02 |
| **Electricity, production mix /TR2009/ U (avoided product)** | -1,09E-01 | -235,61 | -4,30E+03 | -3,33 | -1,49E+03 | -4,68 | -1,09E+01 | -41,83 | -4,07E-02 | -6,15 |
| **Fusi TR** | 3,27E-05 | 0,07 | 9,06E+01 | 0,07 | 2,24E+01 | 0,07 | 1,83E-02 | 0,07 | 4,65E-04 | 0,07 |
| **Hard coal mix, at regional storage/ U** | 1,48E-01 | 319,91 | 1,02E+05 | 78,95 | 2,60E+04 | 81,60 | 1,81E+01 | 69,45 | 5,84E-01 | 88,22 |
| **Natural gas, burned in gas motor, for storage/RU U** | 9,17E-06 | 0,02 | 1,14E-03 | 0,00 | 5,39E-04 | 0,00 | 7,38E-05 | 0,00 | 6,55E-08 | 0,00 |
| **Nitrogen TR** | 1,66E-04 | 0,36 | 1,04E+03 | 0,81 | 2,37E+02 | 0,74 | 6,13E-01 | 2,35 | 3,38E-03 | 0,51 |
| **Pure water TR** | 9,08E-05 | 0,20 | 5,61E+02 | 0,43 | 1,28E+02 | 0,40 | 3,32E-01 | 1,27 | 1,83E-03 | 0,28 |
| **Service water TR** | 1,29E-04 | 0,28 | 4,73E+02 | 0,37 | 1,09E+02 | 0,34 | 2,84E-01 | 1,09 | 1,56E-03 | 0,24 |
| **Sodium hydroxide, 50% in H2O, production mix, at plant/RER U** | 1,18E-04 | 0,26 | 5,59E+01 | 0,04 | 1,24E+01 | 0,04 | 1,54E-02 | 0,06 | 8,47E-04 | 0,13 |
| **Steam TR** | 3,05E-03 | 6,59 | 1,91E+04 | 14,78 | 4,37E+03 | 13,72 | 1,13E+01 | 43,36 | 6,22E-02 | 9,40 |
| **Sulphuric acid, liquid, at plant/RER U w/o transportation** | 1,58E-04 | 0,34 | 7,40E+00 | 0,01 | 1,50E+00 | 0,00 | 1,41E-01 | 0,54 | 9,46E-05 | 0,01 |
| **Total** | 4,63E-02 | 100,00 | 1,29E+05 | 100,00 | 3,19E+04 | 100,00 | 2,61E+01 | 100,00 | 6,62E-01 | 100,00 |

Table 46. Contribution of inputs and outputs to mid-point impact categories for 1 ton of coke production-continued 3

| Inputs/Outputs | Aquatic Acidification ($kg\ SO_2$ eq) | | Aquatic Eutrophication ($kg\ PO_4$ P-lim) | | Global Warming ($kg\ CO_2$ eq) | | Non-renewable Energy (MJ primary) | | Mineral Extraction (MJ surplus) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Amount** | **%** | **Amount** | **%** | **Amount** | **%** | **Amount** | **%** | **Amount** | **%** |
| **Emission Contribution** | 4,96E-01 | 12,96 | 8,95E-03 | 9,91 | 7,69E+01 | -12,78 | 0,00E+00 | 0,00 | 0,00E+00 | 0,00 |
| **Coke oven gas TR** | 2,39E-01 | 6,25 | 5,69E-03 | 6,30 | -3,78E+01 | 6,28 | 1,04E+03 | 6,29 | 8,06E-01 | 6,26 |
| **Electricity generated in facility TR** | 2,98E-01 | 7,79 | -2,60E-03 | -2,88 | 2,64E+01 | -4,39 | 7,99E+01 | 0,48 | 1,00E+00 | 7,77 |
| **Electricity, production mix /TR2009/ U** | 1,09E-02 | 0,28 | 1,73E-03 | 1,92 | 2,80E+00 | -0,47 | 3,74E+01 | 0,23 | 2,37E-04 | 0,00 |
| **Electricity, production mix /TR2009/ U (avoided product)** | -4,46E+00 | -116,58 | -7,08E-01 | -784,04 | -1,14E+03 | 189,51 | -1,53E+04 | -92,60 | -9,68E-02 | -0,75 |
| **Fusi TR** | 2,68E-03 | 0,07 | 6,38E-05 | 0,07 | -4,24E-01 | 0,07 | 1,16E+01 | 0,07 | 9,04E-03 | 0,07 |
| **Hard coal mix, at regional storage/ U** | 4,09E+00 | 106,90 | 8,10E-01 | 897,00 | 2,01E+02 | -33,41 | 2,98E+04 | 180,35 | 9,91E-01 | 7,70 |
| **Natural gas, burned in gas motor, for storage/RU U** | 2,56E-05 | 0,00 | 4,72E-09 | 0,00 | 2,33E-02 | 0,00 | 4,54E-01 | 0,00 | 1,31E-08 | 0,00 |
| **Nitrogen TR** | 1,48E-01 | 3,87 | -1,29E-03 | -1,43 | 1,31E+01 | -2,18 | 3,98E+01 | 0,24 | 4,98E-01 | 3,87 |
| **Pure water TR** | 8,03E-02 | 2,10 | -6,92E-04 | -0,77 | 7,11E+00 | -1,18 | 2,17E+01 | 0,13 | 2,70E-01 | 2,10 |
| **Service water TR** | 6,96E-02 | 1,82 | -2,38E-04 | -0,26 | 6,52E+00 | -1,08 | 2,56E+01 | 0,15 | 2,26E-01 | 1,76 |
| **Sodium hydroxide, 50% in H2O, production mix, at plant/RER U** | 5,34E-03 | 0,14 | 3,92E-04 | 0,43 | 1,16E+00 | -0,19 | 2,38E+01 | 0,14 | 6,31E-04 | 0,00 |
| **Steam TR** | 2,73E+00 | 71,36 | -2,38E-02 | -26,36 | 2,41E+02 | -40,06 | 7,32E+02 | 4,43 | 9,17E+00 | 71,23 |
| **Sulphuric acid, liquid, at plant/RER U w/o transportation** | 1,16E-01 | 3,03 | 9,52E-05 | 0,11 | 6,51E-01 | -0,11 | 1,08E+01 | 0,07 | 2,38E-05 | 0,00 |
| **Total** | 3,83E+00 | 100,00 | 9,03E-02 | 100,00 | -6,02E+02 | 100,00 | 1,65E+04 | 100,00 | 1,29E+01 | 100,00 |

Table 47. Contribution of inputs and outputs to mid-point impact categories for 1 ton of sinter production

| Inputs/Outputs | Carcinogens ($kg\ C_2H_3Cl\ eq$) | | Non-carcinogens ($kg\ C_2H_3Cl\ eq$) | | Respiratory Inorganics (kg PM2.5 eq) | | Ionizing Radiation (Bq C-14 eq) | | Ozone Layer Depletion (kg CFC-11 eq) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Amount** | **%** | **Amount** | **%** | **Amount** | **%** | **Amount** | **%** | **Amount** | **%** |
| **Emission Contribution** | 1,12E-05 | 0,00 | 2,63E-13 | 0,00 | 1,49E+00 | 50,18 | 0,00E+00 | 0,00 | 0,00E+00 | 0,00 |
| **BF flue dust TR** | 1,35E-02 | 1,05 | 1,06E-02 | 0,74 | 3,75E-02 | 1,26 | 1,22E+00 | 0,31 | -3,07E-08 | -1,69 |
| **BF gas cleaning sludge TR** | 1,44E-03 | 0,11 | 1,12E-03 | 0,08 | 3,99E-03 | 0,13 | 1,30E-01 | 0,03 | -3,27E-09 | -0,18 |
| **BOF gas cleaning sludge TR** | 3,22E-02 | 2,49 | 2,32E-02 | 1,62 | 5,73E-03 | 0,19 | 2,41E+00 | 0,62 | 1,54E-08 | 0,85 |
| **Coil mill scale TR** | 1,92E-01 | 14,87 | 1,39E-01 | 9,68 | 4,94E-02 | 1,66 | 1,48E+01 | 3,81 | 9,16E-08 | 5,05 |
| **Coke oven gas TR** | 1,53E-03 | 0,12 | 5,16E-04 | 0,04 | 2,45E-03 | 0,08 | 4,18E-01 | 0,11 | 8,39E-09 | 0,46 |
| **Coke TR** | 4,48E-02 | 3,47 | 1,51E-02 | 1,05 | 7,18E-02 | 2,42 | 1,23E+01 | 3,16 | 2,46E-07 | 13,57 |
| **Converter slag TR** | 2,50E-01 | 19,36 | 1,81E-01 | 12,61 | 4,46E-02 | 1,50 | 1,88E+01 | 4,84 | 1,19E-07 | 6,56 |
| **Dolomite, at plant/RER U** | 5,45E-04 | 0,04 | 7,26E-04 | 0,05 | 2,11E-04 | 0,01 | 3,58E+00 | 0,92 | 1,39E-08 | 0,77 |
| **Dolomite, at plant/RER U (Dunit)** | 1,56E-06 | 0,00 | 2,08E-06 | 0,00 | 6,03E-07 | 0,00 | 1,03E-02 | 0,00 | 3,99E-11 | 0,00 |
| **Electricity generated in facility TR** | 1,04E-01 | 8,05 | 7,72E-02 | 5,38 | 1,73E-01 | 5,83 | 9,49E+00 | 2,44 | -4,86E-08 | -2,68 |
| **Electricity, production mix /TR2009/ U** | 3,03E-03 | 0,23 | 5,82E-03 | 0,41 | 2,89E-03 | 0,10 | 3,69E+00 | 0,95 | 5,73E-08 | 3,16 |
| **Iron ore, 65% Fe, at beneficiation/GLO U** | 7,05E-02 | 5,46 | 4,13E-01 | 28,78 | 1,56E-01 | 5,25 | 1,91E+02 | 49,12 | 6,86E-07 | 37,84 |
| **Limestone, at mine/CH U** | 1,23E-03 | 0,10 | 1,23E-03 | 0,09 | 2,01E-03 | 0,07 | 1,93E-01 | 0,05 | 2,63E-08 | 1,45 |
| **Service water TR** | 7,14E-04 | 0,06 | 5,53E-04 | 0,04 | 1,18E-03 | 0,04 | 8,58E-02 | 0,02 | 1,59E-11 | 0,00 |
| **Sinter dust TR** | 3,66E-01 | 28,34 | 4,06E-01 | 28,29 | 8,39E-01 | 28,26 | 1,10E+02 | 28,29 | 5,13E-07 | 28,30 |
| **Sinter dust TR (Pellet dust)** | 2,09E-02 | 1,62 | 2,32E-02 | 1,62 | 4,79E-02 | 1,61 | 6,29E+00 | 1,62 | 2,93E-08 | 1,62 |
| **Wire rod mill scale TR** | 1,89E-01 | 14,64 | 1,37E-01 | 9,55 | 4,14E-02 | 1,39 | 1,44E+01 | 3,70 | 8,93E-08 | 4,93 |
| **Total** | 1,29E+00 | 100,00 | 1,44E+00 | 100,00 | 2,97E+00 | 100,00 | 3,89E+02 | 100,00 | 1,81E-06 | 100,00 |

