EVALUATION OF BEST ENVIRONMENTAL MANAGEMENT PRACTICES OF AN INTEGRATED IRON AND STEEL PLANT

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EVALUATION OF BEST ENVIRONMENTAL MANAGEMENT PRACTICES OF AN INTEGRATED IRON AND STEEL PLANT

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ABSTRACT

EVALUATION OF BEST ENVIRONMENTAL MANAGEMENT PRACTICES OF AN INTEGRATED IRON AND STEEL PLANT

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European Union published IPPC Directive in 1996 aiming to create an integrated approach in order to manage and control industrial facilities better. IPPC provides the development of a new concept of “Best Available Techniques (BAT)”, the most effective, advanced and applicable methods, preventing emissions to the environment and providing efficient use of resources. Within this framework, numerous sectoral Best Available Techniques Reference Documents were published giving information on the sector and BAT alternatives for this sector. Iron and steel industry, which causes quite significant amount of resource depletion and waste production, is one of the industries within the scope of IPPC Directive. In the this study, environmental performance of an integrated iron and steel plant in Turkey is evaluated and compared with the EU’s integrated iron and steel plants, in order to suggest applicable BAT alternatives for the studied plant. Totally 74 BAT alternatives were evaluated and among them 36 alternatives were determined to be applicable for this plant. Finally, two of these applicable BAT alternatives were selected and compared by use of cross-media effects and financial analysis. The results of this study indicated that dust emission and high energy consumption are the common problems in the facility. Moreover, sintering process was found to be the least compatible sub-process with EU’s iron and steel plants. Additionally, it was determined that with respect to application of BAT alternatives, facility is quite compatible with EU’s iron and steel plants. Furthermore, cross media effect and financial analysis revealed that the selected BAT alternatives, "*Advanced Electrostatic Precipitator (ESP)*" and "*Bag Filter-combined or integrated reduction of solid and gaseous pollutants",* have different cross media effects on the environment, however, the second alternative is a more cost-effective alternative than the first one. Since this study was undertaken in an integrated iron and steel plant that represents Turkish iron and steel industry with respect to its production process, production capacity and environmental performance; the results of this study can be used to aid decision makers to make environmental initiatives in iron and steel industry in Turkey.

Keywords: Best Available Techniques (BAT), Cross-media Effects, Integrated Pollution Prevention and Control (IPPC) Directive, Iron and steel production

ÖZ

BİR ENTEGRE DEMİR ÇELİK TESİSİNİN MEVCUT EN İYİ ÇEVRESEL YÖNETİM TEKNİKLERİNİN DEĞERLENDİRİLMESİ

Çakır, Nur
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Avrupa Birliği 1996 yılında endüstriyel tesislerin daha iyi yönetilebilmesi ve kontrol edilebilmesi için entegre bir yaklaşımı amaçlayan IPPC Direktifini yayınlamıştır. IPPC Direktifi, "çevresel emisyonları önleyen ve verimli kaynak kullanımını sağlayan en verimli, gelişmiş ve uygulanabilir metodlar" anlamına gelen "Mevcut En İyi Teknikler (MET)" kavramının gelişmesini sağlamıştır. Bu çerçevede, sektörel bilgi ve sektöre yönelik MET alternatiflerinin yer aldığı birçok "Mevcut En İyi Teknikler Referans Dökumanı" yayınlanmıştır. Oldukça önemli ölçüde kaynak tüketimine ve atık üretimine neden olan demir çelik sektörü, IPPC Direktifi'nin kapsamında yer alan endüstrilerden biridir. Mevcut çalışmada, Türkiye'de bir entegre demir çelik tesisinin çevresel performensı AB entegre demir çelik tesisleriyle kıyaslanarak değerlendirilmiş, ayrıca tesise ait uygulanabilir MET alternatifleri belirlenmiştir. Toplamda 74 MET alternatifi değerlendirilmiş, bunların içinden 36 alternatif tesiste uygulanabilir olarak belirlenmiştir. Son olarak, söz konusu uygulanabilir MET alternatiflerinden iki tanesi seçilmiş ve çapraz ortam etkisi ve finansal analizler kullanılarak karşılaştırılmıştır. Çalışmanın sonuçları, toz emisyonun ve yüksek enerji tüketimini tesisteki ortak sorunlar olduğunu göstemiştir. Ayrıca, sinterleme ünitesi AB demir çelik tesisleriyle en az uyumlu olan alt proses olarak bulunmuştur. Bunlara ek olarak, MET alternatiflerinin uygulanma durumuna gore, tesisin AB entegre demir çelik tesisleriyle oldukça uyumlu olduğu belirlenmiştir. Ayrıca, çapraz ortam etkisi ve finansal analizler, seçilen *“İleri elektrostatik çöktürücü (ESP)”* ve *“Torbalı Filtre - katı ve gaz kirleticilerin bileşik ya da entegr olarak azaltılması”* MET alternatiflerinin çevre üzerinde farklı çapraz ortam etkilerinin olduğu, ancak ikinci alternatifin ilkine oranla maliyetinin daha uygun olduğu saptanmıştır. Bu çalışma Türk demir çelik endüstrisini üretim prosesi, üretim kapasitesi ve çevresel performansı açısından temsil eden bir entegre demir çelik tesisinde gerçekleştirildiğinden dolayı, bu çalışmanın sonuçları Türkiye’de demir çelik endüstrisinde karar mercilerinin çevresel girişimlerine yardım etmek amacıyla kullanılabilir.

Anahtar Kelimeler: Mevcut En İyi Teknikler (MET), Çapraz Ortam Etkileri, Entegre Kirlilik Önleme ve Kontrolü (EKÖK) Direktifi, Demir Çelik Üretimi

To My Baby

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ABBREVIATIONS

BAT: Best Available Techniques
BEAsT: Best Available Techniques Economic Attractiveness Tool
BEI: Best Available Techniques Emission Index
BF: Blast Furnace
BOF: Basic Oxygen Furnace
BREF: Best Available Techniques Reference Documents
CE: Cost Effectiveness
CFB: Circulating Fluidized Bed
CME: Cross Media Effects
COG: Coke Oven Gas
DEA: Data Envelopment Analysis
EAF: Electrical Arc Furnace
ELV: Emission Limit Value
ESP: Electrostatic Precipitator
EU: European Union
FGD: Flue Gas Desulphurisation
IBFS: Integrated Bag Filter System
IE: Industrial Emissions
IMGS: Intensive Mixing and Granulation System
IPPC: Integrated Pollution Prevention and Control
LCA: Life Cycle Assessment
NPV: Net Present Value
OC: Operating and Maintanance Cost
P-BCAT: Privately Best Combination of Alternative Techniques
PCDD/F: Dioxin/furan
S-BCAT: Socially Best Combination of Alternative Techniques
SCR: Selective Catalytic Reduction

SNCR: Selective Non-Catalytic Reduction
TE: Technical Efficeincy
TEİAŞ: Türkiye Elektrik İletim Anonim Şirketi
US: United States

CHAPTER 1

INTRODUCTION

1.1 General

Steel is a quite durable and sustainable material making it one of the most common materials in the world with its pretty wide range of application. Steel is indispensable for various sectors such as building construction, manufacture of vehicles, machines, household equipments [1].

As a result of increase in economical activities in worldwide and growth of economies of the countries; increase in the demand of house, automobile and other steel products scales up the iron and steel production in the world [2]. In 2011, world steel production ascended up to 1.49 billion tons [3].

Turkey is the tenth in the world and second top steel producer in Europe with the production of 34.1 million tons [3] in 2011. This is an important indicator of the fact that, Turkey has come to a substantial level in steel production. Turkish steel sector increased its production capacity from 25.1 (in 2005) million tons to 47.1 million tons (in 2011) corresponding 87.6% increase in 6 years [4]. Moreover, steel sector is very crucial industry providing added value to Turkish economy and its high export potential.

This industry is also very important regarding resource depletion and waste production. China is the world leader in steel production since 1996, with its output reaching to 635 million tons in 2011. The share of Chinese produced steel in the world increased to 45.8% in 2011 from 5.1% in 1980. China, consumed 15.2% of the national total energy and generated 14% of the national total wastewater and waste gas, and 6% of the total solid waste materials in 2009 [5]. On the other hand, in 2010, Turkish iron and steel industry consumed 10.56% of the total electricity, 4.83% of the total natural gas and ultimately 8.1% of the total national energy [6]. Furthermore, as is known iron and steel industry is one of the most air polluting industries.

Considering decrease of energy sources, raw material and water resources and increase of environmental pollution, sustainable environmental consciousness is developed throughout the world. More stringent limitations in legislations force the industry to meet increased energy efficiency, reuse and recycle.

One of the most important legislation in this context is the European Union's (EU) IPPC Directive published in 1996 (the new IPPC Directive published in 2010 is named as Industrial Emissions Directive). The goal of this directive is to create an integrated approach in order to manage and control the industrial facilities better. So that a high level of environmental protection is succeeded taking into account the emissions in air, water and soil as a whole.

IPPC provides the development a new concept of "Best Available Techniques (BAT)", the most effective, advanced and applicable methods, as the name implies, preventing emissions to the environment and providing efficient use of resources. Within this framework, numerous sectoral Best Available Techniques Reference Documents were published giving information on the sector and BAT alternatives for this sector. Apart from sectorel BREF's, a few BREF's on general environmental issues were published. One of these general documents is *"BREF on Economics and Cross-Media Effect"* [7] giving methodology for selection of BAT for a facility, which is evaluating environment effects and cost-effectiveness of BAT alternatives to be compared.

On the other hand, as a requirement of IPPC Directive, competent authorities should be consider the application of BAT measures in the facility, in giving permission to the industrial facilities. Iron and steel industry is one of the industries which should take these permits.

In the literature, plenty of BAT studies have performed in various countries industrial sectors such as cement manufacturing, casting industry and textile production. However, although iron and steel sector is one the major environmental polluting and resource depleting industries, no study on BAT application in iron and steel sector was encountered. This situation causes a major deficiency in environmental concern.

1.2 Objective and Scope of the Study

The aim of the study is to evaluate the environmental performance of an integrated iron and steel plant in Turkey and to suggest BAT alternatives suitable for this facility, by considering the environmental impacts and cost/effectiveness of these alternatives.

Within the context of this main aim, following tasks were undertaken respectively;

- The process of general iron and steel production and the process of the facility were studied, all inputs and outputs in all sub-processes were determined.

- After processing the data obtained from input/output analysis, specific emission and consumptions of all sub-processes were calculated and compared with European Union's iron and steel plants with the help of *"BREF documents on Iron and Steel Production"* [8],[9].

- Potential BAT list for the facility was created and eliminated according to their applicabilities in the facility.

- Two of the applicable BAT alternatives were selected and their cross-media effects (CME), which is the environmental effects on different impact categories, arising due to the implementation of BAT alternatives, and their cost-effectiveness were calculated and compared with each other. The final decision is left to the competent authority of the facility.

1.3 Thesis Overview

This thesis is composed of six chapters. In Chapter 1, the importance of iron and steel industry in the world and in Turkey is mentioned and information on IPPC directive and the objective & the scope of the study are given. Chapter 2 describes the integrated iron and steel production. Moreover detailed information on environmental concerns of all sub-processes is given in this chapter. Background of this study including relevant legislations and previously undertaken studies are presented in Chapter 3. In Chapter 4, the methodology of the study is described. Chapter 5 covers results presented and interpreted. Additionally, discussions on these results are given in this chapter. Finally, the study is concluded and recommendations are given in Chapter 6.

CHAPTER 2

IRON AND STEEL PRODUCTION

2.1 Overview

Steel production is based on the reduction of iron ore which is followed by the removal of impurities in iron that are silicon, manganese, phosphorus as well as carbon. Iron contains relatively high amount of carbon (around 4%), that makes it hard and brittle. In steel production process, carbon content of iron is reduced to less than 1%, so that it gains a more flexible structure [10]. This carbon reduced form of iron is named as “steel”.

Steel is produced worldwide by four different methods [11];

1. Reduction by Blast Furnace (BF) and Basic Oxygen Furnace (BOF)
2. Direct melting of scrap by electric arc furnaces (EAF)
3. Smelting reduction
4. Direct reduction

The first method is also called as “integrated steel production”. According to 2006 statistics, 58.9% of European total steel production was made by integrated iron and steel plants whereas the shares of electrical arc furnaces and direct reduction plants were 40.2% and 6.8%, respectively. No smelting reduction was applied on a commercial scale in Europe [11].

In Turkey, in the year of 2011, 76% of the total steel production was made by integrated steel plants whereas 24% by electric arc furnaces [3]. Direct reduction and smelting reduction are not being applied in Turkey.

As mentioned above, this study involves only integrated iron and steel production. Therefore only integrated iron and steel production is examined and presented in this study.

Integrated steel production includes six major sub-processes;

1- Sintering
2- Coke making
3- Iron making (Blast Furnace-BF)
4- Steel Making (Basic Oxygen Furnace-BOF)
5- Casting
6- Rolling

Flow scheme of integrated iron and steel production is presented in Figure 2.1.

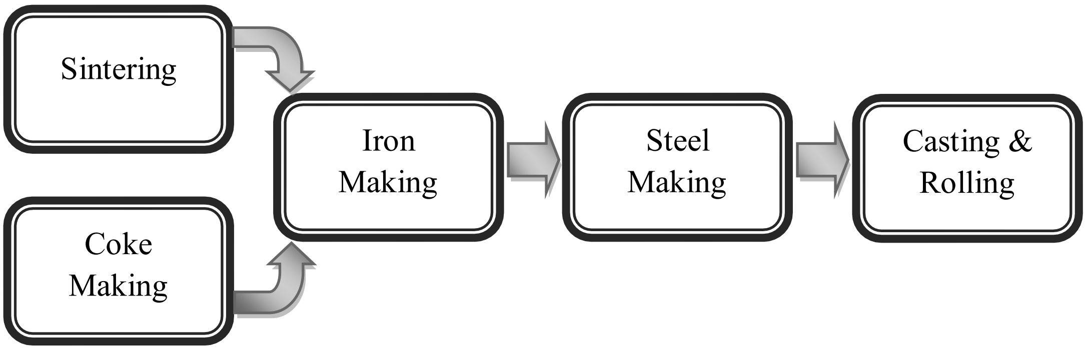


Figure 2.1. Flow scheme of integrated iron and steel production

Detailed information is given in the following sections.

2.2 Sintering

In sintering process, a mixture of fine particles that are fine iron ore, additives (lime, olivine) and recycled iron bearing materials from downstream processes (BF dust, mill scale) is agglomerated by means of ignition of coke breeze added into the mixture.

The product of sintering process, called “sinter”, is sent to BF. Sintering process is applied for the improvement of permeability and reducibility of iron ore in BF [11]. Initially, a mixture of raw materials, additives and recycled wastes is prepared. Coke breeze is also added into the mixture to be used as fuel. This mixture is send to the sinter machine and with the ignition of coke breeze in the mixture, sufficient heat is supplied (temperature becomes 1300-1480°C), so that agglomeration takes place and “sinter” is produced. Afterwards, it is screened in order to eliminate smaller sinter pieces and then sinter pieces that are sufficiently large in size are sent to BF following cooling process. Flow scheme of sintering process is presented in Figure 2.2.

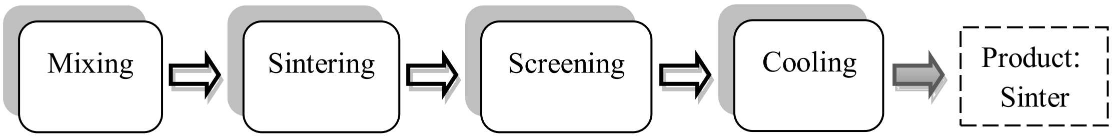


Figure 2.2. Flow scheme of sintering process

Since the wastes of other processes are recycled in sinter plants, emission of this process is quite variable and significant. The most crucial emissions caused by sinter plants are dust, CO, CO_2, SO_2, NO, NO_2, HCl, HF, D/F, heavy metals (Cr, Pb etc.). Another important concern on sintering process is that this process consumes high amount of energy. Hence, efficient use of energy is substantially important for sinter plants.

2.3 Coke Making

Coke is produced from coal by means of pyrolysis. The coal is heated in a close and airless environment, in order the volatiles in coal to move away from coal. The remaining hard and spongy material is called "coke" [12].

The major role of coke in the BF is to be used as energy source. The reason why coke is used instead of coal is that coke behaves as a support material in BF and provides gas circulation due to its spongy nature whereas coal cannot supply these. Coke cannot be wholly replaced by other types of fuel in BF [11].

The process starts with coal preparing. Mixture of various types of coal is prepared and sent to coke ovens. To be converted to coke, coal is heated up to 1000-1100°C for 14-28 hours indirectly via coke ovens. Fuel gas is burned in burning rooms and heat is transferred from burning rooms to coking rooms by means of the walls between them. Several coke ovens combine and constitute a "coke battery". A sketch of coke oven can be seen in Figure 2.3.

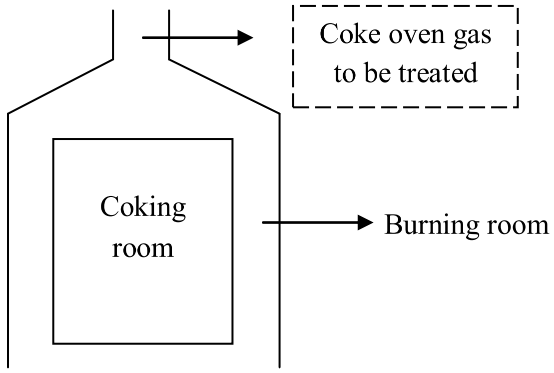


Figure 2.3. Sketch of coke oven

After sufficient coking time mentioned above, coke is pushed from coke oven and quenched by wet or dry methods. Finally coke is sent to BF to be used as fuel. On the other side, coke oven gas (COG) is sent to gas treatment. Coke making process scheme is presented in Figure 2.4.

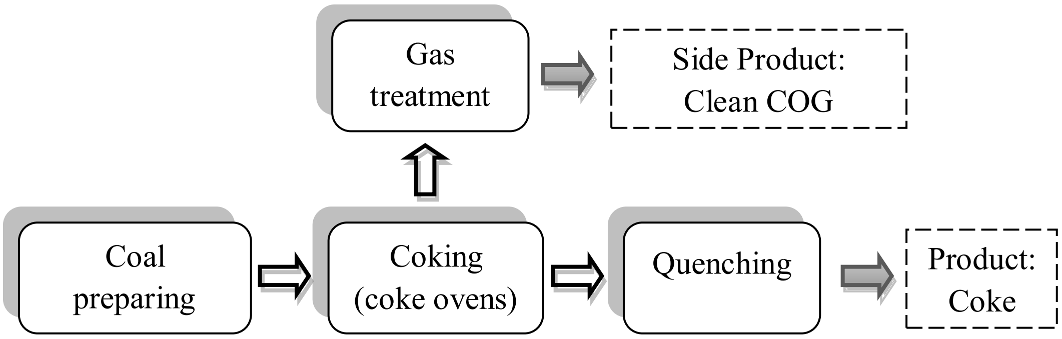


Figure 2.4. Flow scheme of coking process

COG is a valuable gas having calorific value of 17.4-20 MJ/m^3 (~4350 kcal/m^3) [13]. For this reason, COG is treated and used as fuel in integrated iron and steel plants. In the treatment of COG, initially COG that is composed of volatiles and moisture is cooled by spraying ammonia water. During this process, high amount of ammonia containing wastewater is produced. Afterwards, COG is subjected to various processes; during these processes ammonium sulphate, benzole and tar are produced as side-products from the impurities present in COG. Finally, clean COG is stored to be used as an energy source.

The main environmental problem related to coke making is that coke batteries cause significant emissions to air. Aforementioned emissions are generally dust, NO, NOx, SO_2 and CO. For these emissions, precautions should be taken in order not to cause air pollution problems. Another major environmental problem is the wastewater containing high amount of ammonia that is produced during COG treatment. This wastewater should be treated before discharging it to a receiving body. The final significant environmental issue is the energy efficiency. Huge amount of energy is produced and consumed at the same time in coke batteries. Management of both production and consumption of energy is a crucial subject.

2.4 Iron Making

In the production of iron; sinter from sinter plant, lump iron ore, additives (lime etc.) and, as fuel coke from coke battery and pulverized coal from coal preparation unit are filled into the BF and heated up to sufficient degree (~2000°C). A reduction reaction takes place in BF, and hematite (Fe_2O_3) and magnetite (Fe_3O_4) in iron ore are reduced to iron oxide (FeO) [11]. Hot air required for combustion in BF is provided from hot stoves.

The impurities in the iron ore are passed to slag with the help of lime added. Slag has lower density then iron, so that it ascends up to liquid iron. By this way, slag and iron are separated easily. The reduced and liquefied iron is sent to BOF to be converted to liquid steel whereas liquid slag is sent to slag processing unit to be cooled and granulated.

Although BF gas seems to have negligible calorific value (~720 kcal/m^3) [13] comparing to COG, actually it involves sufficient amount of energy which cannot be wasted. Hence, like COG it is cleaned and used as energy source in iron and steel facilities.

Figure 2.5 presents the flow scheme of iron making process.