Table 47. Contribution of inputs and outputs to mid-point impact categories for 1 ton of sinter production-continued 2

| Inputs/Outputs | Respiratory Organics (kg $C_2H_4$ eq) | | Aquatic Ecotoxicity (kg TEG water) | | Terrestrial Ecotoxicity (kg TEG soil) | | Terrestrial Acidifcation/Nitrification (kg $SO_2$ eq) | | Land Occupation ($m^2$org.arable) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Amount** | **%** | **Amount** | **%** | **Amount** | **%** | **Amount** | **%** | **Amount** | **%** |
| **Emission Contribution** | 0,00E+00 | 0,00 | 0,00E+00 | 0,00 | 0,00E+00 | 0,00 | 1,14E+01 | 46,14 | 0,00E+00 | 0,00 |
| **BF flue dust TR** | -4,85E-05 | -0,17 | 8,58E+02 | 1,60 | 1,94E+02 | 1,65 | 2,97E-01 | 1,20 | 2,53E-03 | 2,47 |
| **BF gas cleaning sludge TR** | -5,16E-06 | -0,02 | 9,13E+01 | 0,17 | 2,07E+01 | 0,18 | 3,16E-02 | 0,13 | 2,70E-04 | 0,26 |
| **BOF gas cleaning sludge TR** | 1,33E-04 | 0,48 | 1,34E+02 | 0,25 | 3,16E+01 | 0,27 | 4,97E-02 | 0,20 | 5,73E-04 | 0,56 |
| **Coil mill scale TR** | 8,57E-04 | 3,09 | 1,02E+03 | 1,90 | 2,41E+02 | 2,05 | 4,81E-01 | 1,95 | 4,23E-03 | 4,14 |
| **Coke oven gas TR** | 7,77E-05 | 0,28 | 2,16E+02 | 0,40 | 5,32E+01 | 0,45 | 4,35E-02 | 0,18 | 1,11E-03 | 1,09 |
| **Coke TR** | 2,28E-03 | 8,22 | 6,32E+03 | 11,78 | 1,56E+03 | 13,30 | 1,27E+00 | 5,14 | 3,24E-02 | 31,69 |
| **Converter slag TR** | 1,03E-03 | 3,71 | 1,04E+03 | 1,94 | 2,46E+02 | 2,10 | 3,86E-01 | 1,56 | 4,46E-03 | 4,36 |
| **Dolomite, at plant/RER U** | 5,31E-05 | 0,19 | 4,34E+01 | 0,08 | 1,12E+01 | 0,10 | 3,90E-03 | 0,02 | 9,10E-05 | 0,09 |
| **Dolomite, at plant/RER U (dunit)** | 1,52E-07 | 0,00 | 1,24E-01 | 0,00 | 3,21E-02 | 0,00 | 1,12E-05 | 0,00 | 2,61E-07 | 0,00 |
| **Electricity generated in facility TR** | 5,28E-04 | 1,90 | 3,30E+03 | 6,15 | 7,56E+02 | 6,45 | 1,95E+00 | 7,89 | 1,08E-02 | 10,56 |
| **Electricity, production mix /TR2009/ U** | 4,24E-04 | 1,53 | 1,67E+01 | 0,03 | 5,79E+00 | 0,05 | 4,25E-02 | 0,17 | 1,58E-04 | 0,15 |
| **Iron ore, 65% Fe, at beneficiation/GLO U** | 1,25E-02 | 45,04 | 2,29E+04 | 42,68 | 4,70E+03 | 40,07 | 9,35E-01 | 3,78 | 1,09E-02 | 10,66 |
| **Limestone, at mine/CH U** | 5,47E-04 | 1,97 | 6,95E+02 | 1,30 | 1,78E+02 | 1,52 | 3,85E-02 | 0,16 | 2,63E-04 | 0,26 |
| **Service water TR** | 6,08E-06 | 0,02 | 2,23E+01 | 0,04 | 5,11E+00 | 0,04 | 1,34E-02 | 0,05 | 7,32E-05 | 0,07 |
| **Sinter dust TR** | 7,85E-03 | 28,29 | 1,52E+04 | 28,33 | 3,32E+03 | 28,30 | 6,98E+00 | 28,25 | 2,89E-02 | 28,27 |
| **Sinter dust TR (Pellet dust)** | 4,48E-04 | 1,61 | 8,67E+02 | 1,62 | 1,89E+02 | 1,61 | 3,99E-01 | 1,61 | 1,65E-03 | 1,61 |
| **Wire rod mill scale TR** | 1,07E-03 | 3,86 | 9,28E+02 | 1,73 | 2,18E+02 | 1,86 | 3,86E-01 | 1,56 | 3,82E-03 | 3,74 |
| **Total** | 2,78E-02 | 100,00 | 5,37E+04 | 100,00 | 1,17E+04 | 100,00 | 2,47E+01 | 100,00 | 1,02E-01 | 100,00 |

Table 47. Contribution of inputs and outputs to mid-point impact categories for 1 ton of sinter production-continued 3

| Inputs/Outputs | Aquatic Acidification (kg $SO_2$ eq) | | Aquatic Eutrophication (kg $PO_4$ P-lim) | | Global Warming (kg $CO_2$ eq) | | Non-renewable Energy (MJ primary) | | Mineral Extraction (MJ surplus) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Amount** | **%** | **Amount** | **%** | **Amount** | **%** | **Amount** | **%** | **Amount** | **%** |
| **Emission Contribution** | 4,19E+00 | 54,08 | 0,00E+00 | 0,00 | 2,80E+02 | 57,54 | 0,00E+00 | 0,00 | 0,00E+00 | 0,00 |
| **BF flue dust TR** | 7,57E-02 | 0,98 | -1,46E-03 | -32,06 | 1,84E+00 | 0,38 | 1,49E+01 | 0,73 | 4,34E-01 | 1,17 |
| **BF gas cleaning sludge TR** | 8,05E-03 | 0,10 | -1,55E-04 | -3,40 | 1,96E-01 | 0,04 | 1,58E+00 | 0,08 | 4,62E-02 | 0,12 |
| **BOF gas cleaning sludge TR** | 1,24E-02 | 0,16 | -8,31E-05 | -1,82 | 1,35E+00 | 0,28 | 8,92E+00 | 0,43 | 9,22E-02 | 0,25 |
| **Coil mill scale TR** | 1,23E-01 | 1,59 | -5,23E-04 | -11,49 | 1,06E+01 | 2,18 | 7,04E+01 | 3,43 | 6,28E-01 | 1,69 |
| **Coke oven gas TR** | 6,39E-03 | 0,08 | 1,52E-04 | 3,34 | -1,01E+00 | -0,21 | 2,77E+01 | 1,35 | 2,15E-02 | 0,06 |
| **Coke TR** | 1,87E-01 | 2,41 | 4,45E-03 | 97,73 | -2,96E+01 | -6,08 | 8,11E+02 | 39,49 | 6,30E-01 | 1,69 |
| **Converter slag TR** | 9,65E-02 | 1,25 | -6,47E-04 | -14,21 | 1,05E+01 | 2,16 | 6,94E+01 | 3,38 | 7,17E-01 | 1,93 |
| **Dolomite, at plant/RER U** | 9,19E-04 | 0,01 | 4,37E-05 | 0,96 | 1,76E-01 | 0,04 | 3,29E+00 | 0,16 | 9,67E-05 | 0,00 |
| **Dolomite, at plant/RER U (dunit)** | 2,63E-06 | 0,00 | 1,25E-07 | 0,00 | 5,03E-04 | 0,00 | 9,41E-03 | 0,00 | 2,77E-07 | 0,00 |
| **Electricity generated in facility TR** | 4,72E-01 | 6,09 | -4,11E-03 | -90,26 | 4,18E+01 | 8,59 | 1,27E+02 | 6,18 | 1,59E+00 | 4,28 |
| **Electricity, production mix /TR2009/ U** | 1,73E-02 | 0,22 | 2,75E-03 | 60,39 | 4,44E+00 | 0,91 | 5,93E+01 | 2,89 | 3,76E-04 | 0,00 |
| **Iron ore, 65% Fe, at beneficiation/GLO U** | 1,40E-01 | 1,81 | 3,33E-03 | 73,13 | 9,05E+00 | 1,86 | 1,69E+02 | 8,23 | 2,13E+01 | 57,30 |
| **Limestone, at mine/CH U** | 5,17E-03 | 0,07 | 2,07E-05 | 0,45 | 2,10E-01 | 0,04 | 3,10E+00 | 0,15 | 1,41E-03 | 0,00 |
| **Service water TR** | 3,27E-03 | 0,04 | -1,12E-05 | -0,25 | 3,07E-01 | 0,06 | 1,20E+00 | 0,06 | 1,07E-02 | 0,03 |
| **Sinter dust TR** | 2,19E+00 | 28,27 | 1,28E-03 | 28,11 | 1,38E+02 | 28,36 | 5,81E+02 | 28,29 | 1,05E+01 | 28,25 |
| **Sinter dust TR (Pellet dust)** | 1,25E-01 | 1,61 | 7,32E-05 | 1,61 | 7,85E+00 | 1,61 | 3,32E+01 | 1,62 | 6,00E-01 | 1,61 |
| **Wire rod mill scale TR** | 9,53E-02 | 1,23 | -5,57E-04 | -12,23 | 1,09E+01 | 2,24 | 7,29E+01 | 3,55 | 6,03E-01 | 1,62 |
| **Total** | 7,75E+00 | 100,00 | 4,55E-03 | 100,00 | 4,87E+02 | 100,00 | 2,05E+03 | 100,00 | 3,72E+01 | 100,00 |

Table 48. Contribution of inputs and outputs to mid-point impact categories for 1 ton of liquid iron production

| Inputs/Outputs | Carcinogens (kg $C_2H_3Cl$ eq) | | Non-carcinogens (kg $C_2H_3Cl$ eq) | | Respiratory Inorganics (kg PM2.5 eq) | | Ionizing Radiation (Bq C-14 eq) | | Ozone Layer Depletion (kg CFC-11 eq) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Amount** | **%** | **Amount** | **%** | **Amount** | **%** | **Amount** | **%** | **Amount** | **%** |
| **Emission Contribution** | 0,00E+00 | 0,00 | 0,00E+00 | 0,00 | 3,48E-01 | 13,19 | 0,00E+00 | 0,00 | 0,00E+00 | 0,00 |
| **Blast furnace gas TR** | 1,44E-01 | 15,20 | 1,13E-01 | 15,44 | 4,00E-01 | 15,16 | 1,30E+01 | 16,11 | -3,27E-07 | 14,68 |
| **Coke oven gas TR** | 1,72E-03 | 0,18 | 5,81E-04 | 0,08 | 2,76E-03 | 0,10 | 4,71E-01 | 0,58 | 9,44E-09 | -0,42 |
| **Coke TR** | 1,21E-01 | 12,77 | 4,07E-02 | 5,56 | 1,93E-01 | 7,32 | 3,30E+01 | 40,90 | 6,62E-07 | -29,73 |
| **Dolomite, at plant/RER U** | 9,75E-07 | 0,00 | 1,30E-06 | 0,00 | 3,77E-07 | 0,00 | 6,41E-03 | 0,01 | 2,49E-11 | 0,00 |
| **Electricity generated in facility TR** | 1,85E-02 | 1,95 | 1,38E-02 | 1,89 | 3,08E-02 | 1,17 | 1,69E+00 | 2,09 | -8,67E-09 | 0,39 |
| **Electricity, production mix /TR2009/ U** | 5,41E-04 | 0,06 | 1,04E-03 | 0,14 | 5,17E-04 | 0,02 | 6,59E-01 | 0,82 | 1,02E-08 | -0,46 |
| **Electricity, production mix /TR2009/ U (avoided product)** | -1,87E-01 | -19,73 | -3,60E-01 | -49,18 | -1,79E-01 | -6,78 | -2,28E+02 | -282,58 | -3,54E-06 | 158,96 |
| **Iron ore, 65% Fe, at beneficiation/GLO U** | 4,93E-03 | 0,52 | 2,88E-02 | 3,93 | 1,09E-02 | 0,41 | 1,34E+01 | 16,61 | 4,79E-08 | -2,15 |
| **Limestone, at mine/CH U** | 1,40E-05 | 0,00 | 1,40E-05 | 0,00 | 2,29E-05 | 0,00 | 2,20E-03 | 0,00 | 2,99E-10 | -0,01 |
| **Natural gas, burned in gas motor, for storage/RU U** | 5,80E-08 | 0,00 | 2,26E-07 | 0,00 | 1,59E-06 | 0,00 | 2,30E-04 | 0,00 | 2,53E-12 | 0,00 |
| **Nitrogen TR** | 4,55E-02 | 4,80 | 3,39E-02 | 4,63 | 7,60E-02 | 2,88 | 4,17E+00 | 5,17 | -2,14E-08 | 0,96 |
| **Oxygen TR** | 7,81E-02 | 8,24 | 5,81E-02 | 7,94 | 1,30E-01 | 4,93 | 7,16E+00 | 8,87 | -3,66E-08 | 1,64 |
| **Pulverised lignite, at plant/DE U** | 8,48E-03 | 0,89 | 3,22E-02 | 4,40 | 2,77E-02 | 1,05 | 3,29E+01 | 40,78 | 8,25E-08 | -3,70 |
| **Pure water TR** | 7,55E-03 | 0,80 | 5,63E-03 | 0,77 | 1,26E-02 | 0,48 | 6,96E-01 | 0,86 | -3,48E-09 | 0,16 |
| **Service water TR** | 1,25E-05 | 0,00 | 9,69E-06 | 0,00 | 2,06E-05 | 0,00 | 1,50E-03 | 0,00 | 2,78E-13 | 0,00 |
| **Sinter TR** | 3,67E-01 | 38,73 | 4,07E-01 | 55,60 | 8,41E-01 | 31,88 | 1,10E+02 | 136,33 | 5,14E-07 | -23,08 |
| **Sinter TR (pellet)** | 2,90E-01 | 30,60 | 3,22E-01 | 43,99 | 6,65E-01 | 25,21 | 8,72E+01 | 108,07 | 4,06E-07 | -18,23 |
| **Steam TR** | 4,73E-02 | 4,99 | 3,52E-02 | 4,81 | 7,89E-02 | 2,99 | 4,33E+00 | 5,37 | -2,22E-08 | 1,00 |
| **Total** | 9,48E-01 | 100,00 | 7,32E-01 | 100,00 | 2,64E+00 | 100,00 | 8,07E+01 | 100,00 | -2,23E-06 | 100,00 |

Table 48. Contribution of inputs and outputs to mid-point impact categories for 1 ton of liquid iron production-continued 2

| Inputs/Outputs | Respiratory Organics (kg $C_2H_4$ eq) | | Aquatic Ecotoxicity (kg TEG water) | | Terrestrial Ecotoxicity (kg TEG soil) | | Terrestrial Acidifcation/Nitrification (kg $SO_2$ eq) | | Land Occupation ($m^2$org.arable) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Amount | % | Amount | % | Amount | % | Amount | % | Amount | % |
| **Emission Contribution** | 0,00E+00 | 0,00 | 0,00E+00 | 0,00 | 0,00E+00 | 0,00 | 2,47E-01 | 1,18 | 0,00E+00 | 0,00 |
| **Blast furnace gas TR** | -5,17E-04 | 13,19 | 9,15E+03 | 15,13 | 2,07E+03 | 15,10 | 3,17E+00 | 15,19 | 2,70E-02 | 15,03 |
| **Coke oven gas TR** | 8,75E-05 | -2,23 | 2,43E+02 | 0,40 | 5,99E+01 | 0,44 | 4,90E-02 | 0,23 | 1,25E-03 | 0,70 |
| **Coke TR** | 6,13E-03 | -156,38 | 1,70E+04 | 28,10 | 4,20E+03 | 30,64 | 3,43E+00 | 16,44 | 8,73E-02 | 48,60 |
| **Dolomite, at plant/RER U** | 9,50E-08 | 0,00 | 7,76E-02 | 0,00 | 2,01E-02 | 0,00 | 6,97E-06 | 0,00 | 1,63E-07 | 0,00 |
| **Electricity generated in facility TR** | 9,41E-05 | -2,40 | 5,89E+02 | 0,97 | 1,35E+02 | 0,99 | 3,48E-01 | 1,67 | 1,92E-03 | 1,07 |
| **Electricity, production mix /TR2009/ U** | 7,58E-05 | -1,93 | 2,98E+00 | 0,00 | 1,03E+00 | 0,01 | 7,59E-03 | 0,04 | 2,83E-05 | 0,02 |
| **Electricity, production mix /TR2009/ U (avoided product)** | -2,62E-02 | 668,36 | -1,03E+03 | -1,70 | -3,58E+02 | -2,61 | -2,63E+00 | -12,60 | -9,77E-03 | -5,44 |
| **Iron ore, 65% Fe, at beneficiation/GLO U** | 8,74E-04 | -22,30 | 1,60E+03 | 2,64 | 3,28E+02 | 2,39 | 6,54E-02 | 0,31 | 7,60E-04 | 0,42 |
| **Limestone, at mine/CH U** | 6,23E-06 | -0,16 | 7,91E+00 | 0,01 | 2,03E+00 | 0,01 | 4,38E-04 | 0,00 | 3,00E-06 | 0,00 |
| **Natural gas, burned in gas motor, for storage/RU U** | 4,13E-06 | -0,11 | 5,15E-04 | 0,00 | 2,43E-04 | 0,00 | 3,33E-05 | 0,00 | 2,95E-08 | 0,00 |
| **Nitrogen TR** | 2,32E-04 | -5,92 | 1,45E+03 | 2,40 | 3,32E+02 | 2,42 | 8,58E-01 | 4,11 | 4,73E-03 | 2,63 |
| **Oxygen TR** | 3,98E-04 | -10,15 | 2,49E+03 | 4,12 | 5,70E+02 | 4,16 | 1,47E+00 | 7,04 | 8,11E-03 | 4,51 |
| **Pulverised lignite, at plant/DE U** | 5,25E-04 | -13,39 | 4,15E+01 | 0,07 | 1,53E+01 | 0,11 | 3,01E-01 | 1,44 | 7,17E-04 | 0,40 |
| **Pure water TR** | 3,90E-05 | -0,99 | 2,41E+02 | 0,40 | 5,51E+01 | 0,40 | 1,42E-01 | 0,68 | 7,85E-04 | 0,44 |
| **Service water TR** | 1,06E-07 | 0,00 | 3,90E-01 | 0,00 | 8,96E-02 | 0,00 | 2,34E-04 | 0,00 | 1,28E-06 | 0,00 |
| **Sinter TR** | 7,87E-03 | -200,76 | 1,52E+04 | 25,13 | 3,32E+03 | 24,22 | 6,99E+00 | 33,50 | 2,90E-02 | 16,14 |
| **Sinter TR (pellet)** | 6,22E-03 | -158,67 | 1,20E+04 | 19,84 | 2,63E+03 | 19,19 | 5,53E+00 | 26,50 | 2,29E-02 | 12,75 |
| **Steam TR** | 2,41E-04 | -6,15 | 1,51E+03 | 2,50 | 3,45E+02 | 2,52 | 8,90E-01 | 4,26 | 4,91E-03 | 2,73 |
| **Total** | -3,92E-03 | 100,00 | 6,05E+04 | 100,00 | 1,37E+04 | 100,00 | 2,09E+01 | 100,00 | 1,80E-01 | 100,00 |

Table 48. Contribution of inputs and outputs to mid-point impact categories for 1 ton of liquid iron production-continued 3

| Inputs/Outputs | Aquatic Acidification (kg $SO_2$ eq) | | Aquatic Eutrophication (kg $PO_4$ P-lim) | | Global Warming (kg $CO_2$ eq) | | Non-renewable Energy (MJ primary) | | Mineral Extraction (MJ surplus) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Amount** | **%** | **Amount** | **%** | **Amount** | **%** | **Amount** | **%** | **Amount** | **%** |
| **Emission Contribution** | 3,74E-02 | 0,71 | 0,00E+00 | 0,00 | 1,07E+02 | 86,15 | 0,00E+00 | 0,00 | 7,85E-01 | 2,58 |
| **Blast furnace gas TR** | 8,06E-01 | 15,22 | -1,55E-02 | 14,84 | 1,96E+01 | 15,78 | 1,58E+02 | 15,41 | 4,63E+00 | 15,20 |
| **Coke oven gas TR** | 7,19E-03 | 0,14 | 1,71E-04 | -0,16 | -1,14E+00 | -0,92 | 3,12E+01 | 3,04 | 2,42E-02 | 0,08 |
| **Coke TR** | 5,04E-01 | 9,52 | 1,20E-02 | -11,49 | -7,97E+01 | -64,17 | 2,18E+03 | 212,57 | 1,70E+00 | 5,58 |
| **Dolomite, at plant/RER U** | 1,64E-06 | 0,00 | 7,82E-08 | 0,00 | 3,14E-04 | 0,00 | 5,88E-03 | 0,00 | 1,73E-07 | 0,00 |
| **Electricity generated in facility TR** | 8,42E-02 | 1,59 | -7,33E-04 | 0,70 | 7,45E+00 | 6,00 | 2,26E+01 | 2,20 | 2,83E-01 | 0,93 |
| **Electricity, production mix /TR2009/ U** | 3,10E-03 | 0,06 | 4,91E-04 | -0,47 | 7,93E-01 | 0,64 | 1,06E+01 | 1,03 | 6,72E-05 | 0,00 |
| **Electricity, production mix /TR2009/ U (avoided product)** | -1,07E+00 | -20,21 | -1,70E-01 | 162,80 | -2,74E+02 | -220,61 | -3,67E+03 | -357,85 | -2,32E-02 | -0,08 |
| **Iron ore, 65% Fe, at beneficiation/GLO U** | 9,81E-03 | 0,19 | 2,33E-04 | -0,22 | 6,32E-01 | 0,51 | 1,18E+01 | 1,15 | 1,49E+00 | 4,89 |
| **Limestone, at mine/CH U** | 5,88E-05 | 0,00 | 2,36E-07 | 0,00 | 2,39E-03 | 0,00 | 3,53E-02 | 0,00 | 1,61E-05 | 0,00 |
| **Natural gas, burned in gas motor, for storage/RU U** | 1,16E-05 | 0,00 | 2,13E-09 | 0,00 | 1,05E-02 | 0,01 | 2,05E-01 | 0,02 | 5,91E-09 | 0,00 |
| **Nitrogen TR** | 2,08E-01 | 3,93 | -1,81E-03 | 1,73 | 1,84E+01 | 14,81 | 5,56E+01 | 5,42 | 6,97E-01 | 2,29 |
| **Oxygen TR** | 3,56E-01 | 6,72 | -3,10E-03 | 2,97 | 3,15E+01 | 25,36 | 9,54E+01 | 9,30 | 1,20E+00 | 3,94 |
| **Pulverised lignite, at plant/DE U** | 1,60E-01 | 3,02 | 7,37E-02 | -70,58 | 2,45E+01 | 19,73 | 1,02E+03 | 99,46 | 2,23E-04 | 0,00 |
| **Pure water TR** | 3,44E-02 | 0,65 | -2,97E-04 | 0,28 | 3,05E+00 | 2,46 | 9,29E+00 | 0,91 | 1,16E-01 | 0,38 |
| **Service water TR** | 5,74E-05 | 0,00 | -1,96E-07 | 0,00 | 5,38E-03 | 0,00 | 2,11E-02 | 0,00 | 1,87E-04 | 0,00 |
| **Sinter TR** | 2,20E+00 | 41,55 | 1,28E-03 | -1,23 | 1,38E+02 | 111,11 | 5,82E+02 | 56,75 | 1,05E+01 | 34,48 |
| **Sinter TR (pellet)** | 1,74E+00 | 32,86 | 1,02E-03 | -0,98 | 1,09E+02 | 87,76 | 4,61E+02 | 44,95 | 8,33E+00 | 27,35 |
| **Steam TR** | 2,15E-01 | 4,06 | -1,88E-03 | 1,80 | 1,91E+01 | 15,38 | 5,78E+01 | 5,64 | 7,24E-01 | 2,38 |
| **Total** | 5,30E+00 | 100,00 | -1,04E-01 | 100,00 | 1,24E+02 | 100,00 | 1,03E+03 | 100,00 | 3,05E+01 | 100,00 |