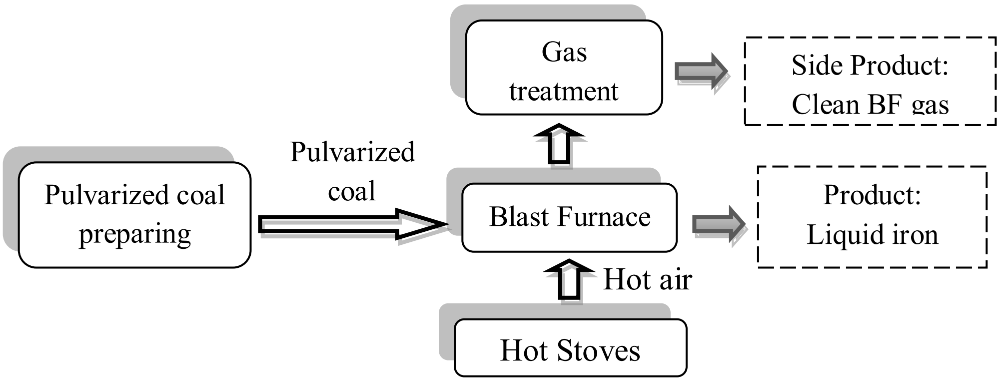


Figure 2.5. Flow scheme of iron making process

Iron particles passing to the BF gas contain high amount of zinc due to the zinc content of iron ore. During gas treatment, these zinc bearing iron particles are collected as sludge or dust, after they are removed from BF gas. Afterwards, this sludge/dust containing high amount of zinc is added to the feed of sintering process, and this causes high zinc content of sinter, that is produced by sinter plants. High zinc bearing sinter consumption leads to operational problems in BF. As a result, usage of BF gas treatment sludge/dust in sintering process is limited in order to prevent operational problems in BF. Reduction of zinc content of BF gas treatment sludge/dust is an important issue; hence it provides safe usage of BF gas treatment sludge/dust in sintering process. By this way solid waste production of iron making process and raw material consumption of sintering process are minimized.

Beside high zinc containing BF gas treatment sludge, there are two more major environmental issues related to iron making process. The first problem is emission of dust, CO, CO_2, SO_2 and NOx. These emissions to air cause air pollution problems. In order to prevent air pollution problem, measures should be taken such as inserting cleaning equipments. The second important issue is the fact that iron making process uses enormous amount of energy both in BFs and hot stoves. Management of energy consumption of iron making process is a crucial concern to be taken into account. Precautions taken in this process can provide high amount of energy saving.

2.5 Steel Making

As mentioned before, in order to produce steel from iron, carbon content of iron should be decreased to about 2% considering desired hardness and flexibility. This is achieved by blowing oxygen into liquid iron in BOF and converting carbon in iron into carbon dioxide. Carbon dioxide is moved away by means of BOF stacks. Beside liquid iron, steel scrap is fed into BOF as raw material. At the same time with the same method with BF, adding lime into the BOF feed, impurities such as silicon, manganese and phosphorus are passed to slag. By this way they are removed from liquid steel [11]. Flow diagram of steel making process can be seen in Figure 2.6.

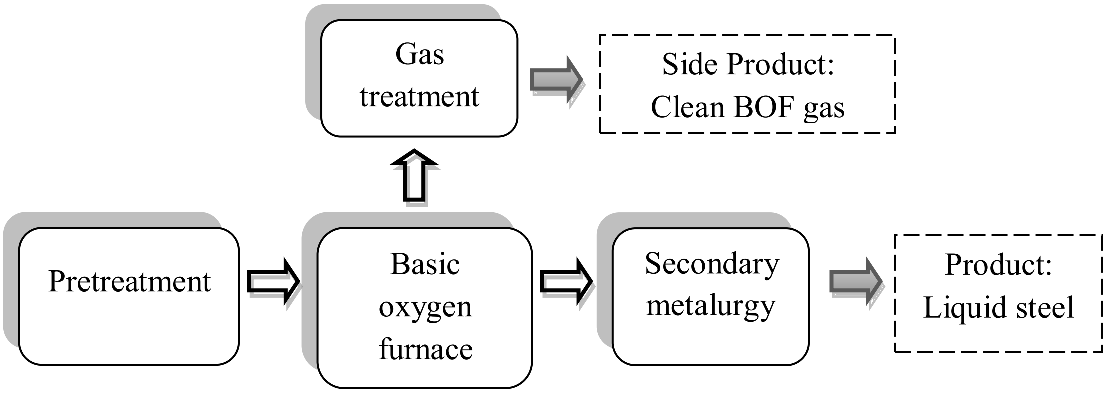


Figure 2.6. Flow scheme of steel making process

As is seen in Figure 2.6, prior to BOF liquid, steel is subjected to pretreatment for removal of sulphur in liquid iron. After the conversion of iron to steel, fine adjustments in the quantitiy of substances in the liquid steel are made in secondary metallurgy unit to provide requested quality of steel.

BOF gas has a calorific value (~1450 kcal/m^3) [13], lower than COG and more than BF gas. It is treated and consumed as energy source in the facility as well as the other ones.

High zinc content in BOF gas treatment dust/sludge is also an important problem for steel making as in iron making. The reason behind the fact that BOF gas treatment dust/sludge has high zinc content is galvanized and painted steel scrap used in the process as raw material. Emissions of CO, CO_2, SO_2 and NOx, and high energy consumption are other prior problems related to steel making process.

2.6 Casting and Rolling

Two types of casting methods are used in steel production; continuous and ingot casting. Continuous casting has several advantages comparing to ingot casting as follows;

- It saves energy, causes less emission and uses less water,
- Working conditions are improved,
- It has high yield rate, up to 95% and high productivity.

Worldwide; 90% of steel is cast by continuous methods whereas this ratio approaches to 97% in Europe [11]. Products of casting are slab, wide in shape; and billet thin and long in shape.

Slab and billet are sent to rolling process to be converted into coil and wirerod, respectively via physical forming. Physical forming of steel is performed by means of hot rolling, cold rolling and drawing. In integrated iron and steel production, hot rolling is applied. Semi products are heated up to annealing temperature (~1250°C) prior to hot rolling. In hot rolling process slab is flattened and billet is extended by compressing between electrically powered rollers repeatedly [9]. Afterwards coil and wirerod, produced as the final product of hot rolling, are subjected to pressurized water in order to be cooled and cleaned from the mill scale which is a recyclable waste into sintering process. The process scheme is presented in Figure 2.7.

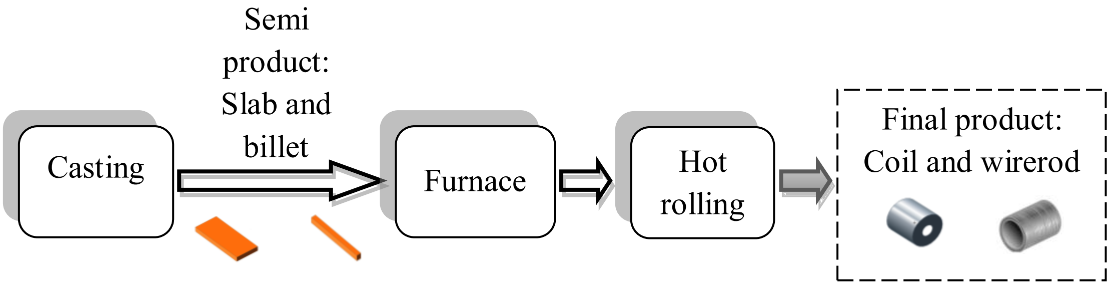


Figure 2.7. Flow scheme of casting and hot rolling processes

The most important environmental problem regarding casting and hot rolling processes is the formation of oily mill scale. It is a valuable waste due to its high steel content. Mill scale is formed during cooling and cleaning of semi-product or final products. In order to obtain a smooth surface, the iron oxide particles on the surface of these products are removed by pressurized cold water as stated above. By this way, cooling of products is provided as well. This cooling water is percolated through rolling machines and therefore it gets contaminated with oil and grease on the surface of rolling machines. As a result, due to the direct contact of oily cooling water, mill scale contaminated with oil and grease. The oil content limits the quantity of mill scale to be recycled into the sintering process, as it causes operational problems in the BF. Therefore oil content of mill scale should be reduced by treatment.

Emissions of CO, CO_2, SO_2 and NOx, and high energy consumption are the other major environmental problems related to casting and rolling.

2.7 Environmental Concern

As can be noticed from the abovementioned issues, the common problems of all processes of an integrated iron and steel plant are;

- Emissions of CO_2, CO, SO_2 and NOx to the air,
- High energy consumption

Environmental impacts of these problems can be summarized as follows;

- CO_2 is the major gas causing global warming.
- CO is a toxic substance for living being.
- SO_2 causes acid rains and harmful for the human respiratory system.
- NOx emission also causes acid rain and eutrophication in water bodies.
- Energy resources in the world have diminishing. Moreover, high energy consumption leads to high emission of abovementioned substances.

In consequence, to manage an integrated iron and steel plant more efficiently and environmental friendly, first of all these emission and high energy consumption problems should be considered and related precautions should be taken.

CHAPTER 3

BACKGROUND

3.1 Legislative Background

On account of diminishing energy sources, raw material and water resources and rising of environmental pollution, sustainable environmental consciousness is developed throughout the world. As a result, more and more stringent limitations in legislations force the industry to increase energy efficiency and reuse and recycle practices.

Within this scope, the most substantial piece of legislation is the "*Integrated Pollution Prevention and control Directive-IPPC*" [14] of the European Union. In the following section, the information about this directive is given.

3.1.1 IPPC Directive

In 1996, European Council's Directive on Integrated Pollution Prevention and Control (96/61/EC) came into force with the aim of achieving integrated pollution prevention and control resulting from industrial activities which are collected under six main topics in this directive: energy industries, production and processing of metals, mineral industry, chemical industry, waste management and other activities [14].

The IPPC Directive establishes regulations to succeed high level of protection of the environment taken as a whole [14]. In other words it brings an integrated approach to environmental protection; therefore it is accepted as a milestone in pollution prevention concept.

The IPPC Directive comprises a broad range of environmental impacts including emissions to air, water and land, waste production, energy use, accidents and site contamination. It prevents not only pollution caused by emissions, but also all any introduction causing harm to the health or quality of the environment such as vibration, heat and noise [15].

The IPPC strengthen the concept of Best Available Techniques (BAT). According to this directive, operators should take all proper preventive measures against pollution particularly by the implementation of the BAT (Article 3-(a)). The concept of BAT is defined in Article 2 of the aforesaid directive as follows:

- 'best available techniques` shall mean the most effective and advanced stage in the development of activities and their methods of operation which indicate the practical suitability of particular techniques for providing in principle the basis for emission limit values designed to prevent and, where that is not practicable, generally to reduce emissions and the impact on the environment as a whole:
- 'techniques` shall include both the technology used and the way in which the installation is designed, built, maintained, operated and decommissioned,
- 'available` techniques shall mean those developed on a scale which allows implementation in the relevant industrial sector, under economically and technically viable conditions, taking into consideration the costs and advantages, whether or not the techniques are used or produced inside the Member State in question, as long as they are reasonably accessible to the operator
- 'best` shall mean most effective in achieving a high general level of protection of the environment as a whole [14]

According to the IPPC Directive, competent authorities in the member states should give permits to the installations. In the IPPC Directive, it is stated that single permits should be given by competent authorities to the facilities for their waste production and emissions to the air and water rather than separate permits. These permits should be given if the installation is in compliance with the measures laid down in Article 3 (Article 9(1)), which means that they are encouraged to apply BAT.

In this context, numerous sectoral reference documents (BREFs) were published on BAT by the IPPC Bureau which has been set up to organize an "*information exchange*" between industry and the Member States regarding BAT. BREFs are the main reference documents used by competent authorities in the Member States when issuing operating permits for the facilities that have an important pollution potential in Europe [16]. BREF Documents includes information on the process(es), current emissions and consumptions as well as BAT of the regarding sector.

There are totally 35 BREF Documents published by the EU up to now. Some of these documents are sector-based and some are non sector-based such as the BREF's on industrial cooling systems, monitoring, economic and cross-media effects. Since BAT have a dynamic character altering with the technological developments, they have been being updated and reviewed within a number of years by the IPPC Bureau.

In 2008, the Directive 2008/1/EC [15] entered into force repealing the IPPC Directive (96/61/EC) And the Directive 2008/1/EC will be repealed by the new Directive on Industrial Emissions-IE (2010/75/EU) known as *new IPPC Directive,* from January 7, 2014 [17]

The Directive on Industrial Emissions (2010/75/EU) [17] that has been adopted on November 2010, requires industrial installations to adopt BAT that are defined in BREFs. The name of "Best Available Reference Documents" firstly mentioned in this directive. In the Industrial Emissions Directive it is stated that "Permit conditions should be set on the basis of best available techniques" and "In order to determine best available techniques and to limit imbalances in the Union as regard the level of emissions from industrial activities, reference documents for BAT should be drawn up, reviewed and, where necessary, updated through an exchange of information with stakeholders and the key elements of BAT reference documents adopted through committee procedure." [17]. These statements mean that the strength of

BREF documents has increased with the Industrial Emission Directive's entry into force.

3.1.1.1 BREF on Iron and Steel Production

According to IPPC Directive, "*Installations for the production of pig iron and steel including continuous casting, with a capacity exceeding 2,5 tonnes per hour*" have to take a permit based on the application of BAT mentioned in the Reference Documents related to the Iron and Steel Industry in order to provide integrated pollution prevention and control (Annex 1-(2.2)).

In this study, three different sectoral BREF Documents were taken as base and investigated in detail; hence they provide detailed information on integrated iron and steel production including BAT. The first one is the BREF Document on iron and steel production published in 2001 including information on sub-processes apart from rolling process. The second one is the draft BREF document revising the first one on iron and steel production as well, published in 2011. Information on rolling process is given in the third BREF Document on ferrous metal processing published in 2001. Detailed information on these documents is presented as follows:

1- *Reference Document on Best Available Techniques in the Iron and Steel Production [8] (December 2001):*

It involves the environmental aspects of integrated iron and steel production including sinter plants, pelletisation plants, coke oven plants, blast furnaces and basic oxygen furnaces and casting, and steel production made by electrical arc furnaces. The structure of this document is as follows;

- General information on the sector comprising statistical data on EU's iron and steel production, the geographical distribution, economic and employment aspects as well as the rough evaluation of the environmental importance of the sector,

- Information on integrated iron and steel production comprising information on the processes, current emission and consumption levels and BAT alternatives,
- Information on electric arc furnace steel production comprising information on the processes, current emission and consumption levels and BAT alternatives [8]

2- *Draft Reference Document on Best Available Techniques in the Iron and Steel Production [11] (June 2011):*

This document is the updated version of the previous one. It also includes information on sintering, coke making, iron making, steel making and casting processes. Only a few more BAT alternatives are included in this document comparing with the previous one. Moreover, this document covers more detailed information especially on common BAT alternatives with the previous document.

3- *Reference Document on Best Available Techniques in the Ferrous Metal Processing [9](July 2001):*

Rolling downstream to casting is not covered in the reference documents mentioned above. Instead, it is included in another reference document on the ferrous metal processing. Part A of this document gives information on hot rolling and Part D states BAT alternatives for hot rolling. In other words, only part A and D are related to iron and steel production. Thus only these parts were considered in this thesis.

3.1.1.2 BREF on Economics and Cross-Media Effects [7]

BAT concept under IPPC consider “cost and benefits of measures” beside protection of the environment taken as a whole. The aim of this approach is to prevent new and more significant environmental problems when solving an already existing problem.

In Article 9(4) of IPPC, it is stated that permit conditions shall be based on BAT considering technical characteristics, geographical location and the local environmental conditions of the installation. This brings a need to determine which option provides higher level of protection of the environment in such local conditions and which option gives more benefits with the same cost [7]. Methodology presented in the BREF on Economics and Cross-Media Effects is for the assessment of the BAT alternatives and for the comparison of BAT alternatives according to their environmental impacts and cost/benefit ratio towards the selection of the most feasible one/ones.

The methodology of "Economics and Cross-Media Effects Analysis" described in the BREF on Economics and Cross-Media Effects mainly includes four steps as follows:

Step 1- Cross-media effects analysis

In this step, BAT alternatives are assessed according to their environmental impacts with the use of four guidelines (Guidelines 1 to 4) presented in the document which help the user to determine which alternative technique is the best environmental option.

Step 2- Cost analysis

Cost of BAT alternatives is calculated transparently by means of further five guidelines (Guidelines 5 to 9) in the second step. By this way the alternatives can be validated, controlled and compared in a fair way.

Step 3- Evaluation the alternatives

Information obtained from the steps 1 and 2 is used to balance the cost of a BAT alternative against the environmental benefit that it brings. It means that cost effectiveness of BAT alternatives is expressed in this step.

Step 4- Evaluation of economic viability in the sector

Apart from the environmental benefits and cost, another important issue related to a BAT alternative is its economic viability in the sector. In the last step, economic viability is evaluated by considering "Market Structure", the "Industry Structure" and the "Resilience" of the sector [7].

More detailed information on "Economics and Cross-Media Effects Analysis" will be presented in Chapter 4.

3.2 Studies Regarding the IPPC Directive and Best Available Techniques

In this part, general studies and sector specific studies performed in different countries and sectors regarding the IPPC Directive and BAT will be assessed.

3.2.1 Non-sectoral Studies

In the literature general studies mostly including general information on the IPPC Directive, BAT, BREF Documents; tools or methodologies used for the selection of candidate BAT or used for evaluation of BAT implementation degree of an installation are present. In this part, examples of these studies will be presented.

A review study giving general information of the IPPC Directive, BAT and BREF Documents was conducted by Martinez [18]. According to Martinez, integrated approach is very crucial since this approach prevents transfer of pollutants from one media to another. In his paper, it is mentioned that the scope of the IPPC Directive is highly polluted large industrial installations. He also stated that, with the application of the IPPC Directive, pollution prevention is adopted rather than "after the fact" approach, moreover this Directive affects the countries trying to enter European Union including Turkey and acceding countries, beside the Member States of the European Union as well. In this paper, BAT was defined and considerations to be taken into account for BAT specifications were listed. Furthermore it was mentioned that Emission Limit Values (ELV) are set based on the selection and application of BAT rather than specific ELV's.

A similar review study was performed by O'Maley [19] with the same goal as Martinez [18]. Both of these studies involve the information on the scope of the IPPC Directive, BAT and ELV's. O'Maley [19] mentioned mainly operator obligations, permit application requirements, BAT information exchange and competent authorities & their responsibilities where Martinez [18] did not mention any of these topics. In the study of O'Maley [19], it was stated that the IPPC Directive focuses on the *"source control"* of pollution primarily instead of end of pipe treatment. The steps in a waste management methodology should be followed according to waste management hierarchy. This concept requires elimination, reduction, recovery, recycle of wastes respectively. If neither of them is applicable, end of pipe techniques should be applied to the wastes. Finally from the study of O'Maley [19], it can be deduced that the IPPC Directive not only protects the environment, but also improves efficiency of business.

Schoenberger [20] conducted a study concentrating on "BAT Information Exchange Process (Sevilla Process)"BAT Information Exchange Process is, as the name implies, sharing information between the Member States and industries concerning BAT. In the study of Schoenberger [20], the aim of BAT Information Exchange Process was presented as helping competent authorities in determination of BAT based permits, balancing the process technology in European Community and supporting of spreading the information on attainable emission and consumption levels in case of application of BAT. BREF Documents, which are unique documents including sectoral emission and consumption levels, are the result of this process. Schoenberger [20] stated that these emission and consumption levels determines whether the installation is "*best performing*" or "*well performing*" or "*not such well performing*".

A more specific study comparing the studies by Martinez [18] and O'Maley [19]was conducted by Dijkmans [21], describing a methodology in his study to choose BAT among candidate BAT at sectoral level. Presented methodology based on mainly two steps: data collection and evaluation of candidate BAT. The first step includes collection of information on sector specific economical data and on candidate BAT. Cross check of the data quality is stated to be very significant in this paper. The second step is composed of four sub-steps which are assessments of technical feasibility, environmental impacts, cost and presence of other better alternatives. Afterwards an evaluation table is prepared presenting BAT candidates versus these sub-steps and each candidate BAT is scored with the signs (+), (-), or (-/+). According to the sum of these signs, BAT candidates are classified as *"always applicable"*, *"not applicable"* and *"applicable depending on local conditions"* for that sector.

Another candidate BAT assessment and selection approach was demonstrated in the paper by Nicholas et al.[22]. They described LCA tool to assess BAT candidates like Dijkmans [21]. In the paper it was mentioned that LCA is a requirement of the IPPC Directive. Moreover it was stated that by Nicholas et al. [22], this tool provides comparison of different environmental impacts on a certain set of impact categories that are acidification, depletion of nonrenewables, depletion of ozone layer, eutrophication, greenhouse effect, photochemical ozone creation, aquatic toxicity, terrestrial toxicity and human toxicity. However, it was also reported that some uncertainties and methodological difficulties of regarding this tool also present. Comparing the study of Nicholas et al.[22] with the previous one undertaken by Dijkmans [21], it can be deduced that LCA is a more complicated tool to evaluate environmental effects of a candidate BAT. On the other hand, the other tool described by Dijkmans [21], one includes assessment on technical feasibility, cost and presence of other better alternatives. Another difference between these studies is that the Dijkmans's [21], study is more suitable for an overall sector whereas Nicholas et al.'s [22] for a certain institution. Finally in this study it was mentioned that some uncertainties and methodological difficulties related to LCA methodology are present.

Georgopoulou et al. [23] performed a study aiming to give information on another tool to choose BAT for as the studies of Dijkmans [21] and Nicholas et al. [22]. This tool named BEAsT (BAT Economic Attractiveness Tool) is developed in Greece within the scope of a reseach project. BEAsT is a Visual Basic based computer program, assessing both environmental and economic benefits of the selected BAT options or their combinations. Comparing with the method mentioned by Dijkmans [21], it is more complicated and comprehensive as LCA [22]. However BEAsT evaluates environmental benefits as well as economic benefits whereas LCA [22] only evaluates environmental benefits. The steps of the methodology of BEAsT were reported as; configuration of installation (Step 1), assessment of environmental benefits (Step 2), assessment of economic cost and benefits (Step 3), and economic evaluation of the total investment cost (Step 4). Georgopoulou et al. [23] described these steps in their paper as follows: First of all, the sector or subsector to be examined should be selected by the user. Then in the first step of the methodology of BEAsT, information of the installation for instance the production capacity, currents emissions-consumptions and possible BAT alternatives or their combinations entered into the program. Afterwards in the second step, the program calculates the new consumption and emissions after the implementation of selected BAT alternatives or their combinations. In the third step; investment cost, operational and maintenance costs, revenues and avoided cost are calculated. Finally, the program calculates the result of benefit/cost ratio considering total costs and total environmental benefits. If benefit/cost ratio is greater than 1, this BAT alternative is attractive. In addition, with the help of this ratio comparison of different BAT alternatives can be made.