Table 49. Contribution of inputs and outputs to mid-point impact categories for 1 ton of liquid steel production

| Inputs/Outputs | Carcinogens (kg $C_2H_3Cl$ eq) | | Non-carcinogens (kg $C_2H_3Cl$ eq) | | Respiratory Inorganics (kg PM2.5 eq) | | Ionizing Radiation (Bq C-14 eq) | | Ozone Layer Depletion (kg CFC-11 eq) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Amount** | **%** | **Amount** | **%** | **Amount** | **%** | **Amount** | **%** | **Amount** | **%** |
| **Emission Contribution** | 0,00E+00 | 0,00 | 0,00E+00 | 0,00 | 4,15E-01 | 10,36 | 0,00E+00 | 0,00 | 0,00E+00 | 0,00 |
| **Anthracite coal, at mine/RNA** | 3,26E-04 | 0,00 | 3,72E-03 | 0,02 | 1,28E-03 | 0,03 | 0,00E+00 | 0,00 | 1,74E-12 | 0,00 |
| **Coke oven gas TR** | 4,31E-03 | 0,02 | 1,46E-03 | 0,01 | 6,92E-03 | 0,17 | 1,18E+00 | 0,07 | 2,37E-08 | 0,22 |
| **Coke TR** | 9,60E-04 | 0,00 | 3,24E-04 | 0,00 | 1,54E-03 | 0,04 | 2,63E-01 | 0,02 | 5,27E-09 | 0,05 |
| **Coke TR (coke breeze)** | 4,43E-04 | 0,00 | 1,50E-04 | 0,00 | 7,11E-04 | 0,02 | 1,21E-01 | 0,01 | 2,43E-09 | 0,02 |
| **Desulfurisation slag TR** | 8,64E-02 | 0,38 | 6,25E-02 | 0,38 | 1,54E-02 | 0,38 | 6,49E+00 | 0,38 | 4,13E-08 | 0,38 |
| **Electricity generated in facility TR** | 1,74E-01 | 0,77 | 1,30E-01 | 0,80 | 2,91E-01 | 7,27 | 1,60E+01 | 0,94 | -8,18E-08 | -0,75 |
| **Electricity, production mix /TR2009/ U** | 5,10E-03 | 0,02 | 9,81E-03 | 0,06 | 4,87E-03 | 0,12 | 6,21E+00 | 0,36 | 9,66E-08 | 0,89 |
| **Iron ore, 65% Fe, at beneficiation/GLO U** | 1,04E-05 | 0,00 | 6,11E-05 | 0,00 | 2,30E-05 | 0,00 | 2,83E-02 | 0,00 | 1,01E-10 | 0,00 |
| **Iron ore, 65% Fe, at beneficiation/GLO U (iron dust)** | 3,65E-07 | 0,00 | 2,14E-06 | 0,00 | 8,06E-07 | 0,00 | 9,91E-04 | 0,00 | 3,55E-12 | 0,00 |
| **Liquid iron TR** | 7,01E-01 | 3,10 | 5,47E-01 | 3,35 | 1,95E+00 | 48,69 | 6,34E+01 | 3,72 | -1,59E-06 | -14,64 |
| **Natural gas, burned in gas motor, for storage/RU U** | 4,01E-05 | 0,00 | 1,56E-04 | 0,00 | 1,10E-03 | 0,03 | 1,59E-01 | 0,01 | 1,75E-09 | 0,02 |
| **Oxygen TR** | 3,44E-01 | 1,52 | 2,56E-01 | 1,57 | 5,74E-01 | 14,33 | 3,15E+01 | 1,85 | -1,61E-07 | -1,48 |
| **Pure water TR** | 9,40E-02 | 0,42 | 7,01E-02 | 0,43 | 1,57E-01 | 3,92 | 8,67E+00 | 0,51 | -4,33E-08 | -0,40 |
| **Quicklime, in pieces, loose, at plant/CH U** | 1,63E-02 | 0,07 | 1,18E-02 | 0,07 | 6,27E-03 | 0,16 | 6,06E+01 | 3,56 | 2,73E-06 | 25,13 |
| **Reinforcing steel, at plant/RER U** | 2,10E+01 | 92,80 | 1,51E+01 | 92,39 | 2,41E-01 | 6,02 | 1,49E+03 | 87,47 | 9,93E-06 | 91,41 |
| **Service water TR** | 7,08E-03 | 0,03 | 5,48E-03 | 0,03 | 1,17E-02 | 0,29 | 8,51E-01 | 0,05 | 1,57E-10 | 0,00 |
| **Steam TR** | 1,96E-01 | 0,87 | 1,46E-01 | 0,89 | 3,27E-01 | 8,17 | 1,80E+01 | 1,06 | -9,21E-08 | -0,85 |
| **Total** | 2,26E+01 | 100,00 | 1,63E+01 | 100,00 | 4,00E+00 | 100,00 | 1,70E+03 | 100,00 | 1,09E-05 | 100,00 |

Table 49. Contribution of inputs and outputs to mid-point impact categories for 1 ton of liquid steel production-continued 2

| Inputs/Outputs | Respiratory Organics (kg $C_2H_4$ eq) | | Aquatic Ecotoxicity (kg TEG water) | | Terrestrial Ecotoxicity (kg TEG soil) | | Terrestrial Acidifcation/Nitrification (kg $SO_2$ eq) | | Land Occupation ($m^2$org.arable) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Amount** | **%** | **Amount** | **%** | **Amount** | **%** | **Amount** | **%** | **Amount** | **%** |
| **Emission Contribution** | 0,00E+00 | 0,00 | 0,00E+00 | 0,00 | 0,00E+00 | 0,00 | 6,85E-02 | 0,20 | 0,00E+00 | 0,00 |
| **Anthracite coal, at mine/RNA** | 7,72E-05 | 0,08 | 1,98E+01 | 0,02 | 2,61E+00 | 0,01 | 2,51E-02 | 0,07 | 0,00E+00 | 0,00 |
| **Coke oven gas TR** | 2,19E-04 | 0,23 | 6,08E+02 | 0,65 | 1,50E+02 | 0,68 | 1,23E-01 | 0,35 | 3,12E-03 | 0,78 |
| **Coke TR** | 4,88E-05 | 0,05 | 1,36E+02 | 0,15 | 3,34E+01 | 0,15 | 2,73E-02 | 0,08 | 6,95E-04 | 0,17 |
| **Coke TR (Coke breeze)** | 2,25E-05 | 0,02 | 6,25E+01 | 0,07 | 1,54E+01 | 0,07 | 1,26E-02 | 0,04 | 3,21E-04 | 0,08 |
| **Desulfurisation slag TR** | 3,57E-04 | 0,38 | 3,61E+02 | 0,39 | 8,50E+01 | 0,38 | 1,33E-01 | 0,38 | 1,54E-03 | 0,38 |
| **Electricity generated in facility TR** | 8,88E-04 | 0,95 | 5,56E+03 | 5,93 | 1,27E+03 | 5,74 | 3,28E+00 | 9,46 | 1,81E-02 | 4,51 |
| **Electricity, production mix /TR2009/ U** | 7,15E-04 | 0,76 | 2,81E+01 | 0,03 | 9,75E+00 | 0,04 | 7,16E-02 | 0,21 | 2,66E-04 | 0,07 |
| **Iron ore, 65% Fe, at beneficiation/GLO U** | 1,85E-06 | 0,00 | 3,39E+00 | 0,00 | 6,95E-01 | 0,00 | 1,38E-04 | 0,00 | 1,61E-06 | 0,00 |
| **Iron ore, 65% Fe, at beneficiation/GLO U (iron dust)** | 6,48E-08 | 0,00 | 1,19E-01 | 0,00 | 2,43E-02 | 0,00 | 4,84E-06 | 0,00 | 5,63E-08 | 0,00 |
| **Liquid iron TR** | -2,51E-03 | -2,68 | 4,45E+04 | 47,47 | 1,01E+04 | 45,61 | 1,54E+01 | 44,40 | 1,31E-01 | 32,65 |
| **Natural gas, burned in gas motor, for storage/RU U** | 2,86E-03 | 3,05 | 3,56E-01 | 0,00 | 1,68E-01 | 0,00 | 2,30E-02 | 0,07 | 2,04E-05 | 0,01 |
| **Oxygen TR** | 1,75E-03 | 1,87 | 1,10E+04 | 11,73 | 2,51E+03 | 11,34 | 6,48E+00 | 18,68 | 3,57E-02 | 8,90 |
| **Pure water TR** | 4,85E-04 | 0,52 | 3,00E+03 | 3,20 | 6,86E+02 | 3,10 | 1,77E+00 | 5,10 | 9,77E-03 | 2,43 |
| **Quicklime, in pieces, loose, at plant/CH U** | 8,56E-03 | 9,14 | 4,90E+02 | 0,52 | 1,10E+02 | 0,50 | 1,57E-01 | 0,45 | 5,72E-04 | 0,14 |
| **Reinforcing steel, at plant/RER U** | 7,91E-02 | 84,48 | 2,15E+04 | 22,94 | 5,69E+03 | 25,70 | 3,28E+00 | 9,46 | 1,79E-01 | 44,61 |
| **Service water TR** | 6,03E-05 | 0,06 | 2,21E+02 | 0,24 | 5,07E+01 | 0,23 | 1,32E-01 | 0,38 | 7,26E-04 | 0,18 |
| **Steam TR** | 1,00E-03 | 1,07 | 6,25E+03 | 6,67 | 1,43E+03 | 6,46 | 3,70E+00 | 10,67 | 2,04E-02 | 5,08 |
| **Total** | 9,36E-02 | 100,00 | 9,37E+04 | 100,00 | 2,21E+04 | 100,00 | 3,47E+01 | 100,00 | 4,01E-01 | 100,00 |

Table 49. Contribution of inputs and outputs to mid-point impact categories for 1 ton of liquid steel production-continued 3

| Inputs/Outputs | Aquatic Acidification (kg $SO_2$ eq) | | Aquatic Eutrophication (kg $PO_4$ P-lim) | | Global Warming (kg $CO_2$ eq) | | Non-renewable Energy (MJ primary) | | Mineral Extraction (MJ surplus) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Amount** | **%** | **Amount** | **%** | **Amount** | **%** | **Amount** | **%** | **Amount** | **%** |
| **Emission Contribution** | 8,78E-03 | 0,10 | 0,00E+00 | 0,00 | 2,29E+02 | 24,12 | 0,00E+00 | 0,00 | 1,53E+00 | 2,37 |
| **Anthracite coal, at mine/RNA** | 1,45E-02 | 0,17 | 3,75E-07 | 0,00 | 8,61E-01 | 0,09 | 6,37E+01 | 1,02 | 0,00E+00 | 0,00 |
| **Coke oven gas TR** | 1,80E-02 | 0,21 | 4,29E-04 | -0,75 | -2,85E+00 | -0,30 | 7,81E+01 | 1,25 | 6,07E-02 | 0,09 |
| **Coke TR** | 4,01E-03 | 0,05 | 9,55E-05 | -0,17 | -2,93E-01 | -0,03 | 1,74E+01 | 0,28 | 1,35E-02 | 0,02 |
| **Coke TR (coke breeze)** | 1,85E-03 | 0,02 | 4,41E-05 | -0,08 | -6,35E-01 | -0,07 | 8,03E+00 | 0,13 | 6,24E-03 | 0,01 |
| **Desulfurisation slag TR** | 3,33E-02 | 0,38 | -2,23E-04 | 0,39 | 3,62E+00 | 0,38 | 2,40E+01 | 0,38 | 2,48E-01 | 0,38 |
| **Electricity generated in facility TR** | 7,95E-01 | 9,17 | -6,92E-03 | 12,11 | 7,03E+01 | 7,40 | 2,13E+02 | 3,40 | 2,67E+00 | 4,14 |
| **Electricity, production mix /TR2009/ U** | 2,92E-02 | 0,34 | 4,63E-03 | -8,10 | 7,48E+00 | 0,79 | 1,00E+02 | 1,60 | 6,33E-04 | 0,00 |
| **Iron ore, 65% Fe, at beneficiation/GLO U** | 2,08E-05 | 0,00 | 4,93E-07 | 0,00 | 1,34E-03 | 0,00 | 2,50E-02 | 0,00 | 3,15E-03 | 0,00 |
| **Iron ore, 65% Fe, at beneficiation/GLO U (iron dust)** | 7,27E-07 | 0,00 | 1,73E-08 | 0,00 | 4,68E-05 | 0,00 | 8,76E-04 | 0,00 | 1,10E-04 | 0,00 |
| **Liquid iron TR** | 3,92E+00 | 45,23 | -7,54E-02 | 131,93 | 9,55E+01 | 10,06 | 7,70E+02 | 12,30 | 2,25E+01 | 34,86 |
| **Natural gas, burned in gas motor, for storage/RU U** | 7,99E-03 | 0,09 | 1,47E-06 | 0,00 | 7,25E+00 | 0,76 | 1,42E+02 | 2,27 | 4,09E-06 | 0,00 |
| **Oxygen TR** | 1,57E+00 | 18,12 | -1,37E-02 | 23,97 | 1,39E+02 | 14,64 | 4,20E+02 | 6,71 | 5,27E+00 | 8,16 |
| **Pure water TR** | 4,29E-01 | 4,95 | -3,69E-03 | 6,46 | 3,80E+01 | 4,00 | 1,16E+02 | 1,85 | 1,44E+00 | 2,23 |
| **Quicklime, in pieces, loose, at plant/CH U** | 3,52E-02 | 0,41 | 2,81E-04 | -0,49 | 3,91E+01 | 4,12 | 2,15E+02 | 3,43 | 1,19E-03 | 0,00 |
| **Reinforcing steel, at plant/RER U** | 8,73E-01 | 10,07 | 4,52E-02 | -79,09 | 2,41E+02 | 25,38 | 3,84E+03 | 61,35 | 2,77E+01 | 42,91 |
| **Service water TR** | 3,25E-02 | 0,38 | -1,11E-04 | 0,19 | 3,05E+00 | 0,32 | 1,19E+01 | 0,19 | 1,06E-01 | 0,16 |
| **Steam TR** | 8,94E-01 | 10,32 | -7,79E-03 | 13,63 | 7,91E+01 | 8,33 | 2,40E+02 | 3,83 | 3,00E+00 | 4,65 |
| **Total** | 8,67E+00 | 100,00 | -5,72E-02 | 100,00 | 9,49E+02 | 100,00 | 6,26E+03 | 100,00 | 6,45E+01 | 100,00 |

Table 50. Contribution of inputs and outputs to mid-point impact categories for 1 ton of billet production

| Inputs/Outputs | Carcinogens (kg $C_2H_3Cl$ eq) | | Non-carcinogens (kg $C_2H_3Cl$ eq) | | Respiratory Inorganics (kg PM2.5 eq) | | Ionizing Radiation (Bq C-14 eq) | | Ozone Layer Depletion (kg CFC-11 eq) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Amount** | **%** | **Amount** | **%** | **Amount** | **%** | **Amount** | **%** | **Amount** | **%** |
| **Emission Contribution** | 0,00E+00 | 0,00 | 0,00E+00 | 0,00 | 0,00E+00 | 0,00 | 0,00E+00 | 0,00 | 0,00E+00 | 0,00 |
| **Argon TR** | 7,75E-04 | 0,00 | 5,78E-04 | 0,00 | 1,29E-03 | 0,03 | 7,11E-02 | 0,00 | -3,64E-10 | 0,00 |
| **Coke oven gas TR** | 3,55E-03 | 0,02 | 1,20E-03 | 0,01 | 5,70E-03 | 0,13 | 9,73E-01 | 0,06 | 1,95E-08 | 0,18 |
| **Electricity generated in facility TR** | 4,19E-02 | 0,19 | 3,12E-02 | 0,19 | 6,99E-02 | 1,65 | 3,84E+00 | 0,23 | -1,96E-08 | -0,18 |
| **Electricity, production mix /TR2009/ U** | 1,23E-03 | 0,01 | 2,37E-03 | 0,01 | 1,18E-03 | 0,03 | 1,50E+00 | 0,09 | 2,33E-08 | 0,22 |
| **Liquefied petroleum gas, at service station/CH U** | 8,43E-04 | 0,00 | 5,80E-04 | 0,00 | 1,03E-04 | 0,00 | 4,50E-01 | 0,03 | 1,37E-07 | 1,27 |
| **Liquid steel TR** | 2,24E+01 | 99,34 | 1,62E+01 | 99,32 | 3,98E+00 | 94,17 | 1,68E+03 | 99,03 | 1,07E-05 | 98,91 |
| **Natural gas, burned in gas motor, for storage/RU U** | 2,25E-07 | 0,00 | 8,79E-07 | 0,00 | 6,16E-06 | 0,00 | 8,95E-04 | 0,00 | 9,83E-12 | 0,00 |
| **Nitrogen TR** | 4,02E-02 | 0,18 | 3,00E-02 | 0,18 | 6,71E-02 | 1,59 | 3,69E+00 | 0,22 | -1,89E-08 | -0,17 |
| **Oxygen TR** | 1,74E-02 | 0,08 | 1,30E-02 | 0,08 | 2,90E-02 | 0,69 | 1,59E+00 | 0,09 | -8,16E-09 | -0,08 |
| **Pure water TR** | 3,18E-02 | 0,14 | 2,37E-02 | 0,15 | 5,30E-02 | 1,25 | 2,93E+00 | 0,17 | -1,46E-08 | -0,13 |
| **Service water TR** | 1,16E-02 | 0,05 | 9,02E-03 | 0,06 | 1,92E-02 | 0,45 | 1,40E+00 | 0,08 | 2,59E-10 | 0,00 |
| **Total** | 2,25E+01 | 100,00 | 1,63E+01 | 100,00 | 4,23E+00 | 100,00 | 1,70E+03 | 100,00 | 1,08E-05 | 100,00 |

Table 50. Contribution of inputs and outputs to mid-point impact categories for 1 ton of billet production-continued 2

| **Inputs/Outputs** | **Respiratory Organics (kg $C_2H_4$ eq)** | | **Aquatic Ecotoxicity (kg TEG water)** | | **Terrestrial Ecotoxicity (kg TEG soil)** | | **Terrestrial Acidifcation/Nitrification (kg $SO_2$ eq)** | | **Land Occupation ($m^2$org.arable)** | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Amount** | **%** | **Amount** | **%** | **Amount** | **%** | **Amount** | **%** | **Amount** | **%** |
| **Emission Contribution** | 0,00E+00 | 0,00 | 0,00E+00 | 0,00 | 0,00E+00 | 0,00 | 0,00E+00 | 0,00 | 0,00E+00 | 0,00 |
| **Anthracite coal, at mine/RNA** | 3,95E-06 | 0,00 | 2,47E+01 | 0,03 | 5,66E+00 | 0,02 | 1,46E-02 | 0,04 | 8,06E-05 | 0,02 |
| **Coke oven gas TR** | 1,81E-04 | 0,19 | 5,01E+02 | 0,51 | 1,24E+02 | 0,54 | 1,01E-01 | 0,27 | 2,57E-03 | 0,62 |
| **Coke TR** | 2,13E-04 | 0,23 | 1,33E+03 | 1,35 | 3,06E+02 | 1,32 | 7,89E-01 | 2,11 | 4,35E-03 | 1,05 |
| **Liquid iron TR** | 1,73E-04 | 0,18 | 6,78E+00 | 0,01 | 2,35E+00 | 0,01 | 1,73E-02 | 0,05 | 6,43E-05 | 0,02 |
| **Natural gas, burned in gas motor, for storage/RU U** | 3,64E-04 | 0,39 | 3,22E+00 | 0,00 | 2,77E-01 | 0,00 | 2,57E-03 | 0,01 | 1,17E-05 | 0,00 |
| **Oxygen TR** | 9,23E-02 | 98,39 | 9,33E+04 | 94,84 | 2,20E+04 | 94,93 | 3,45E+01 | 92,43 | 3,98E-01 | 95,78 |
| **Pure water TR** | 1,61E-05 | 0,02 | 2,00E-03 | 0,00 | 9,44E-04 | 0,00 | 1,29E-04 | 0,00 | 1,15E-07 | 0,00 |
| **Quicklime, in pieces, loose, at plant/CH U** | 2,05E-04 | 0,22 | 1,28E+03 | 1,30 | 2,94E+02 | 1,27 | 7,57E-01 | 2,03 | 4,18E-03 | 1,01 |
| **Reinforcing steel, at plant/RER U** | 8,86E-05 | 0,09 | 5,54E+02 | 0,56 | 1,27E+02 | 0,55 | 3,28E-01 | 0,88 | 1,81E-03 | 0,44 |
| **Service water TR** | 1,64E-04 | 0,17 | 1,01E+03 | 1,03 | 2,32E+02 | 1,00 | 5,99E-01 | 1,60 | 3,30E-03 | 0,79 |
| **Steam TR** | 9,92E-05 | 0,11 | 3,63E+02 | 0,37 | 8,34E+01 | 0,36 | 2,18E-01 | 0,58 | 1,19E-03 | 0,29 |
| **Total** | 9,38E-02 | 100,00 | 9,84E+04 | 100,00 | 2,32E+04 | 100,00 | 3,73E+01 | 100,00 | 4,16E-01 | 100,00 |