Karavanas et al. [24] performed a study on another methodology in order to evaluate facilities in the same sector. This methodology uses operational performance indicators and requires data on emissions, wastes, resource and energy consumptions in annually based. As stated in the previous study conducted by Nicholas et al. [22], in the LCA methodology, impacts categories were defined as acidification, depletion of non-renewables, depletion of ozone layer, eutrophication, greenhouse effect, photochemical ozone creation, aquatic toxicity, terrestrial toxicity and human toxicity. In the study of Karavanas et al. [24], however, environmental impacts are divided into different categories, so called “components”, which are waste production, resources use, energy consumption, water consumption, water pollution, gaseous emissions, noise levels, soil pollution and green house gases emissions. Karavanas et al. [24] produced a function giving a facility a value (FINX) that is an indicator of BAT application degree of the facility. If a facility gain FINX smaller than “one”, it means that this facility is compatible with the IPPC Directive. If FINX is smaller than “two”, larger than “one”; the facility is intermediately compatible with the IPPC Directive. If it is larger than “two”, the facility is far away from compliance of the IPPC Directive. In addition in this paper it was stated that with the help of this method, the facilities in the same sector can be ranked and compared with each other and the advantage of this methodology was said to give integrated picture on BAT implementation of a facility.

All of the studies examined are summarized in Table 3.1.

Table 3.1. Summary table of all general studies

Aim	**Result**	**Reference**
Giving general information of IPPC Directive, BAT and BREF Documents	• Integrated approach is very crucial since this approach prevents transfer of pollutants from one media to another. • Scope of the IPPC Directive is highly polluted large industrial installations. • With the application of the IPPC Directive, pollution prevention is adopted rather than "after the fact" approach. • The countries trying enter European Union including Turkey and acceding countries beside Member States of European Union are affected by the IPPC Directive. • Emission Limit Values (ELV) are set based on the selection and application of BAT rather than specific ELV's.	Martinez [18]
Giving general information of the IPPC Directive, BAT and BREF Documents	• The IPPC Directive focuses on the *"source control"* of pollution primarily instead of end of pipe treatment. • The steps in waste management should be followed are elimination, reduction, recovery, recycle of wastes. If neither of them is applicable, end of pipe techniques should be applied to the wastes. • The Directive both protects the environment and improves efficiency of business.	O'Maley [19]

Table 3.1. Summary table of all general studies- continued

Aim	**Result**	**Reference**
Giving general information on "information exchange process" and BREF Documents	• BAT Information Exchange Process is sharing information between the Member States and industries concerning BAT. • The aim of BAT Information Exchange Process is; - helping competent authorities in determination of BAT based permits, - balancing the process technology in European Community - supporting of spreading the information on attainable emission and consumption levels in case of application of BAT. • BREF Documents are the result of this process. • The emission and consumption levels determines that the whether the installation is "*best performing*" or "*well performing*" or "*not such well performing*". • BREF Documents are dynamic in nature and should be revised due to the improvements in technology.	Schoenberger [20]
Description of a methodology to choose BAT for a sector	• This method is suitable for an overall sector. • It evaluates of both environmental and economical aspects. • Steps of BAT selection are; 1. Data collection on; 1.1. sector specific economic data 1.2. candidate BAT 2. BAT candidate evaluation on; 2.1. technical feasibility 2.2. environmental impacts 2.3. cost 2.4. presence of other better alternatives	Dijkmans [21]

Table 3.1. Summary table of all general studies- continued

Aim	Result	Reference
Giving information on a tool (LCA) to choose BAT for an installation.	• This tool is suitable for a certain installation. • LCA is a quite comprehensive and complicated environmental impact assessment tool. • Some uncertainties and methodological difficulties are present. • LCA is a requirement of the IPPC Directive. • Environmental impacts categories are; o acidification, o depletion of nonrenewables, o depletion of ozone layer, o eutrophication, o greenhouse effect, o photochemical ozone creation, o aquatic toxicity, o terrestrial toxicity and human toxicity, o waste production	Nicholas et al. [22]
Giving information on a tool (BEAsT) to choose BAT for an installation.	• This tool evaluates both environmental and economical benefits of BAT, • It is complicated and comprehensive as LCA. • The steps of BEAsT are; o configuration of installation, o assessment of environmental benefits, o assessment of economic cost and benefits, economic evaluation of the total investment cost. • If Benefit/Cost greater than 1, BAT alternative is attractive. • With Benefit/Cost ration comparison of different BAT alternatives can be made	Georgopoulou et al. [23]

Table 3.1. Summary table of all general studies- continued

Aim	Result	Reference
Description of a methodology to evaluate and rank BAT application degree.	• This method uses operational performance indicators. • It requires of data on emissions, wastes, resource and energy consumptions in annually based. • Environmental impacts categories are; o waste production, o resources use, o energy consumption, o water consumption, o water pollution, o gaseous emissions, o noise levels, o soil pollution, o green house gases emissions • A function is created giving a facility a value (FINX) that is an indicator of BAT application degree of the facility; o FINX < 1 → compatible with the IPPC Directive o 1 < FINX < 2 → intermediately compatible with the IPPC Directive o FINX > 2 → incompatible with the IPPC Directive • Ranking and comparison of the facilities in the same sector may be possible. • Advantage of this methodology is that it gives integrated picture on BAT implementation of a facility.	Karavanas et al. [24]

3.2.2 Sectoral Studies

Apart from the general studies reviewed above, several sector specific BAT application studies are present in the literature. Most of these studies are carried out in real plants. Although most of these studies are related to manufacturing sectors, there are also studies about BAT application on other sectors such as adhesive application, treatment sector etc. Some of the BAT studies are performed to select best alternative for a plant or for overall sector in a country, some of which based on Life Cycle Assessment tool or a model developed. Other purposes might be to evaluate a plants BAT application ratio or to assess the performance of a plant or a country by comparing consumption and emission values by the limit values set in BREF documents.

Valderemma et al. [25] conducted such a sector specific study on a cement manufacturing plant in Spain that increased its production capacity by the addition of a new cement production line which is designed considering BAT for the cement industry. To compare the effects of the new line on the environment with thoseof the previous lines, they used LCA as a tool as Nicholas et al. [22]. The study showed that the implementation of the aforesaid measures provides decreases in negative effects on global warming, acidification, eutrophication, human health, ecosystem quality and resources by 5%, 15%, 17%, 11%, 11% and 14%, respectively. The results also indicated that the new line designed considering BAT for cement industries consumed 8.4%, 14.7% and 25% less electricity, fuel and water respectively. Moreover, 4%, 20.5%, 54% and 84.7% reduction of emissions to air of CO_2, NO_x, SO_2 and dust respectively was achieved.

Instead of LCA, Liu and Wen [26] used an approach, so called “Data Envelopment Analysis (DEA)” for the selection of BAT for thermal power plants in China from the point of view of energy conservation and pollution prevention. DEA is a methodology used for performance evaluation of facilities. They created a model to calculate Technical Efficiency (TE) values to compare BAT alternatives and select the better one for the Chinese thermal power plants. TE values were function of capital and operational costs, electricity and fuel consumption, NO_x, SO_2 and dust emissions. BAT alternatives were evaluated under the topics of: combustion technologies, denitrification technologies, dedusting technologies and desulphurization technologies. Under these topics, totally 22 different BAT measures were compared with the ones serving to the same purposes. For instance, from combustion technologies, the alternatives of chain-grate boiler, pulverized-coal furnace, bubbling fluidized bed and circulating fluidized bed are compared according to their calculated TE values. Data entered into the model was the actual operational data from Chinese thermal power plants. Calculated TE values indicated that as BAT measures *"chain-grate boiler"* from combustion technologies, *"Air Classifier+Selective Catalytic Reduction (SCR)"* from dentrification technologies, "*Electrosatic precipitator (ESP)-fabric filter integrated*" for dedusting technologies, *"Circulating Fluidized Bed (CFB)-Flue Gas Desulphurization (FGD)"* from desulphurization technologies were the best suitable BAT alternatives for Chinese thermal power plants. Moreover 22 different optimal combinations of these BAT alternatives were evaluated by using this model and combinations including CFB were found out to be more appropriate for thermal power plants in China.

A similar study was conducted by Breched and Tulkens [27] for the limestone industry in Belgium using another model.. They selected a combination of BATs for the limestone industry whereas Liu and Wen [26] studied both individual and combination of BAT options. In the study of Breched and Tulkens [27], it is mentioned that both environmental protection and technical-economical viability were considered. The authors benefitted from linear programming during selection of *"Privately Best Combination of Alternative Techniques (P-BCAT)"* to minimize economical cost and *"Socially Best Combination of Alternative Techniques (S-BCAT)"* to minimize environmental cost. Another distinction between the study of Breched and Tulkens [27] and the previous one is that the previous one evaluated BAT measures that require new investments; on the other hand the study by Breched and Tulkens [27] assessed BAT measures that require relatively small alterations in the process such as changing the type of fuel or utilization ratio of different type kilns present in the facility. Results of the model runs for P-BCAT and S-BCAT were nearly the same which are the production of 1,150 kt lime/yr, extraction of 2,649 kt limestone/yr, use of LRK kiln at 82% of its capacity and use of other type of kilns at full capacity. However the result on fuel type to be used differentiated between them, the first one preferred petcoke to be used 5,985 TJ/yr, although the other one preferred lignite to be used 9,985 TJ/yr. Comparing these two BAT scenarios it was stated that S-BCAT provided 2% less amount of CO_2 emission, yet it causes 1.2% increase in economical cost.

Silvo et al. [28] assessed whole Finnish pulp and paper industry instead of a plant study, with regard to their BAT application ratio and comparison of their emission values with the ones presented in “BREF Document on BAT in the Pulp and Paper Industry”. Information on the application of BAT measures given in this BREF Document were gathered from totally 24 different facilities including kraft pulp mills, paper mills and multi-product mills by questionnaires, whereas data on emissions were obtained from Finnish Environment Institute. In the study of Silvo et al. [28], BAT Emission Index (BEI) was generated and calculated as an indicator of BAT related environmental performance of the facilities.As a result, it was indicated that BAT in Pulp and Paper BREF document are widely applied in pulp and paper industry in Finland. Besides, comparing the emission values with the ones in BREF, it was indicated that 40-100% of the Finnish pulp and paper facilities are in the range in the emission limit values presented in BREF. Moreover; comparing BEI index, paper mills and multiproduct mills were shown to have better environmental performance than the kraft mills in Finland.

A similar study was conducted by Li Rosi et al. [29] as a part of a project aiming to develop a technically and economically feasible water reuse technique, for the whole textile sector. In the study of Li Rosi et al. [29], in order to gather information on the best practices of the sector, both a plant study was conducted and questionnaires were prepared and sent to the facilities, like Silvo et al. [28]. Effluent samples were collected during site visits and their treatability was evaluated in the laboratory. A prototype plant was built with membrane wastewater treatment technology and an Expert System was developed for online control of the treatment system. Afterwards, a case study was undertaken in a plant which did not use any water reuse in the process. Concerning aforementioned prototype plant study, water treatment by membrane and reuse of treated water was suggested as BAT. It is mentioned in this paper that with the implementation of this BAT, 50% of water saving, 80-90% removal of total organic matter, 99% removal of total suspended solids, 95-98% removal of color and finally 80% removal of surfactants were expected.

Another study in the textile sector was undertaken by Kocabaş et al. [30] in a textile plant in Turkey with the aim of evaluation of water and energy consumption performances after implementation of proper BAT measures regarding water and energy consumption minimization. During site visits to the facility, production process and water and energy consumptions were examined. After the assessment of gathered information, seven different BAT measures for the minimization of water consumption beside five different BAT measures for the minimization of energy consumption were suggested to the facility. After the implementation of these measures it was observed that 29.5% reduction in total specific water consumption and 9% reduction in total specific energy consumption were achieved. With these reductions, specific water consumption of the plant was below the suggested value in the textile BREF Document; and the specific energy consumption of the plant was at around the limit value.

Fatta et al. [31] performed a study regarding BAT application in a foundry facility in Cyprus. They examined BAT measures applied in the facility and compared them with the ones in *"Foundry BREF Document"* and *"Guideline for foundries"* prepared by National Technical University of Athens in a framework of a project. The results of the study showed that some of these measures were already applied in the plant. However emission values were still above the limits mentioned in BREF. The reason for this situation is mentioned as breakdowns and bad maintenance of the equipment. In conclusion, totally 11 different measures were suggested to the facility. Among these measures, five of them are process integrated measures, three of them are technical measures and three of them are regulations.

Barros et al. [32] also carried out a quite comprehensive study in a plant which produces canned mussel in Spain, with the same goal as Fatta et al. [31], to assess the extent of the application of BAT measures in the facility. They examined the process, input and outputs, consumption and emission level of the facility in a very detailed manner. After these investigations BAT measures applied in the plant were determined and compared with the ones in the literature. The results indicated that most of the BAT measures had already been applied. BAT measures were investigated under five different categories; integrated environmental management tools, manufacturing process, wastewater treatment plant, waste treatment and auxiliary operations. Applied and not applied numbers of the measures under these categories were presented as three to one, seven to three, five to one, three to three and one to two respectively. In other words totally 19 measures were applied in the facility among 29 BAT measures stated in the literature.

As mentioned above, BAT are also used in some sectors other than production. Geldermann et al. [33] conducted a study with the aim of determining candidate BAT for adhesive application in Germany by undertaking case studies in 18 different adhesive applying sectors. As a result of their study it was mentioned that VOC emission is very significant from adhesive application and measures should be taken to prevent this emission. Moreover, as candidate BAT, exhaust gas cleaning systems such as absorption or adsorption, reusing solvents after cleaning were presented. In addition, solvent free or solvent reduced adhesives like powder adhesives, water based adhesives or radiation hardening coating systems were also suggested as BAT. However, it is also mentioned in the paper that in some sectors such as tape production; solvent based adhesives should be used to achieve quality standards.

A table summarizing all above reviewed sector specific studies is presented in Table 3..2.

There are plenty of studies published in the literature in different sectors ranging from fruit and vegetable processing to heavy ceramic industry, from glass production to dairy industry. However, any study similar to the ones mentioned above, i.e. plant studies for BAT application ratio or comparison of emissions with BREF Documents, regarding iron and steel industry was not encountered during the literature search, although iron and steel industry is a prior sector consuming huge amount of raw material, water and energy and producing enormous amount of waste and emission.

Table 3..2. Summary table of all sector specific studies

Sector	**Country**	**Aim**	**Method/Tool**	**Result**	**Reference**
Cement production	Spain	Comparison of the effects of BAT alternatives on the environment	Plant study, LCA as a tool to compare BAT alternatives	BAT implementation provided decreases of negative effects on; • global warming (5%), • acidification (15%), • eutrophication (17%), • human health (11%), • ecosystem quality (11%), • resources (14%), Moreover less consumption of; • Electricity (8.4%), • Fuel (14.7%), • Water (25%) and less emissions to air of; • CO_2 (4%), • NO_x (20.5%), • SO_2 (54%), • Dust (84.7%) were provided.	Valderrama et al. [25]

Table 3.2. Summary table of all sector specific studies - continued

Sector	**Country**	**Aim**	**Method/Tool**	**Result**	**Reference**
Thermal power production	China	Selection of BAT alternatives	A model based on DEA as a tool to compare BAT alternatives	Most suitable BAT alternatives were found as; • combustion → *chain-grate boiler* • dentrification → *Air Classifier+SCR* • dedusting → *ESP-fabric filter integrated* • desulphurization → *CFB-FGD* Moreover combinations including CFB were found out to be more appropriate for thermal power plants in China.	Liu, Wen [26]
Limestone production	Belgium	Selection of BAT combination alternatives	Linear Programming Plant study	Same results of P-BCAT and S-BCAT were as follows; • 1,150 kt lime production/yr , • 2,649 kt limestone extraction/yr, • use of LRK kiln at 82% of its capacity • use of other type of kilns at full capacity diffenent result; • P-BCAT preferred petcoke to be used 5,985 TJ/yr, • S-BCAT prefeffed lignite to be used 9,985 TJ/yr Comparing these two BAT scenarios it was stated that S-BCAT provided 2% less amount of CO_2 emission, yet it causes 1.2% increase in economical cost.	Breched and Tulkens [27]

Table 3.2. Summary table of all sector specific studies - continued

Sector	Country	Aim	Method/Tool	Result	Reference
Pulp and paper production	Finland	Evaluation of Finnish pulp and paper industry with respect to BREF document.	Questionnaires to determine BAT implementation level, BEI calculation	BAT in Pulp and Paper BREF document were widely applied in pulp and paper industry in Finland, 40-100% of the Finnish pulp and paper facilities are in the range in the emission limit values presented in BREF, Comparing BEI index, paper mills and multiproduct mills have better environmental performance than kraft mills in Finland.	Silvo et al. [28]
Textile production	Italy	Development of a technically and economically feasible water reuse technique which is also viable for the overall textile sector.	Questionnaires to gather information on the sector best practices, Plant study	Water treatment by membrane and reuse of treated water was suggested as BAT. With the implementation of this BAT; • 50% of water saving and removal of • 80-90% total organic matter, • 99% total suspended solids, • 95-98% color • 80% surfactants was expected.	Li Rosi et al. [29]

Table 3.2. Summary table of all sector specific studies - continued

Sector	Country	Aim	Method/Tool	Result	Reference
Textile production	Turkey	Evaluation of water and energy consumption performances after implementation of proper BAT measures	Plant study	Measures were suggested to the facility in the following categories; • minimization of water consumption → 7 measures • minimization of energy consumption → 5 mesures Following reductions were achieved after BAT implementation; • 29.5% → total specific water consumption • 9% → total specific energy consumption	Kocabas et al. [30]
Casting industry	Cyprus	Evaluation of BAT application circumstance in a foundry	Plant study	Although some of these measures were applied in the plant, emission values are still above the limits mentioned in BREF. Measures were suggested to the facility in the following categories; • process integrated → *5 measures,* • technical → *3 measures* • regulations →*3 regulations*	Fatta et al. [31]

Table 3.2. Summary table of all sector specific studies – continued

Sector	Country	Aim	Method/Tool	Result	Reference
Seafood industry	Spain	Evaluation of BAT application circumstance in a mussel canning facility	Plant study	• Integrated environmental management tools → 3 applied, 1 not applied • manufacturing process → 7 applied, 3 not applied • wastewater treatment plant → 5 applied, 1 not applied • waste treatment → 3 applied, 3 not applied • auxiliary operations → 1 applied, 2 not applied	Barros et al. [32]
Adhesive application	Germany	Determination of candidate BAT measures for adhesive application sector	Case studies	VOC emission is very significant from adhesive application. As candidate BAT followings were suggested; • exhaust gas cleaning systems such as absorbtion or adsorption, reusing solvents after cleaning • solvent free or solvent reduced adhesives like powder adhesives, water based adhesives or radiation hardening coating systems	Geldermann et al. [33]

3.2.3 Studies on BAT Suggestions for Integrated Iron and Steel Production

The most comprehensive sources including the most detailed and reliable information on BAT for integrated iron and steel production are BREF's. Hence, in this thesis BREF documents are used as the main source to determine the BAT alternatives for the facility.

As it is stated in previous sections, BREF documents used in this thesis are "*Reference Document on Best Available Techniques in the Iron and Steel Production*" [8], "*Draft Reference Document on Best Available Techniques in the Iron and Steel Production*" [11] for sintering, coke making, iron making, steel making and casting and "*Reference Document on Best Available Techniques in the Ferrous Metal Processing*" [9] for rolling (Detailed information these documents were given in section 3.1.1.2). BAT alternatives for integrated iron and steel production plants for all processes listed in BREF's are presented in Table 3.3. As is seen from this table, totally 69 different alternatives are suggested in BREF's.

In this thesis, however, various other techniques apart from techniques in BREF's are found from the literature and examined. After the literature survey it was realized that most of the techniques found in the literature have already been involved in BREF's. There are only a few study found suggesting different techniques from BREF's. BAT alternatives found from the literature as different from the ones listed in BREF Documents are presented in Table 3.4. As is seen from this table, only seven different alternatives different from BREF's are suggested in the literature and they are just for sintering and coke making processes.

In Chapter 5, information on the alternatives listed in Table 3.3 and Table 3.4, and their applicability's for the facility will be evaluated.

Table 3.3. BAT alternatives from BREF Documents

Process	BAT Alternative	Reference BREF
Sintering	*Process Integrated Techniques:* 1. Process optimization for minimization of PCDD/F emissions 2. Recycling iron-containing waste into the sinter plant 3. Lowering the content of volatile hydrocarbons in the sinter feed 4. Lowering the sulphur content of the sinter feed 5. Heat recovery from sintering and sinter cooling 6. Top layer sintering 7. Waste gas recirculation 8. Suppression of PCDD/F formation by addition of nitrogen compounds in the sinter mix	Bref on Iron and steel [8] Draft Bref on Iron and Steel [11]
	End of Pipe Techniques: 1. Electrostatic precipitator (ESP) 2. Fabric filter system 3. Cyclone 4. Fine wet scrubber 5. Desulphurization 6. Regenerative active carbon (RAC) 7. Selective catalytic reduction (SCR) 8. Reduction of PCDD/F by means of ESP and additives	Bref on Iron and steel [8] Draft Bref on Iron and Steel [11]
Coke Making	*Process Integrated Techniques:* 1. Smooth and undisturbed operation of the coke oven plant 2. Maintenance of coke ovens 3. Improvement of oven door and frame seals 4. Maintaining free gas flow in the coke oven 5. Emission reduction during coke oven firing 6. Coke dry quenching (CDQ) 7. Large coke oven chambers 8. Non-recovery coking 9. Waste gas recirculation 10. Closed belt conveyors 11. Stabilized coke dry quenching	Bref on Iron and steel [8] Draft Bref on Iron and Steel [11]

Table 3.3. BAT alternatives from BREF Documents- continued

Process	**BAT Alternative**	**Reference BREF**
	End of Pipe Techniques: 1. Minimizing oven charging emissions 2. Sealing of ascension pipes and charging holes 3. Minimizing leakage between coke oven chamber and heating chamber 4. De-dusting of coke oven pushing 5. Emission minimized wet quenching 6. De-NOx of waste gas from coke oven firing (Selective catalytic reduction -SCR) 7. Coke oven gas desulphurization 8. Removing tar (and PAH) from the coal water 9. Ammonia stripper 10. Gas-tight operation of the gas treatment plant 11. Wastewater treatment plant	Bref on Iron and steel [8] Draft Bref on Iron and Steel [11]
Iron Making	*Process Integrated Techniques:* 1. Direct injection of reducing agents 2. Energy recovery from blast furnace gas 3. Energy recovery from top gas pressure 4. Energy savings at the hot stove 5. Use of tar-free runner linings 6. Gas recovery system from top hopper release	Bref on Iron and steel [8] Draft Bref on Iron and Steel [11]
	End of Pipe Techniques: 1. Blast furnace gas treatment 2. De-dusting of tap holes and runners 3. Fume suppression during casting 4. Hydro-cyclonage of blast furnace sludge 5. Treatment and reuse of scrubbing water 6. Condensation of fume from slag granulation	Bref on Iron and steel [8] Draft Bref on Iron and Steel [11]

Table 3.3. BAT alternatives from BREF Documents- continued

Process	BAT Alternative	Reference BREF
Steel Making and casting	*Process Integrated Techniques:* 1. Energy recovery from BOF gas 2. Lowering the zinc-content of scrap 3. On-line sampling and analysis of steel	Bref on Iron and steel [8] Draft Bref on Iron and Steel [11]
	End of Pipe Techniques: 1. Primary dedusting 2. Particulate matter abatement from pig iron pre-treatment 3. Secondary de-dusting 4. Dust hot briquetting and recycling 5. Treatment of wastewater from wet de-dusting 6. Treatment of wastewater from continuous casting	Bref on Iron and steel [8] Draft Bref on Iron and Steel [11]
Rolling	*Process Integrated Techniques:* 1. Regenerative burner system 2. Recuperator and recuperative burners 3. Limitations of burning temperature 4. Low NOx Burners 5. External flue gas recirculation	Bref on Ferrous Metal Processing [9]
	End of Pipe Techniques: 1. Selective catalytic reduction (SCR) 2. Selective non-catalytic reduction (SNCR) 3. Treatment of cooling water	Bref on Ferrous Metal Processing [9]

Table 3.4. Other techniques suggested in the literature

Process	**Technique**	**Reference**
Sintering	1. Twin layer charging 2. Intensive mixing and granulation system- IMGS 3. Biological treatment of oily mill scale 4. Use of novel filter for dust and heavy metal treatment	[34] [34] [35] [36]
Coke Making	1. Preheating of coal, combustion air and fuel 2. Hydrogen and methanol production from COG 3. Heat recovery from COG	[37] [38],[39] [37]
Iron Making	Any techniques other than the ones in BREF documents can not be found in the literature	-
Steel Making and casting	Any techniques other than the ones in BREF documents can not be found in the literature	-
Rolling	Any techniques other than the ones in BREF documents can not be found in the literature	-

CHAPTER 4

METHODOLOGY

The study was conducted in an integrated iron and steel plant having a production capacity of 4.10 million tons/year crude-steel in 2011. Considering that there are three integrated iron and steel plants in Turkey with a total steel production capacity of 8.17 million tons crude-steel/year (2011) [3], and all of them apply nearly the same manufacture technologies, the plant studied having the share of about 50% in production is considered as a representative sample of Turkish Iron and Steel Industry in terms of manufacturing technologies. The study was carried out in eight stages;

Step 1- Preliminary study: literature study and site visits
Step 2- Input/output analysis
Step 3- Performance evaluation of the facility
Step 4- Determination of potential BAT for the facility
Step 5- Calculation of cross-media effects of selected BAT alternatives
Step 6- Calculation of cost of selected BAT alternatives
Step 7- Evaluation of selected BAT alternatives
Step 8- Evaluation of economic viability in the sector

In the following sections, the methodology followed at each step is described.

4.1 Step 1- Preliminary Study: Literature Study and Site Visits

Initially, a literature review was carried out and five site visits were made to the facility between 2010 and 2011 in order to examine the manufacturing processes and to collect the information necessary to carry out the input/output analysis.

During the literature review, the main documents used were the BREF Documents. In addition to BREF documents, thesis, academic articles and technical reports obtained from literature and from the facility were used.

During site visits to the facility, all sub-processes in steel production were visited to get in depth technical information. The basic steps and crucial points of steel production were learned. The chemical reactions and physical operations taken place in the production processes and physical and biological operations in treatment processes in the facility were studied in detail. In addition, the raw materials used and products, side-products and wastes produced were observed during site visits. The function of raw materials, the characteristics and composition of products, side-products and wastes were determined. Moreover, waste and emission production points were seen as well.

Furthermore, information obtained from the literature was discussed with the technical staff of the plant and process of the facility was compared by integrated iron and steel production in the literature. The methods applied in the facility for the production, emission prevention, recycle, reuse, waste minimization are investigated in detail. During site visits, technical staff gave information on the wastes reused or disposed directly, on emissions and wastes generate problems for the facility.

Finally, the flow pathways of all inputs and outputs were determined and comprehensive process flow diagrams were prepared for all sub-processes.

4.2 Step 2- Input/Output Analysis

In the facility, for a proper management of the operation, comprehensive reports are prepared annually for every sub-processes by the technical staff. These reports include the quantities of all inputs and outputs, some technical parameters indicating the performance of the sub-process, operational pauses, working accidents etc. In this step, these annual reports of all sub-processes of the facility are investigated in detail in order to obtain information on all inputs and outputs of all sub-processes. Afterwards in consideration of this information, a comprehensive material flow analysis was performed for the plant. All inputs (energy, raw material, water etc.) and outputs (product, by-product, waste etc.) involved in all sub-processes in the facility were determined.

Since the facility is an integrated plant, product of a sub-process is raw material of downstream sub-process. Some contradictions between interdependent sub-processes were noticed. As an example, the information gained from “blast furnace annual report” on the amount of liquid iron that is sent to basic oxygen furnace is incompatible with the information obtained from “basic oxygen furnace annual report” on the amount of liquid iron that is taken from blast furnace. Such contradictions among the data are corrected by means of discussions with the technical staff of the plant.

In addition, emissions of all sub-processes to air (as mg/m^3 or g/m^3) are specified by examining various emission reports of the facility.

4.3 Step 3- Performance Evaluation of the Facility

Specific energy (MJ/ton product), water (m^3/ton product) and raw material consumptions (ton/ton product), and waste generation rates (ton/ton product) were calculated simply by dividing the yearly generation of waste, and consumption of energy, water and raw material to the yearly production of the sub-process. Afterwards, calculated specific consumptions and generation rates of all sub-processes compared with the values given in BREF documents. Moreover, air emissions of all sub-processes that are obtained from the previous step are directly compared with the emission values presented in BREF documents as well.

The values given in BREF documents were used to evaluate the performance of the plant, since BREF documents include the most comprehensive and reliable information on iron and steel production as it is mentioned in Chapter 2.

At the end, specific consumption and generation rates, and emission values outside the limits set in BREF documents were determined and the reasons behind these were discussed with the technical staff of the facility.

4.4 Step 4- Determination of Potential BAT for the Facility

All BAT possibilities listed in BREF documents and other sources in the literature were compiled and a long list of BAT options was prepared. These BAT possibilities were mentioned in Section 3.3 previously. Then the BAT options included in the list were evaluated according to their applicabilities in the facility. The techniques that have already been fully and/or partially applied at the plant and can/cannot be applied were determined. Technical feasibility, environmental benefits with respect to air, water, and soil pollution, waste products, energy use, use of natural resources, noise, and cost affordability were considered in the evaluation of the BAT. All possible BAT gathered from the literature were reviewed; and a short-list of BAT was made considering their advantages, disadvantages, benefits on energy and emission reductions and approximate application costs. Finally, applicable BAT alternatives in this short list were suggested to the authority of the facility.

4.5 Step 5-Calculation of Cross-Media Effects of Selected BAT Alternatives

In this step, two of the applicable alternatives which are listed in abovementioned short list were selected. Selection of these BAT alternatives was made considering the most significant environmental problem in the facility, emissions to air (especially dust emission).

As it is mentioned in Section 3.1.1.2, selected two BAT alternatives were assessed according to their environmental impacts with the use of four guidelines (Guidelines 1 to 4) presented in BREF on Economics and Cross-Media Effects [7] which help the user to determine which alternative technique is the best environmental option. These guidelines are “Scope and identification of the alternative options”, “Inventory of emissions”, “Calculation of the cross-media effects” and “Interpretation of the cross-media effects” respectively presented below.

Guideline 1-Scope and identification of the alternative options:

In this step, selected BAT alternatives should be described in sufficient detail. The aim of the application of the alternatives and the average removal efficiencies of the selected BAT alternatives were determined in this stage. In addition, capacity of the suggestion was fixed to provide comparison on an equal basis.

Guideline 2- Inventory of consumptions and emissions:

In this stage, quantity of emissions and consumptions were presented aiming to provide inventory for the following steps described in Guideline 3 and 4. According to BREF on Economics and Cross-Media Effects [7], the amounts of following terms should be determined;

1. Pollutant released,
2. Consumption of energy,
3. Consumption of raw materials including water,
4. Wastes produced

(1) In this study, in order to calculate the amount of pollutant released from BAT alternatives, their emissions to air determined previously in Step 2, are converted from "mg/m^3 to "kg/yr" or "g/yr".

(2) It is stated in BREF on Economics and Cross-Media Effects that, in determination of consumption of energy, average heat and electricity usage of the selected BAT alternatives should be considered. Afterwards emission released for creation of these energy sources utilized should be calculated. Since the selected BAT options consume only electricity as energy source, no heat consumption was determined in this study, instead only electricity consumption was specified for the selected BAT alternatives. The data on annual electricity consumption of the selected BAT options were taken from Draft BREF Document on Iron and Steel Production [11].

According to BREF on Economics and Cross-Media Effects, emissions caused by electricity consumed by the alternatives were calculated according to the Table 1 in Annex 8 of this document. However, in there it is also stated that if the data on local use of primary energy for electricity generation is achievable, using of this data rather than the one presented in BREF Document gives more reliable results, since the emissions are highly dependent on the primary energy of electricity generation. Therefore in this study "mass of emissions for 1 GJ electricity consumption" was calculated using local data.

Initially, Turkish electricity supply distribution was provided from a report belonging to Turkish local authority related to electricity production in Turkey. By this way, percentages of Turkish electricity production from natural gas, coal, hydraulic energy etc. were determined. Afterwards, the amounts of emissions caused by these sources for the production of 1MWh electricity were found from the literature. Finally, by taking weighted mean of all emissions, mass of emissions from MWh electricity production was calculated.

(3) and (4) Since raw material consumptions and waste productions of the selected BAT alternatives could not be found from literature, these values were not taken into account.

Guideline 3- Calculation of the cross-media effects:

The effects of different pollutants released to the environment by the selected alternatives were calculated with respect to seven impact categories; human toxicity, global warming, aquatic toxicity, acidification, eutrophication, ozone depletion, photochemical ozone creation and their effects on the same impact categories were compared.

In these calculations, formulas and tables given in the BREF on Economics Cross-Media Effects were considered. Summary of the cross-media calculation procedure is given in Table 4.1. In this table, unit, medium affected by the pollutant, formula used in the calculation of potential impacts and the reference tables where the values of factors or potentials were obtained are summarized for all impact categories.

For instance; supposing that 1.3 kg of SO_2 emission is achieved with the application of a BAT alternative; human toxicity factor for SO_2 is found to be 13 from Annex 1 of the Reference Document on Economics and Cross-Media Effects. Inserting this value and mass of SO_2 (1.3 kg) into the formula given at the first raw of the Table 4.1, human toxicity potential caused by SO_2 is found 0.1 kg. Calculating for all substances caused with the application of BAT alternative and summing all of them, total human toxicity potential is calculated as CO_2 equivalent.

Table 4.1. Summary of cross-media calculation procedure

Impact category	**Unit (base substance)**	**Affected medium**	**Formula**	**Reference tables**
Human toxicity	kg Pb equivalent	Air	$\text{Human toxicity pot.} = \sum \frac{\text{mass of pollutant released to air (kg)}}{\text{toxicity factor of the pollutant}}$ (1)	*Human toxicity factors*: Annex1
Global warming	kg CO_2 equivalent	Air	$\text{Global warming pot.} = \sum \text{GWP(pollutant) x mass of poll. released (kg)}$ (2)	*Global warming potentials*: Annex 2
Aquatic toxicity	m^3 of water equivalent	Water	$\text{Aquatic toxicity} = \sum \frac{\text{mass of pollutant released (kgx1000)}}{\text{PNEC of the pollutant (mg/L)} * 0.001} \text{ x } 0.001$ (3)	*PNEC:* Annex 3
Acidification	kg SO_2 equivalent	Air	$\text{Acidification} = \sum \text{AP(pollutant) x mass of pollutant released (kg)}$ (4)	*Acidification potentials:* Annex 4
Eutrophication	kg SO_2 equivalent	Water	$\text{Eutrophication pot.} = \sum \text{EP(pollutant) x mass of pollutant released (kg)}$ (5)	*Eutrophication potentials:* Annex 5
Ozone depletion	kg SO_2 equivalent	Air	$\text{Ozone depletion pot.} = \sum \text{ODP(pollutant) x mass of pollutant (kg)}$ (6)	*Ozone depletion potentials:* Annex 6
Photochemical ozone creation	kg SO_2 equivalent	Air	$\text{Ph. Ozone Creat. Pot.} = \sum \text{POCP(pollutant) x mass of poll. released (kg)}$ (7)	*Photochemical ozone creation potential:* Annex 7

Guideline 4- Interpretation of the cross-media effects:

Cross-media effects of the BAT alternatives on the same impact category calculated in the previous stage were compared and interpreted in this stage. Comparison was made with respect to abovementioned seven impact categories as well as energy consumed by the two alternatives. An alternative having the lower environmental impacts was chosen for every impact categories and energy consumption.

4.6 Step 6- Calculation of Cost of Selected BAT Alternatives

In this step, as it is mentioned in Section 3.1.1.2, selected two BAT alternatives were assessed according to their costs including investment cost, operating and maintenance cost etc., with the use of five guidelines (Guidelines 5 to 9) presented in BREF on Economics and Cross-Media Effects [7].

Guideline 5- Scope and identification of the alternative options:

First stage of costing methodology is nearly the same as the cross-media methodology. Yet, costing methodology requires more information in addition to the ones in cross media methodology such as technical characteristic of the alternatives involving technical and economic lifetime of the equipment, and operational data including energy consumption and removal efficiencies.

Guideline 6- Gathering and validation of the cost data:

Investment and operational cost data used in the calculation of cost of the alternatives are taken from the Draft BREF Document on Iron and Steel Production. Since this investment and operational cost data for both alternatives given in this document was as range instead of a single value, average of these ranges were taken for both BAT alternatives. Different sources were researched to validate cost data in the literature and from the design companies; any of appropriate information cannot be obtained.

Guideline 7- Definition of the cost components:

As it is stated in BREF document on Economics and Cross-Media effects, in this stage cost data gathered from the previous stage was divided into components which are investment costs, operating and maintenance costs, avoided costs.

Guideline 8- Processing and presentation of the cost information:

In this stage, initially cash flow analysis was performed in order to see the total expenditures, total revenues and net cash flow for every year during operation period. In cash flow analysis, a table "operation years" versus "revenues, investment cost, operational cost, total cost and net cash flow was prepared as seen in Table 4.2.

Table 4.2. Example table for cash flow analysis

YEAR	**Construction year**	**First operational year**	**.....**	**Last operational year**
Revenues	0	x	x	x
Avoided Cost	0	y	y	y
Investment Cost	z	0	0	0
Operational cost	0	t	t	t
Total Cost	z+0	0+t	0+t	0+t
Net Cash Flow	0+0-(z+0)	x+y-(0+t)	x+y-(0+t)	x+y-(0+t)

- Revenues are the income obtained due to the application of selected BAT options. Examples of revenues are the sales of generated heat, energy or produced by-products.
- Avoided cost is expenditure which will not be made any more with the implementation of BAT option. For instance, savings on labour, energy, capital, maintenance cost due to more effective use of plant; or savings on

charge which should be paid due to the emissions, if the BAT option is not applied.

- Investment cost is the cost arising from the construction of the BAT option, purchase of the equipments etc. Investment cost is valid only for the construction year.
- Operational cost includes energy cost required for the operation of equipments, labour and maintenance costs. Operational cost is “0” in the construction year, on the other hand it is assumed to be same for all years from the first to the last operational year.
- Total cost is the sum of investment and operational cost calculated for each year.
- Net cash flow is calculated by subtracting the total cost from the sum of revenues and avoided cost.

Afterwards *“net present value (NPV)”* and *“annual cost”* of these alternatives were calculated, in order to compare the BAT alternatives on an equal basis.

An evaluation of the net present value is essential for the proper appraisal of projects. NPV is defined as the sum of present values of annual net incomes during the operation of the project [40]. Equation (8) isused in the calculation of NPV;

$$\boxed{Net\ Present\ value = -(investment\ cost) + \sum_{t=0}^{n}\left(\frac{\text{net revenues (t)}}{(1+r)^{\text{t}}}\right) \qquad (8)}$$

Where;

t = year 0 to year n

n = lifetime

net revenues (t) = (revenue – cost) at time t

r = discount rate (Discount rate is the rate at which future cash flows are discounted for convertion of them to present values [41] .)

On the other hand, annual cost is calculated with the conversion of all the cash flows over the life years of the BAT alternative to an equivalent annual cost [7]. The formulation of annual cost is presented below in equation (9).

$$\text{total annual cost} = C\left[\frac{r\,(1+r)^n}{(1+r)^n - 1}\right] + OC \qquad (9)$$

Where;

C = investment cost
n = lifetime
r = discount rate
OC = operating and maintenance cost

Guideline 9- Attribution of cost to environmental protection:

As the stated in the BREF document on Economics and Cross-Media Effects, purpose of the alternative should be transparently distinguished, (1) those to be implemented for reduction or prevention of the environmental pollution, and (2) those for other reasons such as investment expenditure in waste minimization or energy conservation. It is also stated that generally end-of-pipe techniques aim to reduce or prevent emissions. In this stage the purpose of the alternatives were stated clearly.

4.7 Step 7- Evaluation of Selected BAT Alternatives

Evaluation of alternatives was performed with cost effectiveness analysis. It is a well known and simple technique in preparation or implementation of environmental policy [7]. With this method, comparison of two or more BAT alternatives is provided by considering both their costs and effectiveness's, as the name implies.

The basic concept is dividing *"annual cost"* of the implementation of BAT options into *"annual reduction"* provided by the implementation of BAT options. In other words, the unit cost per reduction is calculated. Equational representation of cost effectiveness (CE) calculation is given in Bref Documument on Economics and Crosss-Media Effects [7] as in equation (10);

$$\boxed{Cost\ effectiveness\ (CE) = \frac{annual\ cost}{annual\ reduction} \qquad (10)}$$

Annual cost had already been calculated in the previous section by means of equation (9) in €/yr or $/yr. On the other hand, annual reduction of emission was calculated considering the reduction efficiencies of the alternatives. For instance, if the alternative is implemented in order to provide reduction of dust emission, annual reduction is the mass of annually reduced dust (tons/yr). The unit of CE becomes than €/tons or $/tons.

As stated above, the cost effectiveness analysis is performed in order to compare two or more BAT options. Comparison is made with respect to their CE values. The BAT alternative having smaller CE value means that it provides the same effectiveness with less cost than the one having larger CE value. Therefore the BAT alternative having smaller CE value was selected to be the most feasible option.

4.8 Step 8- Evaluation of Economic Viability in the Sector

Apart from the environmental benefits and cost, another important issue related to BAT alternative is its economic viability in the sector. It is evaluated by considering *"Market Structure"* and *"Industry Structure"* [7] in the last step.

With the examination of industry structure, the socio-economic characteristics of iron and steel sector were determined. In this framework, size and number of the plants in the iron and steel sector was specified. Furthermore, technical and economical characteristics of the facility in the sector and the vision of the facility on the protection of the environment were specified. These issues are very crucial in the application of selected BAT alternative.

Another important issue considered was market structure, since market has a substantial power on the industry. In this context, extent of the market, including situation of iron and steel sector in domestic and foreign market, was examined.

CHAPTER 5

RESULTS AND DISCUSSION

As it was stated in Chapter 1, the main goal of the study is to evaluate the environmental performance of an integrated iron and steel plant in Turkey and to suggest BAT alternatives suitable for this plant, by considering the environmental impacts and cost/effectiveness of these alternatives. Initially the process of general iron and steel production and process of the plant was studied. Afterwards, all inputs and outputs of all sub-processes were determined. After processing the data obtained from input/output analysis, specific emission and consumptions of all sub-processes were calculated and compared with European Union's iron and steel plants. Then, potential BAT list for the plant is determined and eliminated according to their applicabilities in the facility. Finally, two of the applicable BAT alternatives were selected and their Cross-media effects and cost-effectiveness' were calculated and compared with each other.

In the previous chapter, this methodology was described in detail in eight steps. In this chapter, results of these steps were presented respectively.

5.1 Step 1- Preliminary Study: Literature Study and Site Visits

The facility in which the study was conducted is an integrated iron and steel plant. As it was mentioned before, it represents Turkish integrated iron and steel production with respect to the manufacture technologies and production capacity. The facility has a conventional integrated iron and steel production process, including sintering, coke making, iron making, steel making, casting and rolling as sub-process as presented in Figure 5.1.