Table 50. Contribution of inputs and outputs to mid-point impact categories for 1 ton of billet production-continued 3

| Inputs/Outputs | Aquatic Acidification (kg $SO_2$ eq) | | Aquatic Eutrophication (kg $PO_4$ P-lim) | | Global Warming (kg $CO_2$ eq) | | Non-renewable Energy (MJ primary) | | Mineral Extraction (MJ surplus) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Amount** | **%** | **Amount** | **%** | **Amount** | **%** | **Amount** | **%** | **Amount** | **%** |
| **Emission Contribution** | 0,00E+00 | 0,00 | 0,00E+00 | 0,00 | 7,37E+00 | 0,74 | 0,00E+00 | 0,00 | 0,00E+00 | 0,00 |
| **Anthracite coal, at mine/RNA** | 3,53E-03 | 0,04 | -3,08E-05 | 0,05 | 3,13E-01 | 0,03 | 9,48E-01 | 0,01 | 1,19E-02 | 0,02 |
| **Coke oven gas TR** | 1,49E-02 | 0,16 | 3,53E-04 | -0,57 | -2,35E+00 | -0,23 | 6,44E+01 | 0,99 | 5,00E-02 | 0,08 |
| **Coke TR** | 1,91E-01 | 2,05 | -1,66E-03 | 2,69 | 1,69E+01 | 1,69 | 5,12E+01 | 0,79 | 6,41E-01 | 0,97 |
| **Coke TR** | 7,04E-03 | 0,08 | 1,12E-03 | -1,81 | 1,80E+00 | 0,18 | 2,41E+01 | 0,37 | 1,53E-04 | 0,00 |
| **Desulfurisation slag TR** | 6,35E-04 | 0,01 | 2,34E-05 | -0,04 | 1,10E-01 | 0,01 | 1,09E+01 | 0,17 | 6,77E-06 | 0,00 |
| **Oxygen TR** | 8,62E+00 | 92,71 | -5,78E-02 | 93,65 | 9,37E+02 | 93,49 | 6,20E+03 | 95,66 | 6,41E+01 | 96,61 |
| **Pure water TR** | 4,49E-05 | 0,00 | 8,25E-09 | 0,00 | 4,07E-02 | 0,00 | 7,95E-01 | 0,01 | 2,30E-08 | 0,00 |
| **Quicklime, in pieces, loose, at plant/CH U** | 1,83E-01 | 1,97 | -1,60E-03 | 2,59 | 1,62E+01 | 1,62 | 4,91E+01 | 0,76 | 6,16E-01 | 0,93 |
| **Reinforcing steel, at plant/RER U** | 7,93E-02 | 0,85 | -6,91E-04 | 1,12 | 7,01E+00 | 0,70 | 2,13E+01 | 0,33 | 2,66E-01 | 0,40 |
| **Service water TR** | 1,45E-01 | 1,56 | -1,25E-03 | 2,03 | 1,28E+01 | 1,28 | 3,91E+01 | 0,60 | 4,87E-01 | 0,73 |
| **Steam TR** | 5,34E-02 | 0,57 | -1,83E-04 | 0,30 | 5,01E+00 | 0,50 | 1,97E+01 | 0,30 | 1,74E-01 | 0,26 |
| **Total** | 9,30E+00 | 100,00 | -6,17E-02 | 100,00 | 1,00E+03 | 100,00 | 6,48E+03 | 100,00 | 6,63E+01 | 100,00 |

Table 51. Contribution of inputs and outputs to mid-point impact categories for 1 ton of slab production

| Inputs/Outputs | Carcinogens (kg $C_2H_3Cl$ eq) | | Non-carcinogens (kg $C_2H_3Cl$ eq) | | Respiratory Inorganics (kg PM2.5 eq) | | Ionizing Radiation (Bq C-14 eq) | | Ozone Layer Depletion (kg CFC-11 eq) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Amount** | **%** | **Amount** | **%** | **Amount** | **%** | **Amount** | **%** | **Amount** | **%** |
| **Emission Contribution** | 0,00E+00 | 0,00 | 0,00E+00 | 0,00 | 0,00E+00 | 0,00 | 0,00E+00 | 0,00 | 0,00E+00 | 0,00 |
| **Argon TR** | 1,29E-03 | 0,01 | 9,59E-04 | 0,01 | 2,15E-03 | 0,05 | 1,18E-01 | 0,01 | -6,04E-10 | -0,01 |
| **Coke oven gas TR** | 2,43E-03 | 0,01 | 8,22E-04 | 0,01 | 3,91E-03 | 0,09 | 6,66E-01 | 0,04 | 1,34E-08 | 0,13 |
| **Electricity generated in facility TR** | 3,67E-02 | 0,16 | 2,73E-02 | 0,17 | 6,12E-02 | 1,49 | 3,36E+00 | 0,20 | -1,72E-08 | -0,16 |
| **Electricity, production mix /TR2009/ U** | 1,08E-03 | 0,00 | 2,08E-03 | 0,01 | 1,03E-03 | 0,03 | 1,31E+00 | 0,08 | 2,04E-08 | 0,19 |
| **Liquefied petroleum gas, at service station/CH U** | 4,08E-04 | 0,00 | 2,81E-04 | 0,00 | 4,97E-05 | 0,00 | 2,18E-01 | 0,01 | 6,64E-08 | 0,62 |
| **Liquid steel TR** | 2,23E+01 | 99,61 | 1,61E+01 | 99,58 | 3,97E+00 | 96,46 | 1,67E+03 | 99,34 | 1,06E-05 | 99,25 |
| **Natural gas, burned in gas motor, for storage/RU U** | 2,74E-05 | 0,00 | 1,07E-04 | 0,00 | 7,49E-04 | 0,02 | 1,09E-01 | 0,01 | 1,19E-09 | 0,01 |
| **Nitrogen TR** | 3,75E-03 | 0,02 | 2,80E-03 | 0,02 | 6,26E-03 | 0,15 | 3,44E-01 | 0,02 | -1,76E-09 | -0,02 |
| **Oxygen TR** | 2,90E-03 | 0,01 | 2,16E-03 | 0,01 | 4,83E-03 | 0,12 | 2,65E-01 | 0,02 | -1,36E-09 | -0,01 |
| **Pure water TR** | 1,89E-03 | 0,01 | 1,41E-03 | 0,01 | 3,15E-03 | 0,08 | 1,74E-01 | 0,01 | -8,68E-10 | -0,01 |
| **Service water TR** | 3,79E-02 | 0,17 | 2,94E-02 | 0,18 | 6,25E-02 | 1,52 | 4,55E+00 | 0,27 | 8,42E-10 | 0,01 |
| **Total** | 2,24E+01 | 100,00 | 1,62E+01 | 100,00 | 4,12E+00 | 100,00 | 1,68E+03 | 100,00 | 1,07E-05 | 100,00 |

Table 51. Contribution of inputs and outputs to mid-point impact categories for 1 ton of slab production-continued 2

| Inputs/Outputs | Respiratory Organics (kg $C_2H_4$ eq) | | Aquatic Ecotoxicity (kg TEG water) | | Terrestrial Ecotoxicity (kg TEG soil) | | Terrestrial Acidifcation/Nitrification (kg $SO_2$ eq) | | Land Occupation ($m^2$org.arable) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Amount** | **%** | **Amount** | **%** | **Amount** | **%** | **Amount** | **%** | **Amount** | **%** |
| **Emission Contribution** | 0,00E+00 | 0,00 | 0,00E+00 | 0,00 | 0,00E+00 | 0,00 | 0,00E+00 | 0,00 | 0,00E+00 | 0,00 |
| **Argon TR** | 6,56E-06 | 0,01 | 4,10E+01 | 0,04 | 9,39E+00 | 0,04 | 2,42E-02 | 0,07 | 1,34E-04 | 0,03 |
| **Coke oven gas TR** | 1,24E-04 | 0,13 | 3,43E+02 | 0,36 | 8,48E+01 | 0,38 | 6,93E-02 | 0,19 | 1,76E-03 | 0,43 |
| **Electricity generated in facility TR** | 1,87E-04 | 0,20 | 1,17E+03 | 1,22 | 2,68E+02 | 1,19 | 6,91E-01 | 1,91 | 3,81E-03 | 0,93 |
| **Electricity, production mix /TR2009/ U** | 1,51E-04 | 0,16 | 5,94E+00 | 0,01 | 2,06E+00 | 0,01 | 1,51E-02 | 0,04 | 5,63E-05 | 0,01 |
| **Liquefied petroleum gas, at service station/CH U** | 1,76E-04 | 0,19 | 1,56E+00 | 0,00 | 1,34E-01 | 0,00 | 1,24E-03 | 0,00 | 5,67E-06 | 0,00 |
| **Liquid steel TR** | 9,21E-02 | 96,88 | 9,30E+04 | 96,86 | 2,19E+04 | 96,91 | 3,44E+01 | 95,33 | 3,97E-01 | 97,41 |
| **Natural gas, burned in gas motor, for storage/RU U** | 1,95E-03 | 2,05 | 2,43E-01 | 0,00 | 1,15E-01 | 0,00 | 1,57E-02 | 0,04 | 1,39E-05 | 0,00 |
| **Nitrogen TR** | 1,91E-05 | 0,02 | 1,20E+02 | 0,12 | 2,74E+01 | 0,12 | 7,07E-02 | 0,20 | 3,90E-04 | 0,10 |
| **Oxygen TR** | 1,48E-05 | 0,02 | 9,23E+01 | 0,10 | 2,11E+01 | 0,09 | 5,45E-02 | 0,15 | 3,01E-04 | 0,07 |
| **Pure water TR** | 9,72E-06 | 0,01 | 6,01E+01 | 0,06 | 1,38E+01 | 0,06 | 3,55E-02 | 0,10 | 1,96E-04 | 0,05 |
| **Service water TR** | 3,23E-04 | 0,34 | 1,18E+03 | 1,23 | 2,71E+02 | 1,20 | 7,09E-01 | 1,96 | 3,89E-03 | 0,95 |
| **Total** | 9,51E-02 | 100,00 | 9,60E+04 | 100,00 | 2,26E+04 | 100,00 | 3,61E+01 | 100,00 | 4,08E-01 | 100,00 |

Table 51. Contribution of inputs and outputs to mid-point impact categories for 1 ton of slab production-continued 3

| Inputs/Outputs | Aquatic Acidification (kg $SO_2$ eq) | | Aquatic Eutrophication (kg $PO_4$ P-lim) | | Global Warming (kg $CO_2$ eq) | | Non-renewable Energy (MJ primary) | | Mineral Extraction (MJ surplus) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Amount** | **%** | **Amount** | **%** | **Amount** | **%** | **Amount** | **%** | **Amount** | **%** |
| **Emission Contribution** | 0,00E+00 | 0,00 | 0,00E+00 | 0,00 | 1,59E+01 | 1,61 | 0,00E+00 | 0,00 | 0,00E+00 | 0,00 |
| **Argon TR** | 5,86E-03 | 0,07 | -5,11E-05 | 0,09 | 5,19E-01 | 0,05 | 1,57E+00 | 0,02 | 1,97E-02 | 0,03 |
| **Coke oven gas TR** | 1,02E-02 | 0,11 | 2,42E-04 | -0,41 | -1,61E+00 | -0,16 | 4,41E+01 | 0,68 | 3,43E-02 | 0,05 |
| **Electricity generated in facility TR** | 1,67E-01 | 1,85 | -1,46E-03 | 2,48 | 1,48E+01 | 1,50 | 4,48E+01 | 0,69 | 5,62E-01 | 0,86 |
| **Electricity, production mix /TR2009/ U** | 6,17E-03 | 0,07 | 9,79E-04 | -1,66 | 1,58E+00 | 0,16 | 2,11E+01 | 0,33 | 1,34E-04 | 0,00 |
| **Liquefied petroleum gas, at service station/CH U** | 3,07E-04 | 0,00 | 1,13E-05 | -0,02 | 5,34E-02 | 0,01 | 5,27E+00 | 0,08 | 3,28E-06 | 0,00 |
| **Liquid steel TR** | 8,60E+00 | 95,47 | -5,76E-02 | 97,94 | 9,34E+02 | 94,35 | 6,18E+03 | 95,55 | 6,39E+01 | 97,99 |
| **Natural gas, burned in gas motor, for storage/RU U** | 5,45E-03 | 0,06 | 1,00E-06 | 0,00 | 4,95E+00 | 0,50 | 9,67E+01 | 1,50 | 2,79E-06 | 0,00 |
| **Nitrogen TR** | 1,71E-02 | 0,19 | -1,49E-04 | 0,25 | 1,51E+00 | 0,15 | 4,59E+00 | 0,07 | 5,75E-02 | 0,09 |
| **Oxygen TR** | 1,32E-02 | 0,15 | -1,15E-04 | 0,20 | 1,17E+00 | 0,12 | 3,54E+00 | 0,05 | 4,43E-02 | 0,07 |
| **Pure water TR** | 8,59E-03 | 0,10 | -7,40E-05 | 0,13 | 7,61E-01 | 0,08 | 2,32E+00 | 0,04 | 2,89E-02 | 0,04 |
| **Service water TR** | 1,74E-01 | 1,93 | -5,95E-04 | 1,01 | 1,63E+01 | 1,65 | 6,39E+01 | 0,99 | 5,66E-01 | 0,87 |
| **Total** | 9,01E+00 | 100,00 | -5,88E-02 | 100,00 | 9,90E+02 | 100,00 | 6,47E+03 | 100,00 | 6,52E+01 | 100,00 |