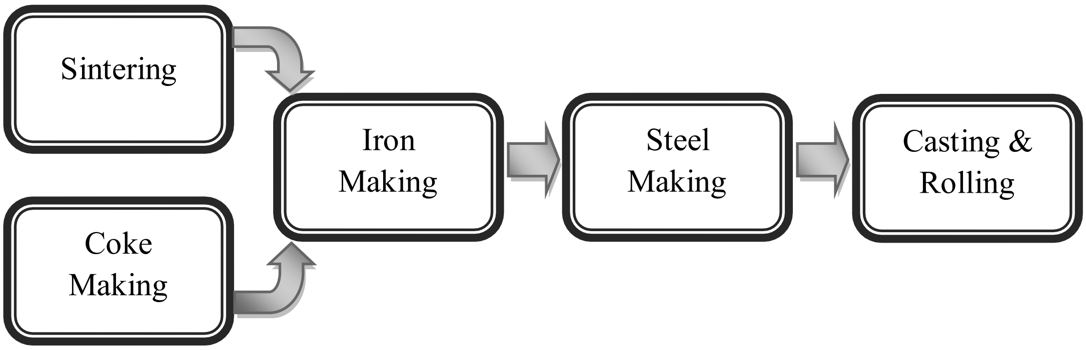


Figure 5.1. Flow scheme of integrated iron and steel production

Detailed information on these sub-processes will be given in the following sections.

5.1.1 Sintering

The fine ore coming by rail or sea are drained to the main stockyard. Fine ore from the main stockyard, recycled materials from the downstream sub-processes (gas treatment dust from blast furnace, mill scale from rolling etc.) and additives (lime, dolomite, coke breeze etc.) are mixed according to the desired sinter quality, and a mixture of 40,000 ton is prepared daily. Fine ore and recycled materials are the main constituents of the mixture with the ratios of 44% and 40% respectively. Both of them provide "Fe" to the mixture. By recycling the materials from the downstream sub-processes, both iron content of these materials are utilized and they are not disposed as waste. Additives compose 16% of the mixture and they provide required characteristics such as basicity (lime) or required energy (coke breeze). This mixture is sent to the sinter machine to be converted to the "*sinter*" by agglomeration by means of heat. Heat is provided by ignition and combustion of coke breeze in the mixture and the temperature rises up to 1300-1480ºC. Waste gas from sinter machine including mainly particulate matter is sent to gas cleaning unit. Cleaned gas is released to the atmosphere. The produced sinter from sinter machine is cooled in order not to harm conveyor belts. The size of the sinter is a crucial parameter for blast furnace. Hence, produced sinter is sieved. Sinter pieces smaller than 7 mm are sent to the stockyard, between 7 mm and 25 mm to sinter the machine and larger than 25 mm to the blast furnace. Process flow of the sintering is presented in Figure 5.2.

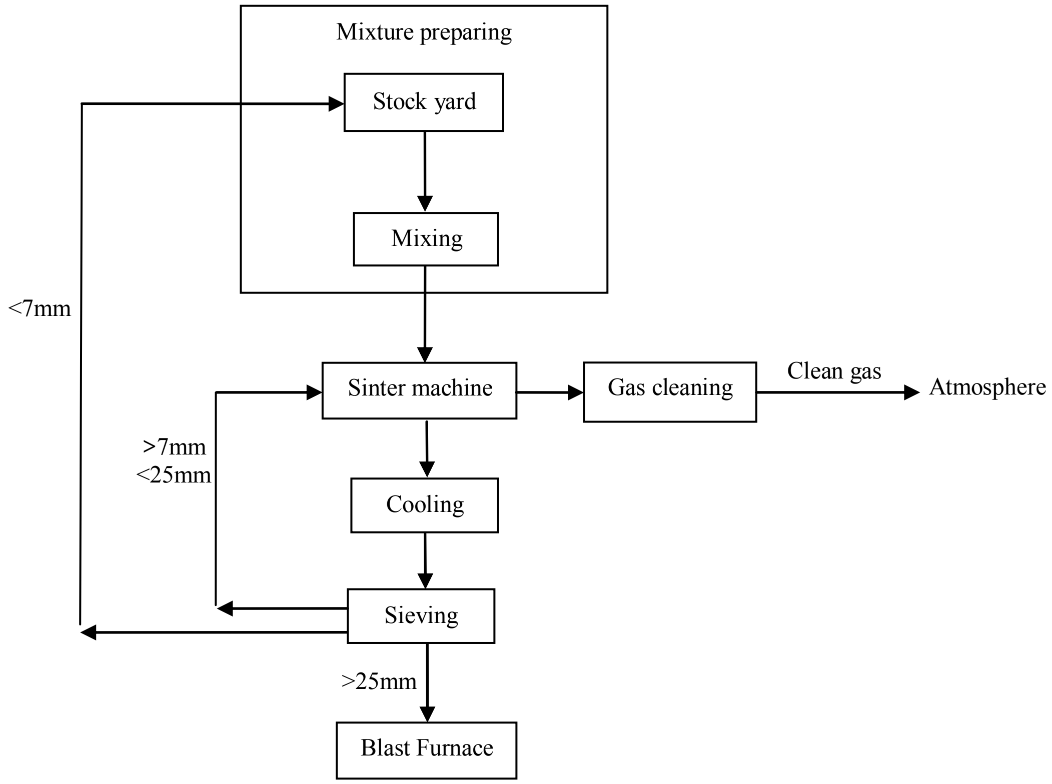


Figure 5.2. Flow diagram of sintering

As all sinter plants, the main problem related to this sinter plant is high emissions especially dust and other substances such as CO, CO_2, SO_2, NO, NO_2, HCl, HF, D/F, heavy metals. Some precautions have been taken in this plant for emission problem, the most important one is gas cleaning unit mentioned above. “Wet cyclones” are being used as gas cleaning devices. However, cyclones are outdated technologies and they have low efficiencies about 70%. As a result, emissions from sinter machines create environmental problems.

Another precaution taken for emission problem are dust collecting systems for dusts arising from charging and conveying. On the other hand, for the other important concern for sinter plants, energy efficiency, waste heat from sinter cooler is reused in this sinter plant.

5.1.2 Coke Making

Coal coming from Canada, Australia, USA, Poland, China and Ukraine by sea is drained into the stockyard. Different types of coal are prepared and mixed according to the desired coke quality and sent to the coke batteries. In the facility, six coke batteries are present, two of them are old, two of them are new, one of them is being modernized and the last one is not used. Every battery is composed of 65-69 coke ovens, where coking process takes place. After 19 hours coking time, coal is converted to coke by pyrolisis as mentioned in detail in Section 1.3 and pushed from coke ovens.

Finally the temperature of coke produced is decreased, in other words it is quenched, in order to be transferred easily. There are two types of quenching process, wet and dry quenching and both of them are being used in this coke oven plant. Dry quenching is a more environmental friendly method comparing to wet quenching. In wet quenching, water is sprayed onto the hot coke whereas in dry quenching, nitrogen gas is passed above hot coke, so that the heat is transferred from coke to the nitrogen gas indirectly. With dry quenching emissions are prevented, in addition the heated nitrogen gas is used in steam generation. By this way energy is hot coke is reused. Moreover, in dry quenching no water is used. However, operation of dry quenching is more complex and construction cost is higher comparing to wet quenching.

After quenching, coke is sent to blast furnace (iron making) to be used as fuel in order to provide sufficient heat for melting of iron.

As it is mentioned in Section 2.3, coke oven gas (COG) is a valuable gas having a high calorific value (~4350 kcal/m^3) that is originated from its high amount of H_2

and CH_4 components. Composition of COG from the facility is presented in Table 5.1.

Table 5.1. Composition of COG

Component	% (volume based)
H_2	59.60
CH_4	25.28
CO	6.05
N_2	4.72
C_nH_m	2.63
CO_2	1.35
O_2	0.39

Before using COG as fuel, it should be cleaned, in other words undesired substances should be removed from COG, in other words COG should be treated. The flow diagram of COG treatment process is presented in Figure 5.3.

First of all, COG is washed with ammonia water in “goose neck” in order to be cooled. This cooling provides that tar in gas form in the COG becomes liquid. COG, tar and ammonia water mixture is separated in “separator” and COG is sent to ammonium sulphate production unit whereas, ammonia water and tar mixture comes to “decanter” to be separated again. In decanter unit, ammonia water, tar and tar and coke breeze mixture are separated physically with respect to their densities. Ammonia water (~1 gr/cm^3) is sent to goose neck to be reused in gas cooling. However, due to the moisture in the coal, the amount of ammonia water in the system increases in time. The quantity of ammonia water in the system should be fixed, hence the excess ammonia water is removed from the system and sent to “ammonia stripping” unit prior to “biological treatment”. After biological treatment, clean water is disposed to receiving body (Mediterranean Sea). On the other hand, tar (~1.2 gr/cm^3) is taken from decanter and stored whereas tar and coke breeze mixture

(~1.25 gr/cm^3) is sent to coke ovens in order to be incinerated after “sedimentation unit”.

On the other side, in ammonium sulphate production unit, ammonia present in the COG is converted to ammonium sulphate (fertilizer) by addition of sulphuric acid. Finally, COG comes to benzole scrubbers, where benzole in COG is removed. So that, COG becomes exactly clean and ready to be used as fuel in the facility.
As stated earlier, ammonium sulphate (fertilizer), benzole and tar are the side products of COG treatment process and they are sold.

Previously, the main environmental problem related to coke ovens was stated as emissions. This is valid for this coke oven plant as well. More crucial emissions arising are dust, NO, NOx, SO_2 and CO. For dust emission prevention, dust collection systems for dusts arising from charging and conveying, and a sprinkler system in stockyard for dust emission due to the wind are being in use in this coke oven plant. For the other important issue which is energy consumption, neither precaution is taken in this coke oven plant.

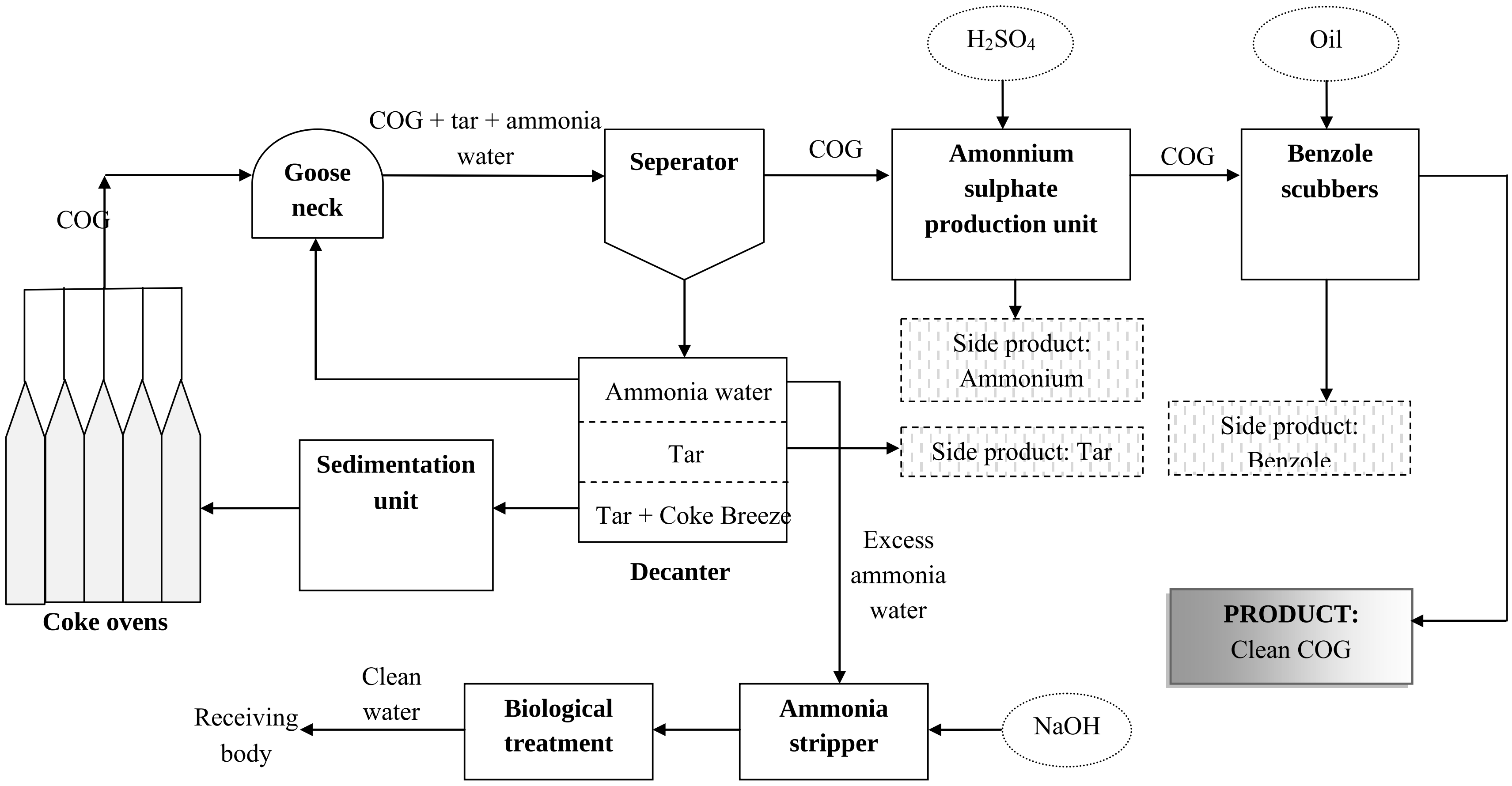


Figure 5.3. Flow scheme of COG treatment process

5.1.3 Iron Making

In iron making process, sinter from sinter plant, lump iron ore, additives (limestone, dolomite, dunit, magnesite), coke from coke oven plant and pulverized coal from coal preparation unit are filled into blast furnace (BF). To supply heat, coke and pulverized coal is burned by the hot air provided from hot stoves. After blast furnace feed is liquefied, liquid slag and liquid iron are separated from each other by density difference. Finally most of the liquid iron is sent to the basic oxygen furnace (steel making) to be converted to liquid slag. On the other hand, a small portion of the liquid iron is sent to pig iron casting plant and sold to the foundries. In the facility three blast furnaces are in use, one of them is new comparing to other two. In the new blast furnace, an integrated slag granulation system is present which granulates slag on site, whereas the liquid steel produced in the old ones are sent to slag granulation plant to be granulated. Granulated slag is sold to cement plants as a raw material. Composition of the BF slag in the facility is shown in Table 5.2.

Table 5.2. Composition of the BF slag

Composition	**SiO_2**	**CaO**	**Al_2O_3**	**MgO**	**FeO**	**S**	**MnO**	**K_2O**	**TiO_2**	**Na_2O**
%	41.36	35.35	11.97	7.11	0.19	0.70	1.16	0.99	0.53	0.32

Stack gas from blast furnaces are collected and treated in order to be used as fuel in the facility due to its remarkable amount of CO component. Composition of BF gas is presented in Table 5.3. Dirty gas is cleaned by spraying water following a dry dust collection system. The wastes that are dust from dry cleaning systems and sludge from wet cleaning systems are sent to sinter plant to be reused in sintering process. However, as it is mentioned before, due to the high zinc content of this dust and sludge, its usage in sinter plant is limited. Therefore these wastes are stored in the facility. This situation creates a substantial problem in the facility.

Table 5.3. Composition of the BF gas

Component	% (volume) based
CO_2	22
CO	22
N_2	51
H_2	5

Another important problem related to the blast furnace is high emissions. Despite the gas cleaning system and other dust collection systems for dust arising from conveying and charging, emissions of dust, CO, CO_2, SO_2 and NOx create problems related to blast furnace operation as well as aforementioned units.

For energy efficiency in blast furnaces and hot stoves, neither precaution is taken in this blast furnace plant.

5.1.4 Steel Making

Steel is produced in basic oxygen furnace (BOF) by blowing oxygen into liquid iron coming from BF. There are three BOF in the facility. As raw material, beside liquid iron, steel scrap is used in approximately 20%. As stated in section 1.5, liquid iron is subjected to desulphurization process before BOF to remove sulphur form liquid iron. Like in BF, in BOF impurities are passed to the scrap with the help of lime added to the BOF. The composition of BOF slag is shown in Table 5.4. The slag from desulphurization process and BOF cannot be granulated to be used as raw material in cement plants due to their nature, instead they are sent to slag storage area after cooling. A limited amount of BOF slag is sent to sinter plant in order to be added to the sinter mixture. Produced liquid steel is sent to secondary metallurgy before continuous casting in order to make fine adjustments by adding additives for requested steel quality.

Table 5.4. Composition of BOF slag

	Fe	**Mn**	**CaO**	**MgO**	**SiO_2**	**Al_2O_3**	**moisture**	**others**
%	18.8	2.7	45.9	3.8	11.4	2.1	2.7	12.6

BOF gas has a quite high CO content as can be seen in Table 5.5. Therefore it can be used as fuel after being cleaned. Gas cleaning in this BOF is performed by means of wet cleaning system similar to BF gas treatment system. In this system sludge is produced. As it was mentioned before, this gas treatment sludge includes high amount of zinc due to the painted and galvanized steel scrap used, and its usage in sintering process is limited. It creates an important problem for the facility.

Table 5.5. Composition of BOF gas

	CO	**H_2**	**CO_2**	**N_2 + Ar**	**others**
%	72.5	3.3	16.2	2.7	5.3

Other problems of basic oxygen furnaces in general which are emission and energy efficiency are valid for this facility. To prevent emissions of dust, collection systems for dust arising from conveying and charging are used in addition to abovementioned wet gas cleaning system. Moreover, for energy efficiency that is another important issue for BOF's, stack gas arising from BOF is subjected to indirect cooling by passing around water. This water is converted to steam to produce electricity. By this way waste heat is reused.

5.1.5 Casting and Rolling

As it was mentioned before, there are two types of casting methods, continuous and ingot casting. In the facility, continuous casting is applied. In the casting plant of the facility, liquid steel from steel making is cast into moulds as *"slab"* and *"billet"*

(Figure 5.4 and Figure 5.5) which are wide and long semi-products respectively. The dimensions of the moulds are set according to the desired quality. Following to casting, semi-products are left to cool until their temperature become appropriate to be transferred. Some portion of slabs and billets are sent to other rolling mills to be processed further, whereas most of them are brought to hot rolling mills in the facility. In the facility two rolling mills are in use; slab and billet rolling mills.

Figure 5.4. Slabs

Figure 5.5. Billets

In slab rolling mill, slabs are heated in furnaces up to annealing temperature approximately 1250°C, afterwards flattened by compressing between electrically powered rollers repeatedly up to 1.2-22 mm thickness and 700-2050 mm width according to the customers desire. The name of produced product from slab rolling mill is "*coil*", shown in Figure 5.6. Coil is used as raw material in automotive and white goods industry, and in ship building.

Figure 5.6. Coil

In billet rolling mill, billets are heated as well, and extended with the same method up to 5.5-16 mm diameter. The product of billet rolling mill is called as "*wirerod*" presented in Figure 5.7. After being process in other facilities, construction steel, screw, loaf etc. are produced from wirerod.

Figure 5.7. Wirerod

As mentioned in section 1.6, the main environmental problem related to casting and rolling is oily rolling mill which arises from cooling and cleaning of slab, billet, coil and wirerod. In the facility, cooling water containing oily mill scale is collected with canals and filled in sedimentation tanks. Due to the density difference, oil rises up and mill scale settles down. At certain periods oil is skimmed, then sent to oil recovery facilities, and mill scale separated from oil (called coarse mill scale) is collected from the bottom of the tank, and then sent to sinter plant. However, fine mill scale particles that cannot be separated from oil remains suspended in the water. After being further processed, oily mill scale (i.e. fine mill scale) is separated from water, collected and stored. Due to its high oil content up to 10%, it cannot be reused in sinter process and this situation causes an environmental and operational problem. In the facility, any measures are not taken against, however the authority of the facility are searching for methods to overcome this problem.

For NOx emission, low NOx generating boilers are in use in furnaces, however for other emissions such as CO, CO_2, SO_2, any precautions are not taken in this rolling mills. Considering energy efficiency, recuperators are used.

5.2 Step 2– Input/Output Analysis

The reason of input/output analysis was to provide data for the next step, performance evaluation of the facility. As stated in methodology part, in order to determine inputs and outputs of the sub-process, reports of each sub-processes for years 2009 and 2010 were examined and some calculations were made. However, due to the lack of measurements of some parameters (solid wastes, wastewaters, air emissions etc.), some of the inputs and outputs could not be determined. Amount of unidentified inputs and outputs are indicated as "*dnf*" (data not found) in the following tables presenting inputs and outputs of all sub-processes.

It should be noted that, there may be inconsistancies between the amounts of inputs and outputs. The reasons of these inconsistencies can be listed as follows;

- Lack of measurements of some parameters such as
  - gas treatment sludges,
  - gas cleaning waters,
  - cooling waters,
  - wastewater,
  - some other wastes
- Air emissions which can not be caught by air cleaning devices
- Errors in the measurements performed by the technical staff of the facility
- Moisture content in the raw materials which evapotares

The results of input/output analysis, for all sub-processes are given in the following sections in detail.

5.2.1 Sintering

Results of input/output analysis for sintering process for the years 2009 and 2010 presented in Table 5.6.

The only raw material utilized is fine iron ore and various additives that are limestone, dolomite, dunite, magnesite are put into the sinter mixture according to the desired sinter quality. As it was mentioned before, sinter plant is also operated as the recycling plant of the facility, which means all iron bearing materials are added to the sinter mixture that are returned sinter after screening (<7mm), pellet dust, BOF slag, BF gas treatment sludge, mill scale from casting and rolling mill and other wastes. Coke breeze is the main energy source for sintering of sinter feed. Moreover, among energy sources, COG and BF gas are used for ignition of coke breeze and electricity is used for the operation of sinter machine and other equipments such as pumps. In chapter 2, it was stated that for stack gas cleaning is performed wet cyclones, hence water is required for this process. Furthermore, for cooling of pumps cooling water is used in sinter plants. The quantity of gas treatment water for both of the years and quantity of cooling water could not be identified as these values are not recorded in the facility.

Table 5.6. Inputs and outputs of sintering process

INPUTS			
	Unit	**2009**	**2010**
Raw materials			
Fine iron ore	ton	1,720,951	2,357,645
Additives			
Limestone	ton	380,856	466,358
Dolomite	ton	21,010	1,697
Dunite	ton	60,261	102,049
Magnesite	ton	3,141	0
Wastes reused			
Returned sinter after sieving	ton	1,337,504	1,837,578
Pelet dust	ton	76,371	138,192
BOF slag	ton	35,563	92,806
BF gas treatment dust	ton	43,962	55,057
Mill scale	ton	52,477	66,902
Other wastes	ton	59,902	71,925
Energy			
Electricity (*1000)	kwh	90,400	134,115
COG (*1000)	Nm^3	10,877	12,561
BF gas (*1000)	Nm^3	0	43,695
Coke breeze	ton	154,358	207,565
Water			
Gas treatment water	m^3	dnf	dnf
Cooling water (*1000)	m^3	dnf	2,190
OUTPUTS			
	Unit	**2009**	**2010**
Product			
Sinter	ton	1,933,241	2,733,897
Wastes			
Sinter dust remain. under sieve	ton	1,337,504	1,837,578
Wastewater (*1000)	m^3	dnf	657
Gas treatment sludge	ton	dnf	dnf
Air emissions	ton	dnf	dnf

dnf: data could not be found

The only product of sinter plant is sinter and wastes arising are sinter dust remaining in underflow of sieve (i.e. <7mm), wastewater and gas treatment sludge. As presented in the following table, the amount of abovementioned sinter dust is huge, almost equal to the sinter produced. Whole waste sinter dust produced is recycled to the sintering process. If examined carefully, it is seen that the amount “returned sinter after sieving” in inputs and the amount of “sinter dust remaining under sieve” are exactly equal to each other. On the other hand, amount of wastewater produced in 2009, and gas treatment sludge produced in both of the years cannot be specified.

During the examination of several annual reports of sintering process, it is noticedthat total inputs are averagely 15-20% greater than total outputs. This big difference is called *“ignition loss”*, which arises mainly from the conversion of coke breeze in the mixture to CO_2 by combustion.. Ignition loss is a very crucial parameter followed by the technical staff of sinter plant indicating the efficiency of sintering process.

5.2.2 Coke Making

Inputs and outputs of coke making process and their quantities of yearly consumption & production in 2009 and 2010 are presented in Table 5.7.

As raw material, coal is utilized for coke making process. Moreover for manufacture of side-products, sulphuric acid (H_2SO_4), sodium hydroxide (NaOH) and oil are used for ammonium sulphate (fertilizer) production, distillation of ammonia wastewater and benzole recovery from COG respectively. Like in sinter plants, tar and coke breeze mixture produced as waste from side-product manufacture is used in coke ovens as energy source beside COG, natural gas and BF gas. Furthermore for other equipments related to the operation of coke oven plant electricity is used in order to provide energy. For wet quenching applied batteries, water is consumed. In addition water and steam are used for cooling and cleaning purposes respectively. The amount of cooling water could not be determined as it is shown in Table 5.7.

The products of coke oven plant are coke and COG originated from batteries and steam from dry quenching. Dry quenching unit in the facility was in maintenance between 2009 and 2010, steam generation was not recorded properly. The values of steam generation mentioned in coke oven plant and energy plant in the facility are inconsistent; as a result it is not included in input/output analysis of coke making process. Benzole, tar and ammonium sulphate are side-products produced from COG treatment. Wastes arising from coke oven plant are tar and coke breeze mixture that is used in coke oven plant as fuel, ammonia wastewater which is arise due to the moisture content of the coal and treated treated biologically, sludge from aforementioned treatment, and wet quenching water. The quantity of biological wastewater treatment sludge could not be specified due to the lack information.

Table 5.7. Inputs and outputs of coke making process

INPUTS			
	Unit	**2009**	**2010**
Raw materials			
Coal	ton	2,709,895	2,953,556
Other raw materials			
Sulfuric acid	ton	20,629	21,157
Sodium hydroxide	ton	2,757	3,168
Oil	ton	388	494
Wastes reused			
Tar + coke breeze mixture	ton	1,628	1,708
Energy			
Electricity (*1000)	kwh	47,555	52,936
COG (*1000)	Nm^3	318,474	191,631
Natural gas (*1000)	Sm^3	29	0
BF gas (*1000)	Nm^3	0	694,657
Water			
Quenching water	ton	876,000	876,000
Cooling water	m^3	dnf	dnf
Steam (*1000)	ton	399,896	346,207
OUTPUTS			
	Unit	**2009**	**2010**
Products			
Coke	ton	1,915,938	2,192,966
COG (*1000)	Nm^3	756,884	845,864
	ton	370,873[1]	414,473[1]
Steam	ton	dnf	dnf
Side products			
Benzole	ton	11,440	11,621
Tar	ton	77,690	82,780
Ammonium sulphate	ton	22,745	18,958
Wastes			
Tar + coke breeze mixture	ton	1,628	1,708
Ammonia wastewater	ton	230,612	235,694
Biol. wastewater treatm. sludge	ton	dnf	dnf
Wet quenching water	ton	876,000	876,000
Air emissions	ton	dnf	dnf

[1] density of COG is taken as 490 kg/m^3

dnf: data could not be found

5.2.3 Iron Making

Table 5.8 presents the results of input/output analysis for iron making process for 2009 and 2010 years.

In iron making process, three different iron bearing raw materials are consumed, sinter produced in sinter plant, pellet and lump iron ore purchased. Besides, lime stone for slag producing and dolomite, magnesite and quartzite for other purposes are used as additives. As the main energy source for reducing and melting iron bearing feed of BF's coke is required. Beside coke, pulverized coal is used in relatively small quantity. In addition, COG, natural gas and BF gas is consumed in hot stoves in order to heat the air needed in BF for combustion of coke and coal. As in the upstream sub-processes electricity is used for other operational energy requirements such as pumps and dust collection systems. Required water for steel making is for BF stack gas treatment and for cooling of pumps. The amount of gas treatment water used in 2009 and cooling water in both of the years could not be determined during input/output analysis of iron making process. Other than abovementioned inputs, steam, air, oxygen and nitrogen are consumed with the aim of cleaning, combustion in BF, enriching of air required for this combustion and transfer of pulverized coal, respectively.

The only products of iron making process are liquid iron and BF gas whereas various types of wastes are produced which are liquid slag, scrap, stack dust from dry as cleaning, sludge from wet gas cleaning. However as it was mentioned before, among these wastes, slag is granulated and sold to cement plants and the remaining wastes all of which have iron content are reused in the sintering process. Furthermore, from stack gas treatment process, wastewater arises and its amount could not be identified since it is not recorded in the facility.

Table 5.8. Inputs and outputs of iron making process

INPUTS			
	Unit	**2009**	**2010**
Raw materials			
Sinter	ton	2,140,363	2,733,898
Pellet	ton	1,692,646	2,133,178
Lump iron ore	ton	332,137	606,477
Additives			
Limestone	ton	11,903	11,112
Dolomite	ton	101	1,598
Magnesite	ton	48,561	16,849
Quartzite	ton	72,175	97,045
Energy			
Coke	ton	1,147,737	1,440,900
Pulvarized coal	ton	197,272	357,109
Electricity (*1000)	kwh	35,955	47,961
COG (*1000)	Nm^3	29,072	28,998
Natural gas (*1000)	Sm^3	44	196
BF gas (*1000)	Nm^3	1,211,038	1,553,950
Water			
Gas treatment water (*1000)	m^3	dnf	3,110
Cooling water	m^3	dnf	dnf
Others			
Steam	ton	131,600	172,614
Air (*1000)	ton	3,472	4,335
Oxygen (*1000)	Nm^3	91,000	152,536
Nitrogen (*1000)	Nm^3	11,020	11,020
OUTPUTS			
	Unit	**2009**	**2010**
Products			
Liquid iron	ton	2,603,147	3,371,884
BF gas (*1000)	Nm^3	4,252,134	5,309,760
	ton	5,485,253	6,849,590
Wastes			
Liquid slag	ton	744,007	983,027
Scrap	ton	33,197	181
Stack dust	ton	22,160	37,385
Gas treatment sludge	ton	20,000	26,000
Wastewater	m^3	dnf	dnf
Air emissions	ton	dnf	dnf

*density of BF gas is taken as 1,290 kg/m^3

dnf: data could not be found

5.2.4 Steel Making

In Table 5.9, inputs consumed and outputs produced from steel making process for the years 2009 and 2010 are presented.

Liquid iron produced in BF's is the only raw material of BOF's. Other than that, other metallic inputs that are great amount of scrap (purchased scrap and defective slabs and billets), and relatively small amount of returned steel whose quality is not sufficient, pig iron, iron ore and other materials. Moreover as additive, oxygen is provided for oxidizing carbon in liquid iron to be convert it to liquid steel, and lime is added as slag making agent. In addition, as it is presented in Table 5.9, various other additives are consumed in BOF's and in secondary metallurgy for required quality of the steel. COG and natural gas are consumed by BOF's and electricity is used for other equipments as energy source in steel making process. Water for stack gas treatment of BOF's, cooling water for pumps and steam for cleaning purposes are other inputs of the steel making process. The amount of gas treatment water and cooling water could not be identified for 2009 due to the aforementioned reason.

As presented Table 5.9, liquid steel and BOF gas are the product of steel making process and the wastes are desulphurization and BOF slag, gas treatment sludge, scale (scattered steel during transfer of steel) and wastewater originating from stack gas treatment.

Table 5.9. Inputs and outputs of steel making process

INPUTS			
	Unit	**2009**	**2010**
Raw materials			
Liquid iron	ton	2,552,010	3,313,018
Metallic inputs			
Returned steel	ton	4,978	3,547
Scrap	ton	619,851	785,738
Pig iron	ton	200	242
Iron ore	ton	10,005	21,809
Other	ton	13,641	914
Additives			
Oxygen	ton	220,195	279,844
Lime	ton	165,966	238,510
Magnesite	ton	504	6,045
Dolomite	ton	0	14,455
Coke	ton	3,596	3,960
Hard coal	ton	5,768	2,395
Fe Mn+ Fe Si	ton	8,439	9,277
Si Mn	ton	21,655	19,423
Coke breeze	ton	1,719	27
Al	ton	2,118	5,328
FeCr + FeMo + FeV	ton	104	296
Floride	ton	1,090	1,479
Other	ton	1,261	1,433
Energy			
Electricity (*1000)	kwh	72,408	215,433
COG (*1000)	Nm^3	15,959	10,900
Natural gas (*1000)	Sm^3	122	200
Water			
Gas treatment water (*1000)	m^3	dnf	4,507
Cooling water (*1000)	m^3	dnf	887
Steam	ton	186,067	188,208
OUTPUTS			
	Unit	**2009**	**2010**
Products			
Liquid steel	ton	2,820,895	3,674,945
BOF gas (*1000)	Nm^3	168,606	353,283
	ton^2	224,245	469,866
Wastes			
Desulpurisation slag	ton	76,560	99,390
BOF slag	ton	307,965	433,554
Gas treatment sludge	ton	114,576	240,073
Scale	ton	3,505	3,921
Wastewater (*1000)	m^3	dnf	118
Air emissions	ton	dnf	dnf

*density of BOF gas is taken as 1,330 kg/m^3

dnf: data could not be found

5.2.5 Casting and Rolling

Input/output analysis results for casting and rolling processes are presented in Table 5.10 and Table 5.11 respectively.

Raw material of casting process is liquid steel provided from BOF. Electricity, COG, natural gas and LPG are the main energy sources of casting process for different purposes. Oxygen is consumed for shaving of slabs and billets, whereas nitrogen and argon are used for hydraulic equipments. Another input for this process is water that is used for cooling and cleaning of semi-products and cooling of pumps.

Table 5.10. Inputs and outputs of casting process

INPUTS			
	Unit	**2009**	**2010**
Raw materials			
Liquid steel	ton	2,820,895	3,674,944
Energy			
Electricity (*1000)	kwh	35,028	41,342
COG (*1000)	Nm^3	21,355	17,253
Natural gas (*1000)	Sm^3	2,178	3,046
LPG	kg	421	381
Oxygen (*1000)	Nm^3	4,801	5,524
Nitrogen (*1000)	Nm^3	10,734	7,270
Argon(*1000)	Nm^3	362	467
Water			
Water	m^3	222,830	223,670
OUTPUTS			
	Unit	**2009**	**2010**
Products			
Slab	ton	853,534	2,124,497
Billet	ton	1,896,095	1,439,980
Wastes			
Slab scrap	ton	40,820	10,411
Billet scrap	ton	26,852	3,861
Wastewater	m^3	dnf	dnf
Oil	ton	dnf	dnf
Fine mill scale	ton	dnf	dnf
Coarse mill scale	ton	dnf	dnf
Air emissions	ton	dnf	dnf

dnf: data could not be found

The products of casting process are slab and billets (semi-products) differentiated only in shape. The wastes originated from this process is slab and billet scrap which are unqualified products, coarse and fine mill scales of semi-products and wastewater arising from semi-product cooling and cleaning, oil skimmed from sedimentation tanks. The amount of wastewater, oil, fine and coarse mill scales arising from casting for years 2009 and 2010 could not be determined due to the same reason as the abovementioned sub-processes.

As it is shown in Table 5.11, raw materials of rolling process are slab and billet which are the semi-products of casting process. COG and Natural gas are used for heating furnaces and electricity is consumed for mechanical equipment of rolling mill. Almost the whole electricity is utilized for huge engines of rollers. On the other hand, oxygen and nitrogen gases are needed for shaving of coil and wirerods and hydraulic equipments in the rolling mills.

Products of rolling mills are coil and wirerod. Wastes arising from rolling mills are similar with casting process, since here coil and wirerod are cooled and cleaned with the same method. Aforementioned wastes are coil and wirerod scrap which are unqualified products, coarse and fine mill scales of coil and wirerod, wastewater and oil skimmed from sedimentation tanks. Different form casting process, the amount of coarse mill scales from coil and wirerod were determined whereas other wastes which are oil and fine mill scales could not be determined as well for both of the years. On the other hand the quantity of wastewater produced in 2010 was identified while the one in 2009 could not be specified.

Table 5.11. Inputs and outputs of rolling process

INPUTS			
	Unit	**2009**	**2010**
Raw materials			
Slab	ton	622,209	2,046,013
Billet	ton	540,270	466,225
Energy			
Electricity (*1000)	kwh	159,703	250,042
COG (*1000)	Nm^3	67,397	138,994
Natural gas (*1000)	Sm^3	21,454	23,707
Oxygen (*1000)	Nm^3	220	1,391
Nitrogen (*1000)	Nm^3	250	2,021
Water			
Water (*1000)	m^3	dnf	4,800
OUTPUTS			
	Unit	**2009**	**2010**
Products			
Coil	ton	605,431	1,983,301
Wirerod	Nm^3	517,514	445,067
Wastes			
Coil scrap	ton	4,436	17,188
Wirerod scrap	ton	17,325	15,444
Coil coarse mill scale	ton	12,342	45,524
Wirerod coarse mill scale	ton	5,431	5,714
Wirerod fine mill scale	ton	dnf	dnf
Billet fine mill scale	ton	dnf	dnf
Oil	ton	dnf	dnf
Wastewater (*1000)	m^3	dnf	1,760
Air emissions	ton	dnf	dnf

dnf: data could not be found

5.3 Step 3 – Performance Evaluation of the Facility

In the facility, since 2002 modernization processes have been carried out for capacity increase and protection of environment. Since then 160 million US dollars have been spent for environmental modifications. These provided a substantial development of environmental performance of the facility comparing before 2002. Emissions to air have decreased in a considerable amount. Moreover from 2001 to 2009 specific water consumption have been reduced from 29.5 m^3/ton crude steel to 9.8 m^3/ton crude steel, on the other hand energy consumption have decreased from 7.9 Mcal/ ton crude steel to 5.5 Mcal/ ton crude steel .

As stated in Chapter 4, with the aim of evaluation of environmental and operational performance of the facility, specific consumptions and emissions of all sub-processes were calculated one by one, based on the product of each sub-process and they were compared with the ones listed in BREF Documents (on iron and steel production and on surface treatment of metals). Afterwards, the parameters outside the limits were specified and the reason behind them was researched during the site visits to the facility. Emission values of the facility were taken from an emission report provided by technical staff of the facility, prepared according to the measured emission values in 2009. The facility have this report prepared once every three years, therefore 2010 emissions could not be compared with BREF Documents. Moreover, some of the emission parameters which are present in BREF Documents were not mentioned in aforesaid emission report; hence these could not be evaluated as well.

In the following sections, results of aforementioned study are presented for each sub-processes. Parameters that are outside of the limit values are indicated by bold fonts. Moreover, the exceed percentages of these parameters are given in Section 5.3.6.

5.3.1 Sintering

In sintering process, the amount of all inputs are divided into mass of sinter produced whereas outputs are divided into the mass of liquid steel (LS) produced by steel making process considering BREF document. By this way specific consumptions and emissions of the sinter plant is calculated and compared with the limit values mentioned in BREF Document (Table 5.12).

As it can be seen in Table 5.12, the amount of returned sinter after sieving is significantly higher than the upper limit set in BREF Document because of the long distance between sinter plant and BF plant. Since sieves are placed just before BF sinter and sinter produced in sinter plant fragmentizes during the transfer. This creates an operational and financial problem, however because sinter and BF plant cannot be replaced, this problem cannot be overcame.

Moreover, specific consumptions of iron ore in both of the years and limestone and additives in 2009 are slightly higher than the limits. It indicates that the iron content, i.e., the quality, of iron ore used up is a slightly lower than the one in Europe. Qualified iron ore is composed of nearly 60-65% Fe, where the iron content of the ore utilized in the facility is 50-55%. The amount of limestone and additives can alter according to the desired characteristics of the steel produced. Hence, this situation is accepted as normal.

Considering energy consumption of this sinter plant, it can be realized that total usage of COG, BF gas and natural gas are between the limits, however specific consumption of coke and electricity is significantly higher. When total energy usage is calculated by summing upper and lower limits of BREF Document and 2009 and 2010 energy consumptions individually, it can be concluded that total energy consumption of the sinter plant is very high. This indicates that energy is used in sinter plant inefficiently. In addition, water consumption in 2010 is found out to be significantly higher than the limits.

As it can be seen in Table 5.12, most of the emissions such as dust, Cd, Cu, Mn, Ni, V, NOx and SO_2, arising from sinter plant are quite higher than the ones in European sinter plants,. On the other hand, some of the parameters, Cd and TI are slightly higher and Hg, CO and PCDD/F values are within the limit values. Finally, HCl and HF emissions and wastewater production are found to be quite lower than the limits.

Consequently, as a result of this study sinter plant is evaluated to be incompatible with the European sinter plants with respect to environmental and operational performance criteria.

Table 5.12. Comparison of specific emissions and consumptions of sintering process with BREF document

INPUTS	Unit	BREF Range	Facility		OUTPUTS	Unit	BREF Range	Facility	
			2009	**2010**				**2009**	**2010**
Raw materials					**Product**				
Iron ore	kg/t sinter	680 – 850	**890**	**862**	Sinter	kg/t sinter	1000	1000	1000
Other ferrous materials	kg/t sinter	37 – 125	67	75	**Air emissions**				
Lime	kg/t sinter	0.5 – 14	0	0	Dust	g/t LS	170 - 280	**1159**	**-**
Limestone	kg/t sinter	105 – 190	**197**	170	Cd	g/t LS	0.002 – 0.04	0.055	-
Additives	kg/t sinter	26 – 42	**43.7**	38	Cr	g/t LS	0.005 – 0.05	**19**	**-**
BF gas treatment dust	kg/t sinter	11 – 27	22.7	20.1	Cu	g/t LS	0.007 – 0.16	**0.75**	**-**
Recycled material	kg/t sinter	42 – 113	49.4	86.6	Hg	mg/t LS	16-149	18	-
Retur. sinter after sieving	kg/t sinter	230 – 375	**692**	**672**	Mn	g/t LS	0.02 – 0.4	**4.29**	**-**
Energy					Ni	g/t LS	0.002 – 0.04	**16.63**	**-**
COG, BF gas, natural gas	MJ/t sinter	57 – 200	103.8	131.8	Pb	g/t LS	0.04 – 7	0.574	-
Coke	MJ/t sinter	1260 – 1380	**1972**	**1875**	Tl	g/t LS	0.005 – 0.03	0.048	-
Electricity	MJ/t sinter	96 – 114	**450**	**472**	V	g/t LS	0.005 – 0.02	**0.338**	**-**
Total energy (calculated)	MJ/t sinter	1413-1694	**2525.8**	**2478.8**	Zn	g/t LS	0.002- 1.8	-	-
Others					HCl	g/t LS	17 – 65	7	-
Compressed air	Nm^3/t sinter	1.2 – 3	dnf	dnf	HF	g/t LS	1.4 – 3.5	0.32	-
Water	m^3/t sinter	0.01 – 0.35	dnf	**0.8**	NOx	g/t LS	440 - 710	**848**	**-**
					SO_2	g/t LS	900 - 1850	**3025**	**-**
					CO	kg/t LS	13 – 43	31.22	-
					CO_2	kg/t LS	205 - 240	-	-
					VOC	g/t LS	15	-	-
					PAH	mg/t LS	115 - 915	-	-
					PCDD/F	µg I-TEQ/t LS	0.5 – 6.5	2.59	-
					Wastes/Side Products				
					Dust	kg/t LS	0.9 – 15	dnf	-
					Gas treatm. sludge	kg/t LS	3.0	dnf	dnf
					Wastewater	m^3/t LS	6.00	dnf	0.18

dnf: data could not be found LS: liquid steel

5.3.2 Coke Making

In performance evaluation of coke making process, coke production is taken as base in calculation of specific consumption and waste production, and liquid steel is considered in specific emission calculation. The results of this performance evaluation presented in Table 5.13.