Table 52. Contribution of inputs and outputs to mid-point impact categories for 1 ton of wire rod production

| Inputs/Outputs | Carcinogens (kg $C_2H_3Cl$ eq) | | Non-carcinogens (kg $C_2H_3Cl$ eq) | | Respiratory Inorganics (kg PM2.5 eq) | | Ionizing Radiation (Bq C-14 eq) | | Ozone Layer Depletion (kg CFC-11 eq) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Amount** | **%** | **Amount** | **%** | **Amount** | **%** | **Amount** | **%** | **Amount** | **%** |
| **Emission Contribution** | 0,00E+00 | 0,00 | 0,00E+00 | 0,00 | 3,28E-02 | 0,65 | 0,00E+00 | 0,00 | 0,00E+00 | 0,00 |
| **Billet TR** | 2,25E+01 | 97,97 | 1,63E+01 | 97,82 | 4,23E+00 | 83,91 | 1,69E+03 | 96,62 | 1,08E-05 | 99,50 |
| **Electricity generated in facility TR** | 4,08E-01 | 1,78 | 3,04E-01 | 1,82 | 6,80E-01 | 13,49 | 3,74E+01 | 2,14 | -1,91E-07 | -1,76 |
| **Electricity, production mix /TR2009/ U** | 1,19E-02 | 0,05 | 2,29E-02 | 0,14 | 1,14E-02 | 0,23 | 1,45E+01 | 0,83 | 2,26E-07 | 2,08 |
| **Natural gas, burned in gas motor, for storage/RU U** | 4,46E-04 | 0,00 | 1,74E-03 | 0,01 | 1,22E-02 | 0,24 | 1,77E+00 | 0,10 | 1,95E-08 | 0,18 |
| **Oxygen TR** | 1,71E-03 | 0,01 | 1,28E-03 | 0,01 | 2,86E-03 | 0,06 | 1,57E-01 | 0,01 | -8,04E-10 | -0,01 |
| **Service water TR** | 4,37E-02 | 0,19 | 3,39E-02 | 0,20 | 7,21E-02 | 1,43 | 5,25E+00 | 0,30 | 9,71E-10 | 0,01 |
| **Total** | 2,30E+01 | 100,00 | 1,67E+01 | 100,00 | 5,04E+00 | 100,00 | 1,75E+03 | 100,00 | 1,09E-05 | 100,00 |

| Inputs/Outputs | Respiratory Organics (kg $C_2H_4$ eq) | | Aquatic Ecotoxicity (kg TEG water) | | Terrestrial Ecotoxicity (kg TEG soil) | | Terrestrial Acidifcation/Nitrification (kg $SO_2$ eq) | | Land Occupation ($m^2$org.arable) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Amount** | **%** | **Amount** | **%** | **Amount** | **%** | **Amount** | **%** | **Amount** | **%** |
| **Emission Contribution** | 0,00E+00 | 0,00 | 0,00E+00 | 0,00 | 0,00E+00 | 0,00 | 6,26E-01 | 1,34 | 0,00E+00 | 0,00 |
| **Billet TR** | 9,38E-02 | 72,30 | 9,84E+04 | 87,17 | 2,32E+04 | 87,45 | 3,73E+01 | 79,57 | 4,16E-01 | 89,67 |
| **Electricity generated in facility TR** | 2,08E-03 | 1,60 | 1,30E+04 | 11,52 | 2,98E+03 | 11,23 | 7,68E+00 | 16,38 | 4,24E-02 | 9,14 |
| **Electricity, production mix /TR2009/ U** | 1,67E-03 | 1,29 | 6,57E+01 | 0,06 | 2,28E+01 | 0,09 | 1,67E-01 | 0,36 | 6,22E-04 | 0,13 |
| **Natural gas, burned in gas motor, for storage/RU U** | 3,18E-02 | 24,51 | 3,96E+00 | 0,00 | 1,87E+00 | 0,01 | 2,56E-01 | 0,55 | 2,27E-04 | 0,05 |
| **Oxygen TR** | 8,73E-06 | 0,01 | 5,46E+01 | 0,05 | 1,25E+01 | 0,05 | 3,23E-02 | 0,07 | 1,78E-04 | 0,04 |
| **Service water TR** | 3,72E-04 | 0,29 | 1,36E+03 | 1,20 | 3,13E+02 | 1,18 | 8,18E-01 | 1,74 | 4,48E-03 | 0,97 |
| **Total** | 1,30E-01 | 100,00 | 1,13E+05 | 100,00 | 2,65E+04 | 100,00 | 4,69E+01 | 100,00 | 4,64E-01 | 100,00 |

Table 52. Contribution of inputs and outputs to mid-point impact categories for 1 ton of wire rod production-continued 2

| Inputs/Outputs | Aquatic Acidification (kg $SO_2$ eq) | | Aquatic Eutrophication (kg $PO_4$ P-lim) | | Global Warming (kg $CO_2$ eq) | | Non-renewable Energy (MJ primary) | | Mineral Extraction (MJ surplus) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Amount** | **%** | **Amount** | **%** | **Amount** | **%** | **Amount** | **%** | **Amount** | **%** |
| **Emission Contribution** | 7,99E-02 | 0,69 | 0,00E+00 | 0,00 | 4,70E+01 | 3,54 | 0,00E+00 | 0,00 | 0,00E+00 | 0,00 |
| **Billet TR** | 9,29E+00 | 80,12 | -6,16E-02 | 90,94 | 1,00E+03 | 75,27 | 6,48E+03 | 73,16 | 6,63E+01 | 90,55 |
| **Electricity generated in facility TR** | 1,86E+00 | 16,04 | -1,62E-02 | 23,92 | 1,64E+02 | 12,34 | 4,98E+02 | 5,62 | 6,24E+00 | 8,52 |
| **Electricity, production mix /TR2009/ U** | 6,82E-02 | 0,59 | 1,08E-02 | -15,94 | 1,75E+01 | 1,32 | 2,34E+02 | 2,64 | 1,48E-03 | 0,00 |
| **Natural gas, burned in gas motor, for storage/RU U** | 8,88E-02 | 0,77 | 1,63E-05 | -0,02 | 8,06E+01 | 6,07 | 1,57E+03 | 17,72 | 4,54E-05 | 0,00 |
| **Oxygen TR** | 7,80E-03 | 0,07 | -6,80E-05 | 0,10 | 6,91E-01 | 0,05 | 2,09E+00 | 0,02 | 2,62E-02 | 0,04 |
| **Service water TR** | 2,00E-01 | 1,72 | -6,86E-04 | 1,01 | 1,88E+01 | 1,42 | 7,38E+01 | 0,83 | 6,52E-01 | 0,89 |
| **Total** | 1,16E+01 | 100,00 | -6,77E-02 | 100,00 | 1,33E+03 | 100,00 | 8,86E+03 | 100,00 | 7,32E+01 | 100,00 |

Table 53. Contribution of inputs and outputs to mid-point impact categories for 1 ton of coil production

| Inputs/Outputs | Carcinogens (kg $C_2H_3Cl$ eq) | | Non-carcinogens (kg $C_2H_3Cl$ eq) | | Respiratory Inorganics (kg PM2.5 eq) | | Ionizing Radiation (Bq C-14 eq) | | Ozone Layer Depletion (kg CFC-11 eq) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Amount** | **%** | **Amount** | **%** | **Amount** | **%** | **Amount** | **%** | **Amount** | **%** |
| **Emission Contribution** | 0,00E+00 | 0,00 | 0,00E+00 | 0,00 | 6,81E-01 | 11,45 | 0,00E+00 | 0,00 | 0,00E+00 | 0,00 |
| **Coke oven gas TR** | 4,55E-02 | 0,20 | 1,53E-02 | 0,09 | 7,30E-02 | 1,23 | 1,24E+01 | 0,70 | 2,49E-07 | 2,27 |
| **Electricity generated in facility TR** | 4,72E-01 | 2,04 | 3,52E-01 | 2,10 | 7,88E-01 | 13,24 | 4,33E+01 | 2,44 | -2,22E-07 | -2,02 |
| **Electricity, production mix /TR2009/ U** | 1,38E-02 | 0,06 | 2,66E-02 | 0,16 | 1,32E-02 | 0,22 | 1,68E+01 | 0,95 | 2,61E-07 | 2,37 |
| **Nitrogen TR** | 3,26E-03 | 0,01 | 2,43E-03 | 0,01 | 5,44E-03 | 0,09 | 2,99E-01 | 0,02 | -1,53E-09 | -0,01 |
| **Oxygen TR** | 1,20E-03 | 0,01 | 8,91E-04 | 0,01 | 2,00E-03 | 0,03 | 1,10E-01 | 0,01 | -5,61E-10 | -0,01 |
| **Service water TR** | 1,68E-01 | 0,73 | 1,30E-01 | 0,78 | 2,77E-01 | 4,66 | 2,02E+01 | 1,14 | 3,73E-09 | 0,03 |
| **Slab TR** | 2,24E+01 | 96,95 | 1,62E+01 | 96,85 | 4,11E+00 | 69,08 | 1,68E+03 | 94,75 | 1,07E-05 | 97,36 |
| **Total** | 2,31E+01 | 100,00 | 1,67E+01 | 100,00 | 5,95E+00 | 100,00 | 1,77E+03 | 100,00 | 1,10E-05 | 100,00 |