Coal consumption in 2009 is determined to be slightly higher than the limit values in BREF Documents due to the quality of coke utilized. Considering energy consumption of coke oven plant, it is noticed that BF gas and coke oven gas usage is lower than limits, on the other hand electricity consumed is significantly higher. When looking at total consumption, it can be concluded that total energy consumption of coke oven plant is compatible with BREF Document. Moreover, steam consumption is calculated to be significantly higher than the limits.

Examining the specific productions, it is specified that quite high amount of COG is produced in both of the years comparing with the BREF Document. Normally, high COG production is an indicator of poor coal quality. However in this facility, the reason behind high COG production is different: Some of the coke produced in coke oven plant is sold to another integrated iron and steel plant in Turkey instead of using in itself for steel production. Since the limit value set in the BREF document is calculated by dividing COG production into liquid steel produced, it becomes higher than expected.

Among 13 emission parameters specified in BREF document, only four of them are measured and reported in 2009. Hence only four parameters can be compared and evaluated. Among them only dust emission found out significantly higher than the limit value. In addition, ammonium sulphate ($(NH_4)_2SO_4$) production is calculated as quite higher than expected, which means ammonium in COG originated from coal characteristics is high. More ammonium sulphate production provides more income for the facility with its sale. Finally wastewater production is slightly lower than limits. In consequence, coke oven plant of the facility is not compatible with European coke oven plants, but it is more compatible than sinter plant.

Table 5.13. Comparison of specific emissions and consumptions of coke making process with BREF document

INPUTS	**Unit**	**BREF Range**	**Facility**		**OUTPUTS**	**Unit**	**BREF Range**	**Facility**	
			2009	**2010**				**2009**	**2010**
Raw materials					**Products**				
Coal (dry basis)	kg/t coke	1250 – 1350	**1414**	1346	Coke (dry)	kg/ton coke	1000	1000	1000
Energy					COG	MJ/t LS	2500 - 3200	**4950**	**4346**
BF gas+COG	MJ/t coke	3200 – 3900	3067	2567	Steam	MJ/t LS	3 - 500	188	126
Electricity	MJ/t coke	20 – 170	**239**	**232**	**Air emissions**				
Total energy (calculated)	MJ/t coke	3220-4070	3306	2799	Dust	g/t LS	17 - 75	**525**	-
Others					SOx	g/t LS	27 - 950	78	-
Steam	MJ/t coke	60 - 300	**720.2**	**687**	NOx	g/t LS	230 - 600	242	-
Compressed air	Nm^3/t coke	7 – 15	dnf	dnf	NH_3	g/t LS	0.8 – 3.4	-	-
Cooling water	m^3/t coke	0.8 - 10	0.45	0.40	H_2SO_4	g/t LS	0.7	-	-
					HCN	g/t LS	0.02 – 0.4	-	-
					H_2S	g/t LS	4 -20	-	-
					CO	g/t LS	130 - 1500	1174	-
					CO_2	kg/t LS	175- 200	-	-
					CH_4	g/t LS	27	-	-
					VOC	g/t LS	4 - 8	-	-
					Benzene	g/t LS	0.3 - 15	-	-
					PAH	mg/t LS	170 - 500	-	-
					Wastes/Side Products				
					Benzene	kg/t coke	8 - 15	5.97	5.3
					H_2SO_4	kg/t coke	4 - 9	*	*
					Tar	kg/t coke	25 - 46	40.5	37.7
					$(NH_4)_2SO_4$ (as SO_4^{-2})	kg/t coke	1.7 – 3.4	8.6	8.6
					Sulphur	kg/t coke	1.5 – 2.3	*	*
					wastewater	m3/t coke	0.3 – 0.4	0.27	dnf

dnf: data could not be found LS: liquid steel * no sulphur recovery is applied in the facility

5.3.3 Iron Making

In calculation of specific consumptions of iron making process liquid iron (LI) is accepted as base, whereas for specific emissions and waste production LS is considered, in order to compare them with BREF Document. Comparison of specific consumptions and emissions for iron making process are shown in Table 5.14.

Considering raw materials, coke consumptions in both of the years are determined to be slightly higher than the limits set in BREF Documents. Besides, it is noticed that some of the inputs specified in BREF documents that are heavy oil, lime, recycled materials and plastics, were not consumed in both of the years. On the other hand, some additives which are consumed in the facility are not mentioned in BREF Document, which are limestone, dolomite, quartzite and manganese. Their usage depends on the desired quality of liquid iron produced.

Natural gas and electricity usage are significantly lower than expected, moreover total energy consumption of the iron making plant is within the limit values.

Only four emission parameters can be compared and evaluated. Two of them are quite higher than limits which are dust and CO whereas the remaining two, NOx and SOx are between the limits. Finally, top gas sludge arising from wet treatment of stack gas is specified as slightly higher than the limits.

As a result, except for some parameters, iron making process is compatible with BREF Document.

Table 5.14. Comparison of specific emissions and consumptions of iron making process with BREF document

INPUTS	Unit	BREF Range	Facility		OUTPUTS	Unit	BREF Range	Facility	
			2009	**2010**				**2009**	**2010**
Raw materials					**Products**				
Sinter	kg/t LI	720 – 1480	822	811	Liquid iron	kg/t LI	1000	1000	1000
Iron ore	kg/t LI	25 –350	128	180	**Energy**				
Pelet	kg/t LI	100 – 770	650	633	BF gas	MJ/t LI	4400 – 5000	4808	4747
Coke	kg/t LI	280 – 410	440	427	Electricity	MJ/t LI	750	*****	*****
Coal	kg/t LI	0 – 180	75	106	**Air emissions**				
Heavy oil	kg/t LI	0 – 60	0	0	Dust	g/t LS	10 – 50	**1066**	-
Lime	kg/t LI	0 –10	0	0	Mn	g/t LS	< 0.01 – 0.13	-	-
Recycled materials	kg/t LI	2 – 8	0	0	Ni	g/t LS	< 0.01 – 0.02	-	-
Plastic	kg/t LI	0 –30	0	0	Pb	g/t LS	< 0.01 – 0.12	-	-
Lime stone	kg/t LI	dnm	4.6	3.3	SOx	g/t LS	20 – 230	21	-
Dolomide	kg/t LI	dnm	0.039	0.47	NOx	g/t LS	30 – 120	68	-
Quartzite	kg/t LI	dnm	27.7	28.8	H_2S	g/t LS	0.2 – 20	-	-
Manganese	kg/t LI	dnm	18.6	5	CO	g/t LS	770 – 1750	**2624**	-
Energy					CO_2	kg/t LS	280 – 500	-	-
BF gas	MJ/t LI	1050 – 2700	1369	1371	PCDD/F	µg I-TEQ/t LS	<0.001–0.004	-	-
COG	MJ/t LI	90 – 540	206	159	**Wastes/Side Poducts**				
Natural gas	MJ/t LI	50 – 230	0.58	1.99	Slag	kg/t LS	200 – 290	266	267
Electricity	MJ/t LI	270 – 370	133	137	Top gas dust	kg/t LS	6 – 16	7.9	10.2
Total energy (calculated)	MJ/t LI	1460-3840	1709	1669	Top gas sludge	kg/t LS	3 – 5	**7.16**	**7.7**
Others					Wastewater	m3/t LS	0.1 – 3.3	dnf	dnf
Oxygen	m^3/t LI	25 – 55	35	45					
Steam	MJ/t LI	22 – 30	**142**	**144**					
Compressed air	m^3/t LI	9 – 11	-	-					
Water	m^3/t LI	0.8 - 50	dnf	dnf					

dnm: data not mentioned in BREF doc. dnf: data could not be found LI: liquid iron LS: liquid steel *no top gas turbine

5.3.4 Steel Making and Casting

In BREF document, limit values for steel making and continuous casting processes are given in the same table, hence they were evaluated together in this study as well. Base unit is taken as liquid steel for specific consumptions as well as specific emissions and waste productions.Table 5.15 presents the specific inputs and outputs compared with BEF documents.

When looking at the table below, it is seen that the amounts of some of the raw material consumptions differentiate with the ones in BREF documents. This results from the differences in required steel quality.

Coke oven gas consumed in the steel making and casting processes is not specified in BREF document. On the other hand, although natural gas usage determined to be low, electricity consumption is so great that calculated total energy becomes quite higher than the limit values. This means that energy is not used efficiently in these processes of the facility. Moreover, steam consumption of these processes is significantly higher when comparing with the values mentioned in BREF Document.

As outputs, the quantity of produced BOF gas is low resulting in low energy recovery. In addition steam generated from BOF gas pretty high comparing to BREF documents.

Considering emissions, it can be realized that only three emissions can be compared and evaluated, and among them dust is found out to be quite high, NOx is within the limit values and CO is lower than the limits. Additionally, among wastes produces, desulphurization slag production in 2009 and 2010 is significantly higher than the limits set in BREF Document, whereas BOF slag production in 2010 is slightly higher.

In consequence, as a result of this study steel making and casting processes are evaluated to be incompatible with the ones in Europe with respect to environmental and operational concerns.

Table 5.15. Comparison of specific emissions and consumptions of steel making and casting processes with BREF document

INPUTS	Unit	BREF Range	Facility		OUTPUTS	Unit	BREF Range	Facility	
			2009	2010				2009	2010
Raw materials					**Products**				
Liquid iron	kg/t LS	820 – 980	914	908	Slab/billet	kg/t LS			
Scrap	kg/t LS	170 – 255	220	214	BOF gas	MJ/t LS	650 – 840	**392**	**636**
Iron ore	kg/t LS	7 – 20	3.6	6	Steam	MJ/t LS	20 – 270	**431**	**308**
Other ferrous mat.	kg/t LS	7 – 10	7.1	1.8	**Gas emissions**				
Coke	kg/t LS	0.02 – 0.48	0.046	0.014	Dust	g/t LS	15 – 80	**519**	-
Lime	kg/t LS	30 – 55	50.7	54.7	Cr	g/t LS	0.01 – 0.36	-	-
Dolomite	kg/t LS	1.5 – 4	0	3.9	Cu	g/t LS	0.01 – 0.04	-	-
Energy					Pb	g/t LS	0.13 – 0.9	-	-
Natural gas	MJ/t LS	20 – 55	1.5	1.9	Mn	g/t LS	<0.01 – 1.2	-	-
Electricity	MJ/t LS	38 – 120	**616**	**564**	NOx	g/t LS	5 – 20	7.9	-
COG	MJ/t LS	-	54.9	55.1	CO	g/t LS	1500 – 7960	7	-
Total energy (calculated)	MJ/t LS	58 - 175	**672.4**	**621**	CO_2	kg/t LS	11.2 – 140	-	-
Other					PAH	mg/t LS	0.08 – 0.16	-	-
Oxygen	m^3/t LS	45 – 55	55	54	PCDD/F	µg I-TEQ/t LS	<0.001 – 0.06	-	-
Steam	MJ/t LS	30 – 140	**218**	**169**	**Wastes/Side Products**				
Compressed air	Nm^3/t LS	4 – 18	-	-	Desulphurisation slag	kg/t LS	2.2 – 19.2	**27.7**	**27.2**
Water	m^3/t LS	0.4 – 5	dnf	1.46	BOF slag	kg/t LS	85 – 110	110	**118**
					Secondary metal. slag	kg/t LS	2 – 16	dnf	dnf
					Dust	kg/t LS	1.5 – 7	dnf	dnf
					Cont.casting slag	kg/t LS	4 – 5	dnf	dnf
					Wastewater	m^3/t LS	-	dnf	0.03

dnf: data could not be found LS: liquid steel

5.3.5 Rolling

In rolling process, base is taken as mass of product which are coil and wirerod. Emission and consumptions of slab rolling mill is divided into coil production whereas the ones of billet rolling mill into divided into wirerod production. Results of performance evaluation of rolling mills are shown in Table 5.16 below.

Energy consumptions is not evaluated according to total consumption of slab rolling mill and billet rolling mill, instead the evaluation is performed by summing of the energy consumptions of furnaces and rolling systems of both of the mills with respect to the BREF Document. As it can be seen from the table below, energy consumptions of furnaces and rolling systems are within the limits.

Water consumption of rolling systems which is used for cooling and cleaning of coil and wirerod can only be calculated for 2010. Its value is between the limits as well.

When looking at emissions, among the five emission parameters specified in BREF Document, three of them were measured and reported in 2009. Hence only they were compared with the limit values set in BREF Documents. Among them only dust is above the limits, NOx is between the limits and CO is determined to be pretty low than the limits.

Considering wastes produced, only mill scale arising from coil production in 2009 and 2010 is determined to be significantly higher, however wastewater produced due to the cooling and cleaning of coil and wirerod in 2010 is calculated as slightly over than the aforementioned limit values.

In conclusion, rolling mills in the facility is pretty compatible with BREF Document when neglecting some parameters.

Table 5.16. Comparison of specific emissions and consumptions of rolling process with BREF document

INPUTS	Unit	BREF Range	Facility		OUTPUTS	Unit	BREF Range	Facility	
			2009	2010				2009	2010
Energy					**Products**				
Energy (Furnaces)	GJ/ton product	1.1-2.2	1.84	1.45	Wirerod/Coil	kg/ton product	1000	1000	1000
Energy (Rolling)	kwh/ton product	72-140	135	97	**Gas emissions**				
Others					Dust	g/ton product	1-10	**19.1**	-
Water (Rolling)	m^3/ton product	1-15.5	dnf	1.97	NOx	g/ton product	2-600	59.4	-
					SO_2	g/ton product	0.3-600	**-**	**-**
					CO	g/ton product	5-850	0.68	-
					Hydrocarbon	g/ton product	0-5	-	-
					Wastes/Side products				
					Mill scale	kg/t LS	1.2 – 6	2.8 (wirerod) **13** (coil)	2.6 (wirerod) **20** (coil)
					Wastewater	m^3/ton product	0.8-15.3	dnf	0.72

dnf: data could not be found product: wirerod for billet rolling mill, coil for slab rolling mill

5.3.6 Results Overview

As a result of this study, it was noticed that despite the abovementioned modifications having been performed in the facility since 2002, still some parameters are outside the ranges set in BREF documents, in other words more improvements are required in environmental concern in the facility.

Two summary tables on the specific consumptions and emission of parameters outside the limits and creating problems for the facility are prepared and presented below. In Table 5.17 and Table 5.18 aforementioned parameters for inputs and outputs are shown. Moreover in these tables, the percentiles how much the specific emissions and consumption exceed the upper limit set in BREF documents for 2009 and 2010 separately and average of these years are presented. Exceed percentiles were calculated with respect to the upper limit of the range. On the other hand, specific emission and consumptions of some of the parameters were compared with respect to the lower limit, since for these parameters lower value indicates poor performance. Parameters slightly higher than the limits, the ones lower than the limits indicating good performance are not covered in these tables.

Table 5.17. Comparison of input parameters (raw materials, energy, water and other inputs) outside the limits set in BREF documents

Parameter	**Unit**	**BREF Range**	**Facility**				
			2009		**2010**		**Avg.**
			value	**exceed %**	**value**	**exceed %**	**exceed %**
Raw materials							
Sintering							
Returned sinter after sieving	kg/t sinter	230- 375	692	**84.5**	672	**79.2**	**81.9**
Energy							
Sintering							
Coke	MJ/t sinter	1260 - 1380	1972	**42.9**	1875	**35.9**	**39.4**
Electricity	MJ/t sinter	96 – 114	450	**295**	472	**314**	**305**
Total energy (calculated)	MJ/t sinter	1413-1694	2526	**49.1**	2479	**46.3**	**47.7**
Coke making							
Electricity	MJ/t coke	20 – 170	239	**40.6**	232	**36.5**	**38.6**
Total energy (calculated)	MJ/t LS	58 - 175	672	**284**	621	**255**	**270**
Steel making and casting							
Electricity	MJ/t LS	38 – 120	616	**413**	564	**355**	**384**
Water							
Sintering							
Water	m^3/t sinter	0.01 – 0.35	dnf	**-**	0.8	**129**	**129**
Other inputs							
Coke making							
Steam	MJ/t coke	60 - 300	720	**140**	687	**129**	**135**
Iron making							
Steam	MJ/t LI	22 – 30	142	**373**	144	**380**	**377**
Steel making and casting							
Steam	MJ/t LS	30 – 140	218	**55.7**	169	**20.7**	**382**

dnf: data could not be found

As it can be seen in Table 5.17, the common problem related to inputs are energy and steam consumptions of the sub-processes. As energy, electricity is consumed quite higher than the limit values mentioned in BREF Documents. In Figure 5.8 and Figure 5.9, percent exceed of the limits set in BREF Documents regarding electricity and steam consumption is presented respectively.

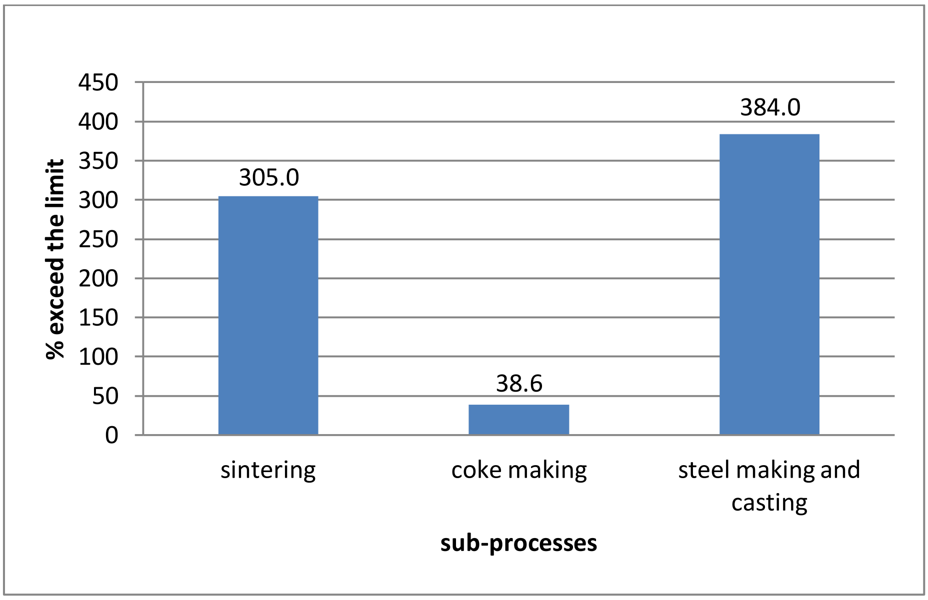


Figure 5.8. Percentile of exceed of electricity consumption limits (average of 2009 and 2010)

As it can be clearly seen from Figure 5.8, in terms of electricity consumption, steelmaking and casting process is the most problematic sub-process with the exceed limit of 384% and it is followed by sintering and coke making processes with 305% and 38.6% respectively. On the other side, when looking at Figure 5.9, it can be noticed that steel making and casting process exceeds steam consumption limits priory as well with the exceed limit of 382%. Iron making process exceed slightly less than steel making and casting process with 377% and they are followed by coke making process with 135%.

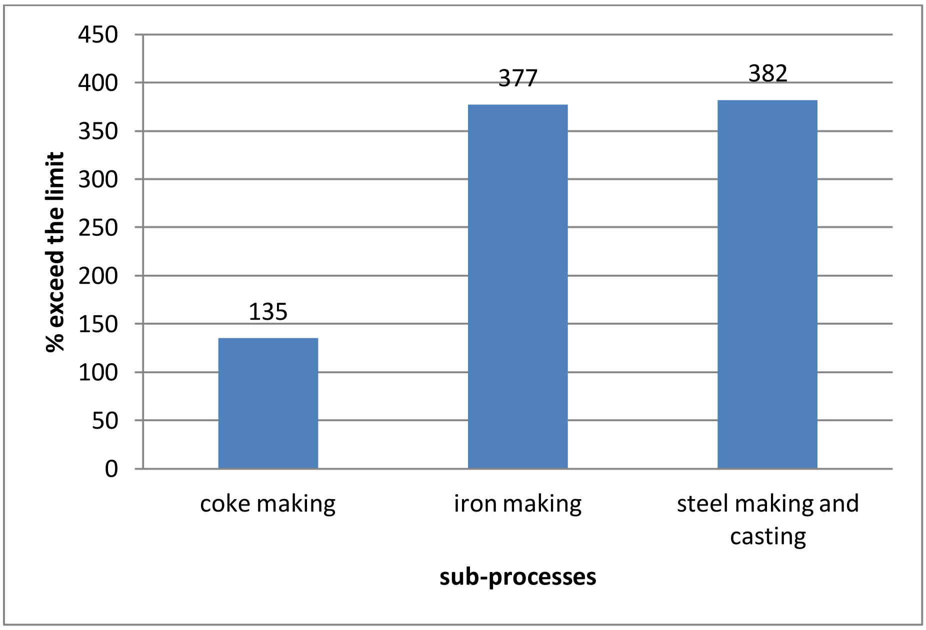


Figure 5.9. Percentile of exceed of steam consumption limits (average of 2009 and 2010)

Moreover, the summary table showing the problematic specific outputs and their percent exceed limits of BREF documents are presented in Table 5.18.