Table 53. Contribution of inputs and outputs to mid-point impact categories for 1 ton of coil production-continued 2

| Inputs/Outputs | Respiratory Organics (kg $C_2H_4$ eq) | | Aquatic Ecotoxicity (kg TEG water) | | Terrestrial Ecotoxicity (kg TEG soil) | | Terrestrial Acidifcation/Nitrification (kg $SO_2$ eq) | | Land Occupation ($m^2$org.arable) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Amount** | **%** | **Amount** | **%** | **Amount** | **%** | **Amount** | **%** | **Amount** | **%** |
| **Emission Contribution** | 0,00E+00 | 0,00 | 0,00E+00 | 0,00 | 0,00E+00 | 0,00 | 8,26E+00 | 14,25 | 0,00E+00 | 0,00 |
| **Coke oven gas TR** | 2,31E-03 | 2,24 | 6,41E+03 | 5,22 | 1,58E+03 | 5,47 | 1,29E+00 | 2,23 | 3,29E-02 | 6,47 |
| **Electricity generated in facility TR** | 2,41E-03 | 2,34 | 1,50E+04 | 12,21 | 3,45E+03 | 11,94 | 8,89E+00 | 15,34 | 4,91E-02 | 9,66 |
| **Electricity, production mix /TR2009/ U** | 1,94E-03 | 1,88 | 7,61E+01 | 0,06 | 2,64E+01 | 0,09 | 1,94E-01 | 0,33 | 7,21E-04 | 0,14 |
| **Nitrogen TR** | 1,66E-05 | 0,02 | 1,04E+02 | 0,08 | 2,38E+01 | 0,08 | 6,14E-02 | 0,11 | 3,39E-04 | 0,07 |
| **Oxygen TR** | 6,09E-06 | 0,01 | 3,81E+01 | 0,03 | 8,73E+00 | 0,03 | 2,25E-02 | 0,04 | 1,24E-04 | 0,02 |
| **Service water TR** | 1,43E-03 | 1,39 | 5,23E+03 | 4,26 | 1,20E+03 | 4,15 | 3,14E+00 | 5,42 | 1,72E-02 | 3,38 |
| **Slab TR** | 9,50E-02 | 92,13 | 9,60E+04 | 78,14 | 2,26E+04 | 78,23 | 3,61E+01 | 62,29 | 4,08E-01 | 80,25 |
| **Total** | 1,03E-01 | 100,00 | 1,23E+05 | 100,00 | 2,89E+04 | 100,00 | 5,80E+01 | 100,00 | 5,08E-01 | 100,00 |



| Inputs/Outputs | Aquatic Acidification (kg $SO_2$ eq) | | Aquatic Eutrophication (kg $PO_4$ P-lim) | | Global Warming (kg $CO_2$ eq) | | Non-renewable Energy (MJ primary) | | Mineral Extraction (MJ surplus) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Amount** | **%** | **Amount** | **%** | **Amount** | **%** | **Amount** | **%** | **Amount** | **%** |
| **Emission Contribution** | 2,66E+00 | 17,89 | 0,00E+00 | 0,00 | 4,09E+01 | 3,19 | 0,00E+00 | 0,00 | 0,00E+00 | 0,00 |
| **Coke oven gas TR** | 1,90E-01 | 1,28 | 4,52E-03 | -7,14 | -3,00E+01 | -2,34 | 8,23E+02 | 9,76 | 6,40E-01 | 0,85 |
| **Electricity generated in facility TR** | 2,15E+00 | 14,46 | -1,87E-02 | 29,55 | 1,90E+02 | 14,80 | 5,77E+02 | 6,85 | 7,23E+00 | 9,56 |
| **Electricity, production mix /TR2009/ U** | 7,90E-02 | 0,53 | 1,25E-02 | -19,75 | 2,02E+01 | 1,57 | 2,71E+02 | 3,21 | 1,72E-03 | 0,00 |
| **Nitrogen TR** | 1,49E-02 | 0,10 | -1,29E-04 | 0,20 | 1,32E+00 | 0,10 | 3,99E+00 | 0,05 | 4,99E-02 | 0,07 |
| **Oxygen TR** | 5,45E-03 | 0,04 | -4,75E-05 | 0,08 | 4,82E-01 | 0,04 | 1,46E+00 | 0,02 | 1,83E-02 | 0,02 |
| **Service water TR** | 7,69E-01 | 5,17 | -2,63E-03 | 4,16 | 7,22E+01 | 5,62 | 2,83E+02 | 3,36 | 2,50E+00 | 3,31 |
| **Slab TR** | 9,00E+00 | 60,53 | -5,88E-02 | 92,91 | 9,89E+02 | 77,02 | 6,47E+03 | 76,75 | 6,52E+01 | 86,20 |
| **Total** | 1,49E+01 | 100,00 | -6,33E-02 | 100,00 | 1,28E+03 | 100,00 | 8,43E+03 | 100,00 | 7,56E+01 | 100,00 |

# APPENDIX J

## NORMALIZED IMPACT ASSESSMENT RESULTS PER MID-POINT IMPACT CATEGORIES OF DIFFERENT PRODUCTION SCENARIOS

Table 54. Normalized impact assessment results of Scenario 1

| Mid-point impact category | Billet TR (Pt) | Slab TR (Pt) | Wire rod TR (Pt) | Coil TR (Pt) | Mechanical workshop TR (Pt) | Total (Pt) | Total (%) |
|---|---|---|---|---|---|---|---|
| **Carcinogens** | 4,69E-03 | 6,66E-04 | 1,60E-03 | 2,06E-03 | 2,93E-06 | 9,02E-03 | 1,35 |
| **Non-carcinogens** | 3,40E-03 | 4,83E-04 | 1,16E-03 | 1,50E-03 | 2,25E-06 | 6,54E-03 | 0,98 |
| **Respiratory inorganics** | 2,20E-01 | 3,06E-02 | 8,74E-02 | 1,33E-01 | 1,44E-03 | 4,73E-01 | 70,54 |
| **Ionizing radiation** | 7,00E-05 | 9,95E-06 | 2,41E-05 | 3,14E-05 | 6,16E-08 | 1,36E-04 | 0,02 |
| **Ozone layer depletion** | 8,44E-07 | 1,20E-07 | 2,83E-07 | 3,69E-07 | -1,16E-10 | 1,62E-06 | 0,00 |
| **Respiratory organics** | 1,49E-05 | 2,15E-06 | 6,85E-06 | 7,01E-06 | 1,70E-08 | 3,09E-05 | 0,00 |
| **Aquatic ecotoxicity** | 1,91E-04 | 2,66E-05 | 7,29E-05 | 1,02E-04 | 8,65E-07 | 3,94E-04 | 0,06 |
| **Terrestrial ecotoxicity** | 7,09E-03 | 9,89E-04 | 2,70E-03 | 3,80E-03 | 3,13E-05 | 1,46E-02 | 2,18 |
| **Terrestrial acid/nutri** | 1,50E-03 | 2,07E-04 | 6,26E-04 | 9,95E-04 | 1,47E-05 | 3,34E-03 | 0,50 |
| **Land occupation** | 1,75E-05 | 2,45E-06 | 6,49E-06 | 9,18E-06 | 6,21E-08 | 3,56E-05 | 0,01 |
| **Aquatic acidification** | 0,00E+00 | 0,00E+00 | 0,00E+00 | 0,00E+00 | 0,00E+00 | 0,00E+00 | 0,00 |
| **Aquatic eutrophication** | 0,00E+00 | 0,00E+00 | 0,00E+00 | 0,00E+00 | 0,00E+00 | 0,00E+00 | 0,00 |
| **Global warming** | 5,34E-02 | 7,53E-03 | 2,36E-02 | 2,93E-02 | 3,13E-04 | 1,14E-01 | 17,03 |
| **Non-renewable energy** | 2,25E-02 | 3,21E-03 | 1,03E-02 | 1,26E-02 | 7,84E-05 | 4,87E-02 | 7,27 |
| **Mineral extraction** | 2,30E-04 | 3,24E-05 | 8,48E-05 | 1,13E-04 | 7,34E-07 | 4,61E-04 | 0,07 |
| **Total Pt** | **3,13E-01** | **4,38E-02** | **1,28E-01** | **1,83E-01** | **1,88E-03** | **6,70E-01** | **100,00** |
| **Total %** | **46,80** | **6,54** | **19,00** | **27,40** | **0,28** | **100,00** | **-** |

Table 55. Normalized impact assessment results of Scenario 2

| Mid-point impact category | Billet TR (Pt) | Slab TR (Pt) | Mechanical workshop TR (Pt) | Total (Pt) | Total (%) |
|---|---|---|---|---|---|
| **Carcinogens** | 6,25E-03 | 2,67E-03 | 2,93E-06 | 8,92E-03 | 1,50 |
| **Non-carcinogens** | 4,52E-03 | 1,93E-03 | 2,24E-06 | 6,45E-03 | 1,08 |
| **Respiratory inorganics** | 2,94E-01 | 1,22E-01 | 1,44E-03 | 4,17E-01 | 70,22 |
| **Ionizing radiation** | 3,53E-05 | 1,50E-05 | 2,46E-08 | 5,04E-05 | 0,01 |
| **Ozone layer depletion** | 1,12E-06 | 4,79E-07 | -1,16E-10 | 1,60E-06 | 0,00 |
| **Respiratory organics** | 1,98E-05 | 8,61E-06 | 1,70E-08 | 2,85E-05 | 0,00 |
| **Aquatic ecotoxicity** | 2,54E-04 | 1,06E-04 | 8,64E-07 | 3,61E-04 | 0,06 |
| **Terrestrial ecotoxicity** | 9,42E-03 | 3,94E-03 | 3,13E-05 | 1,34E-02 | 2,25 |
| **Terrestrial acid/nutri** | 1,99E-03 | 8,26E-04 | 1,47E-05 | 2,84E-03 | 0,48 |
| **Land occupation** | 2,33E-05 | 9,79E-06 | 6,21E-08 | 3,31E-05 | 0,01 |
| **Aquatic acidification** | 0,00E+00 | 0,00E+00 | 0,00E+00 | 0,00E+00 | 0,00 |
| **Aquatic eutrophication** | 0,00E+00 | 0,00E+00 | 0,00E+00 | 0,00E+00 | 0,00 |
| **Global warming** | 7,12E-02 | 3,01E-02 | 3,13E-04 | 1,02E-01 | 17,09 |
| **Non-renewable energy** | 3,00E-02 | 1,28E-02 | 7,84E-05 | 4,30E-02 | 7,22 |
| **Mineral extraction** | 3,07E-04 | 1,29E-04 | 7,34E-07 | 4,37E-04 | 0,07 |
| **Total Pt** | **4,18E-01** | **1,75E-01** | **1,88E-03** | **5,95E-01** | **100,00** |
| **Total %** | **70,20** | **29,50** | **0,32** | **100,00** | **-** |

Table 56. Normalized impact assessment results of Scenario 3

| Mid-point impact category | Wire rod TR (Pt) | Coil TR (Pt) | Mechanical workshop TR (Pt) | Total (Pt) | Total (%) |
|---|---|---|---|---|---|
| **Carcinogens** | 6,38E-03 | 2,75E-03 | 2,93E-06 | 9,14E-03 | 1,21 |
| **Non-carcinogens** | 4,62E-03 | 1,99E-03 | 2,24E-06 | 6,61E-03 | 0,87 |
| **Respiratory inorganics** | 3,50E-01 | 1,77E-01 | 1,44E-03 | 5,28E-01 | 69,84 |
| **Ionizing radiation** | 3,65E-05 | 1,59E-05 | 2,46E-08 | 5,25E-05 | 0,01 |
| **Ozone layer depletion** | 1,13E-06 | 4,93E-07 | -1,16E-10 | 1,62E-06 | 0,00 |
| **Respiratory organics** | 2,74E-05 | 9,35E-06 | 1,70E-08 | 3,68E-05 | 0,00 |
| **Aquatic ecotoxicity** | 2,91E-04 | 1,36E-04 | 8,64E-07 | 4,28E-04 | 0,06 |
| **Terrestrial ecotoxicity** | 1,08E-02 | 5,05E-03 | 3,13E-05 | 1,58E-02 | 2,09 |
| **Terrestrial acid/nutri** | 2,50E-03 | 1,33E-03 | 1,47E-05 | 3,84E-03 | 0,51 |
| **Land occupation** | 2,60E-05 | 1,22E-05 | 6,21E-08 | 3,83E-05 | 0,01 |
| **Aquatic acidification** | 0,00E+00 | 0,00E+00 | 0,00E+00 | 0,00E+00 | 0,00 |
| **Aquatic eutrophication** | 0,00E+00 | 0,00E+00 | 0,00E+00 | 0,00E+00 | 0,00 |
| **Global warming** | 9,44E-02 | 3,90E-02 | 3,13E-04 | 1,34E-01 | 17,68 |
| **Non-renewable energy** | 4,10E-02 | 1,68E-02 | 7,84E-05 | 5,79E-02 | 7,66 |
| **Mineral extraction** | 3,39E-04 | 1,50E-04 | 7,34E-07 | 4,90E-04 | 0,06 |
| **Total Pt** | **5,10E-01** | **2,44E-01** | **1,88E-03** | **7,56E-01** | **100,00** |
| **Total %** | **67,40** | **32,30** | **0,25** | **100,00** | **-** |