Table 5.18. Comparison of output parameters (products, air emissions, wastes and side products) outside the limits set in BREF Documents

Parameter		**Unit**	**BREF Range**	**Facility**				
				2009		**2010**		**Avg.**
				value	**exceed %**	**value**	**exceed %**	**exceed %**
Products								
Coke making								
COG		MJ/t LS	2500 - 3200	4950	**54.6**	4346	**35.8**	**45.2**
Steelmaking and casting								
BOF gas		MJ/t LS	650 – 840	392	**-39.7***	636	**-2.1***	**-20.7***
Air emissions								
Sintering								
Dust		g/t LS	170 - 280	1159	**314**	-	-	**314**
Heavy metals	Cr	g/t LS	0.005 – 0.05	19	**37900**	-	-	**37900**
	Cu	g/t LS	0.007 – 0.16	0.75	**369**	-	-	**369**
	Mn	g/t LS	0.02 – 0.4	4.29	**973**	-	-	**973**
	Ni	g/t LS	0.002 – 0.04	16.63	**41475**	-	-	**41475**
	V	g/t LS	0.005 – 0.02	0.338	**1590**	-	-	**1590**
NOx		g/t LS	440 - 710	848	**19.4**	-	-	**19.4**
SO_2		g/t LS	900 - 1850	3025	**63.5**	-	-	**63.5**
Coke making								
Dust		g/t LS	17 - 75	525	**600**	-	-	**600**
Iron making								
Dust		g/t LS	10 – 50	1066	**2032**	-	-	**2032**
CO		g/t LS	770 – 1750	2624	**49.9**	-	-	**49.9**
Steel making and casting								
Dust		g/t LS	15 – 80	519	**549**	-	-	**549**
Rolling								
Dust		g/t product	1-10	19	**90**	-	-	**90**
Wastes/Side Products								
Iron Making								
Top gas sludge		kg/t LS	3 – 5	7.16	**30.1**	7.7	**54**	**42**
Steel making and casting								
Desulphurisation slag		kg/t LS	2.2 – 19.2	27.7	**44.3**	27.2	**41.7**	**43**
Rolling								
Mill scale (coil)		kg/t LS	1.2 – 6	13	**117**	20	**233**	**175**

* Minus sign means that BOF is produced less than it should be. This indicates poor performance. Exceed percentile is based on lower limit.

From Table 5.18, it is clearly seen that dust emission is the common problem for the facility among other parameters. As seen in Figure 5.10, iron making is the leading sub-process by far with the exceed limit 2032% and it is followed by coke making, steel making and casting, sintering and rolling processes with the exceed limits 600%, 549%, 314% and 90% respectively. It can be deduced that all sub-processes have dust emission problem, among them rolling process exceeds the limits in negligible quantities comparing with the others.

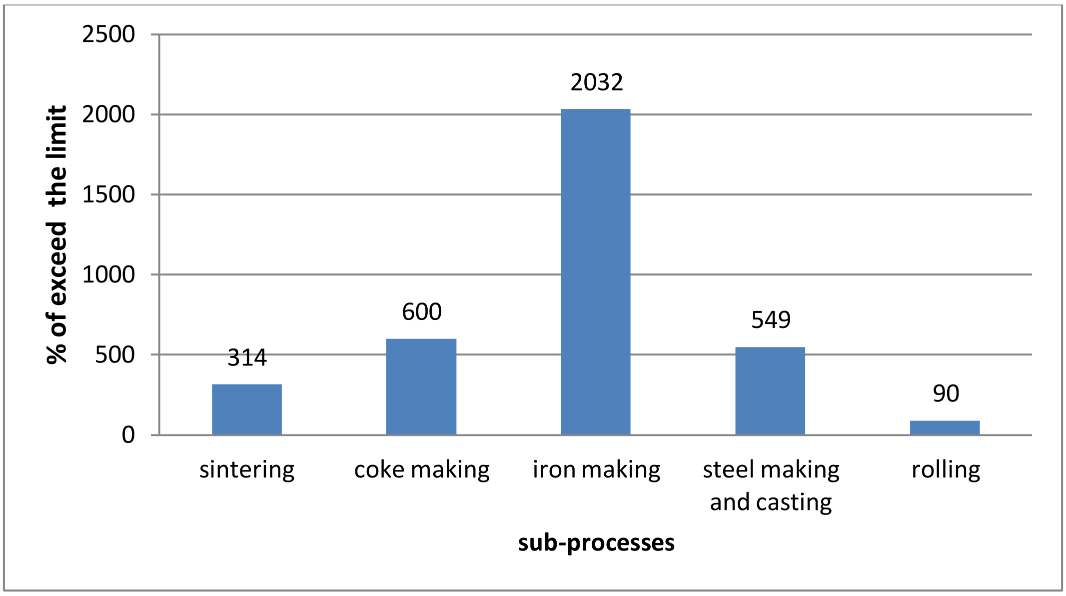


Figure 5.10. Exceed percentiles of dust emissions

Another remarkable point noticed from Table 5.18 is the fact that the amount of heavy metal emissions arising from sintering process is so enormous that dust emissions from this process becomes negligible. As it can be seen from Figure 5.11, especially emissions of Ni and Cr are high with the exceed limits 41475% and 37900% comparing to other emissions that are V (1590%), Mn (973%), Cu (369%), dust (314%), SO_2 (63.5%) and NOx (19.4%).

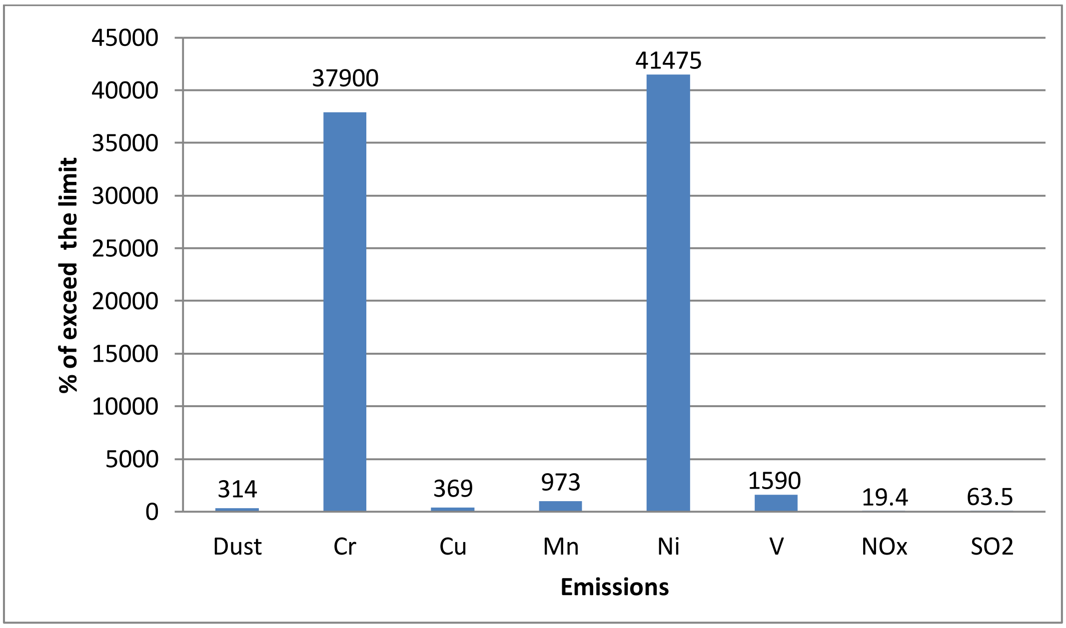


Figure 5.11. Air emissions of sintering process

Furthermore, comparing the number of parameters outside the limits of each sub-processes of the facility between each other, it can be clearly realized that sintering is the most problematic sub-process, especially with respect to its energy consumption and air emissions. As it is deduced from Table 5.17 and Table 5.18, the number of parameters outside the limits of sintering process is 13, eight of them being air emissions (Figure 5.12). Sintering process is followed by steel making-casting processes (5), coke making process (5) and iron making process (4). On the other hand, among all, rolling process is evaluated as the most environmental friendly sub-process comparing with the other ones with only two parameters outside the limits.

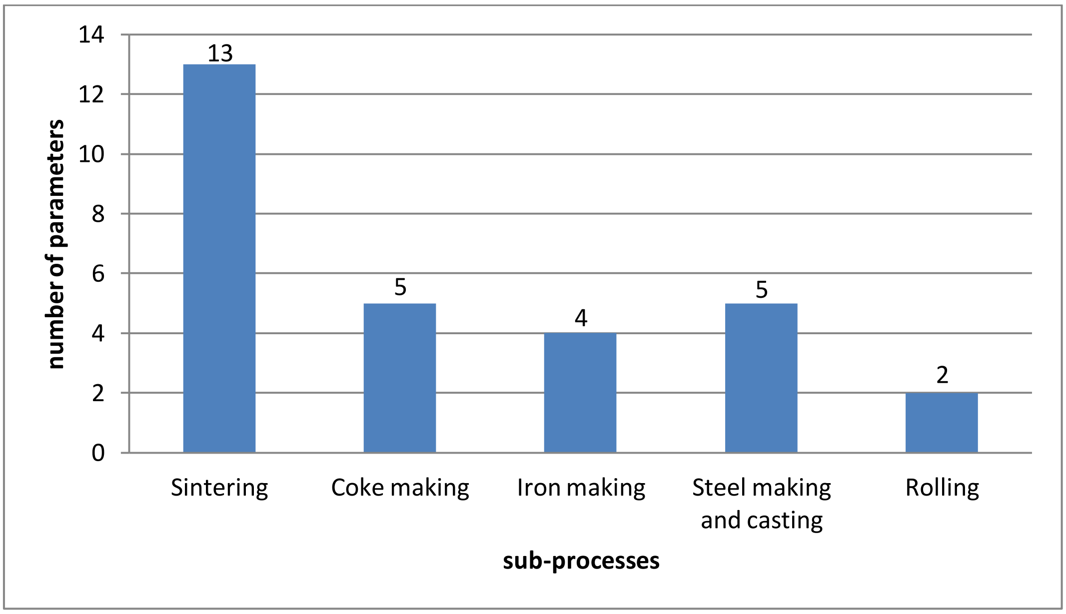


Figure 5.12. Number of parameters outside the limits

5.4 Step 4 – Determination of Potential BAT for the Facility

In Section 3.2.3. BAT alternatives for integrated iron and steel plants obtained from literature were presented. In this section, results of evaluation of these alternatives with respect to their applicability to the facility will be presented.

As it was mentioned before, total of 74 alternative BAT measures were specified. However, after examination of the process of the facility during site visits, it was noticed that some of these measures had already been applied and some of them are not applicable to the facility due to various reasons. With the aim of determining the suitable BAT options to the facility, aforesaid measures were eliminated. To this end, list of BAT alternatives showing their applicability to the facility and the targets of their applications for all sub-processes were prepared and presented following sections. In order to show its applicability, every BAT alternative was marked with the signs that are plus (+), minus (-) and check (√) indicating *"already applied"*, *"not applicable"* and *"suggested"* respectively. Detailed information on suggested BAT alternatives and the reasons why BAT alternatives are not applicable to the facility are presented in Table A.1 (Apendix A) and Table B.1 (Apendix B), respectively. In addition, when the target of these BAT alternatives are examined, it is realized that most of them help to provide energy efficiencies and to overcome emission problems other operational problems mentioned in Chapter 2 for every sub-processes.

5.4.1 Sintering

In the previous chapter, sintering process was determined to be the least compatible sub-process with BREF Document considering its specific consumption and emission values. Parallel to this result, in this part of the study, it is realized that sinter plant in the facility does not apply most of the BAT alternatives stated in the literature. Looking at Table 5.19 which presents the BAT alternatives for sintering process, it is noticed that among 20 alternatives, one is not suitable and among the rest 19 ones, only four alternatives have already been applied in this sinter plant. It means that, this sinter plant applies only 21% of the potential BAT alternatives. Suggested 15 BAT alternatives can be seen in Table 5.19.

Table 5.19. BAT alternatives for sintering process

	BAT Alternative	**Target**	+ / - / √	**Ref.**
	Process Integrated Techniques			
1	Process optimization for minimization of PCDD/F emissions	Emission minimization	+	[8],[11]
2	Recycling iron-containing waste into the sinter plant	Waste reuse	+	[8],[11]
3	Lowering the content of volatile hydrocarbons in the sinter feed	Emission minimization	√	[8],[11]
4	Lowering the sulphur content of the sinter feed	Emission minimization	-	[8],[11]
5	Heat recovery from sinter cooling	Energy recovery	+	[8],[11]
6	Top layer sintering	Waste reuse	√	[8],[11], [34]
7	Waste gas recirculation	Emission minimization, Energy recovery	√	[8],[11], [34], [42]
8	Suppression of PCDD/F formation by addition of nitrogen compounds in the sinter mix	Emission minimization	√	[11], [36]
9	Twin layer charging	Energy efficiency, Quality increase	√	[34]
10	Intensive mixing and granulation system-IMGS	Energy efficiency, Quality increase	√	[34]

+: already applied -: not applicable √: suggested

Table 5.19. BAT alternatives for sintering process- continued

	BAT Alternative	**Target**	+ / - / √	**Ref.**
	End of Pipe Techniques			
11	Advanced electrostatic precipitator (ESP)	Emission minimization	√	[8],[11]
12	Integrated bag filter system (ESP + bag filter)	Emission minimization	√	[8],[11]
13	Cyclone	Emission minimization	+	[8],[11]
14	Fine wet scrubber (AIRFINE)	Emission minimization	√	[8],[11]
15	Desulphurization	Emission minimization	√	[8],[11]
16	Regenerative active carbon (RAC)	Emission minimization	√	[8],[11], [42]
17	Selective catalytic reduction (SCR)	Emission minimization	√	[8],[11]
18	Reduction of PCDD/F by means of ESP and additives	Emission minimization	√	[11]
19	Biological treatment of oily mill scale	Waste reuse	√	[35]
20	Use of novel filter for dust and heavy metal treatment	Emission minimization	√	[36]

+: already applied -: not applicable √: suggested

5.4.2 Coke Making

The list of BAT alternatives and their applicabilities is presented in Table 5.20. As shown in this table, 14 of the total 25 alternatives have already been applied in this coke oven plant, where three of them are not applicable. This coke oven plant seems to be environmental friendly with respect to the 63.6% of the BAT application ratio. However, coke making process was determined to be relatively compatible with

BREF Document comparing to sinter plant. From this determination it can be deduced that either these applied BAT measures are not applied properly or more BAT measures should be applied.

Table 5.20. BAT alternatives for coke making process

	BAT Alternative	**Target**	+ / - / √	**Ref.**
	Process Integrated Techniques:			
1	Smooth and undisturbed operation of the coke oven plant	Emission minimization	+	[8],[11]
2	Maintenance of coke ovens	Emission minimization	+	[8],[11]
3	Improvement of oven door and frame seals	Emission minimization	+	[8],[11]
4	Maintaining free gas flow in the coke oven	Emission minimization	+	[8],[11]
5	Emission reduction during coke oven firing	Emission minimization	-	[8],[11]
6	Coke dry quenching (CDQ)	Emission minimization, Energy recovery	+	[8],[11]
7	Large coke oven chambers	Emission minimization, Energy recovery	-	[8],[11]
8	Non-recovery coking	Emission minimization, Energy recovery	-	[8],[11]
9	Waste gas recirculation	Emission minimization, Energy recovery	√	[11]

+: already applied -: not applicable √: suggested

Table 5.20. BAT alternatives for coke making process- continued

	BAT Alternative	**Target**	**+ / - / √**	**Ref.**
10	Closed belt conveyors	Emission minimization	√	[11],[43]
11	Stabilized coke wet quenching	Emission minimization	√	[11]
12	Preheating of coal, combustion air and fuel	Energy recovery	√	[37]
	End of Pipe Techniques:			
13	Minimizing oven charging emissions	Emission minimization	+	[8],[11]
14	Sealing of ascension pipes and charging hole	Emission minimization	+	[8],[11]
15	Minimizing leakage between coke oven chamber and heating chamber	Emission minimization	+	[8],[11]
16	De-dusting of coke oven pushing	Emission minimization	+	[8],[11]
17	Emission minimized wet quenching	Emission minimization	+	[8],[11]
18	De-NOx of waste gas from coke oven firing (Selective catalytic reduction -SCR)	Emission minimization	√	[8],[11]
19	Coke oven gas desulphurization	Emission minimization	√	[8],[11]
20	Removing tar (and PAH) from the coal water	Emission minimization	+	[8],[11]
21	Ammonia stripper	Emission minimization	+	[8],[11]
22	Gas-tight operation of the gas treatment plant	Emission minimization	+	[8],[11]
23	Wastewater treatment plant	Emission minimization	+	[8],[11]
24	Hydrogen and methanol production from COG	Waste reuse	√	[38],[39]
25	Heat recovery from COG	Energy recovery	√	[37]

+: already applied -: not applicable √: suggested

5.4.3 Iron Making

For iron making process, relatively less BAT alternatives could be found from the literature. During the site visits, it was determined that all of the possible 12 BAT options are applicable to the iron making process of the facility, four of them have already been implemented in this facility whereas eight of them can be applied, as presented in Table 5.21. In other words 33.3% of the BAT options is in application in this iron making plant. Although this ratio is relatively low, iron making process was found to be compatible with BREF Document with respect to specific consumption and emissions in the previous section. The reason behind that may be the appropriate operation of implemented BAT measures.

Table 5.21. BAT alternatives for iron making process

	BAT Alternative	**Target**	+ / - / √	**Ref.**
	Process Integrated Techniques			
1	Direct injection of reducing agents	Fuel cost decrease, Waste reuse	√	[8],[11], [44],[45]
2	Energy recovery from blast furnace gas	Energy recovery	+	[8],[11]
3	Energy recovery from top gas pressure	Energy recovery	√	[8],[11]
4	Energy savings at the hot stove	Energy saving	+	[8],[11]
5	Use of tar-free runner linings	Emission minimization	√	[8],[11]
6	Gas recovery system from top hopper release	Emission minimization	√	[11]

+: already applied -: not applicable √: suggested

Table 5.21. BAT alternatives for iron making process- continued

	BAT Alternative	**Target**	+ / - / √	**Ref.**
	End of Pipe Techniques			
7	Blast furnace gas treatment	Emission minimization, Energy recovery	+	[8],[11]
8	De-dusting of tap holes and runners	Emission minimization	√	[8],[11]
9	Fume suppression during casting	Emission minimization	√	[8],[11]
10	Hydro-cyclonage of blast furnace sludge	Waste reuse	√	[11],[46]
11	Treatment and reuse of scrubbing water	Wastewater reuse	+	[11]
12	Condensation of fume from slag granulation	Emission minimization	√	[8],[11]

+: already applied -: not applicable √: suggested

5.4.4 Steel Making and Casting

In BREF Documents BAT alternatives for steel making and casting processes are given together as in the previous section, performance evaluation of the facility. Hence, in this study BAT alternatives of these two processes are evaluated together. Table 5.22 presents the BAT alternatives and their applicabilities for steel making and casting processes. As it can be noticed from the table below, among nine alternatives, six BAT measures have already been applied and one is not applicable to the steel making and casting plants of the facility. In other words, 75% of the BAT alternatives have been implemented before this study. Despite this high ratio, in the previous section it was stated that specific emission and consumption levels of steel making and casting processes are not compatible with BREF Documents. From this result is can be deduced that the applied BAT measures are not operated properly.

For instance, although a primary dedusting system is present near BOF's in the facility, dust emissions are huge due to the low efficiency of the dedusting equipments.

Table 5.22. BAT alternatives for steel making and casting processes

	BAT Alternative	**Target**	+ / - / √	**Ref.**
	Process Integrated Techniques			
1	Energy recovery from BOF gas	Energy recovery	+	[8],[11]
2	Lowering the zinc-content of scrap	Waste reuse	-	[8],[11]
3	On-line sampling and analysis of steel	Production efficiency	+	[8],[11]
	End of Pipe Techniques			
4	Primary dedusting	Emission minimization	+	[8],[11]
5	Particulate matter abatement from pig iron pre-treatment	Emission minimization	+	[8],[11]
6	Secondary de-dusting	Emission minimization	+	[8],[11]
7	Dust hot briquetting and recycling	Waste reuse	√	[8],[11],[47],[48]
8	Treatment of wastewater from wet de-dusting	Wastewater reuse	+	[8],[11]
9	Treatment of wastewater from continuous casting	Wastewater reuse	√	[8],[11]

+: already applied -: not applicable √: suggested

5.4.5 Rolling

In the previous section, rolling process was determined to be the most compatible sub-process with BREF Document considering its specific emission and consumptions. However, in this part of study it is determined that eight BAT alternatives are present in the literature for rolling mills and two of them are not suitable to the mills in the facility, whereas three of them have already been applied and remaining three is suggested to the facility. It means, 50% of the BAT alternatives are in use in the facility. Considering the result of the previous section, this percentage seems to be low. The reason of this circumstance is that the options are alternative for each other. In other words, one cannot be applied if another one has already been implemented. The result of evaluation of BAT alternatives for rolling mills is presented in Table 5.23.

Table 5.23. BAT alternatives for rolling process

	BAT Alternative	**Target**	+ / - / √	**Ref.**
	Process Integrated Techniques			
1	Regenerative burner system	Energy recovery	√	[9]
2	Recuperator and recuperative burners	Energy recovery	+	[9]
3	Limiting air preheating temperature	Emission minimization	-	[9]
4	Low NOx Burners	Emission minimization	+	[9]
5	External flue gas recirculation (FGR)	Emission minimization	√	[9]

+: already applied -: not applicable √: suggested

Table 5.23. BAT alternatives for rolling process- continued

	BAT Alternative	**Target**	+ / - / √	**Ref.**
	End of Pipe Techniques			
6	Selective catalytic reduction (SCR)	Emission minimization	√	[9]
7	Selective non-catalytic reduction (SNCR)	Emission minimization	-	[9]
8	Treatment of cooling water	Wastewater reuse	+	[9]

+: already applied -: not applicable √: suggested

5.4.6 Results Overview

As stated before, 74 different BAT alternatives were evaluated with respect to their applicabilities in the facility, in other words, BAT measures that have been already applies, are not applicable to the facility and are suggested are determined. A summary table showing the results of this part of the study is presented in Table 5.24.

Table 5.24. Summary of applicabilities of BAT alternatives in the facility

Sub-process	**Applied (+)**	**Not applicable (-)**	**Suggested (√)**	**TOTAL**
Sintering	4	1	15	**20**
Coke making	14	3	8	**25**
Iron making	4	0	8	**12**
Steel making and casting	6	1	2	**9**
Rolling	3	2	3	**8**
TOTAL	**31**	**7**	**36**	**74**

Table 5.24 shows that comparing the number of BAT alternatives, coke is the prior sub-process having 25 BAT possible alternatives, followed by sintering, iron making, steel making and casting, and rolling processes with the number of possible BAT alternatives 20, 12, nine and eight respectively. The percentile distribution of these values is presented in Figure 5.13.

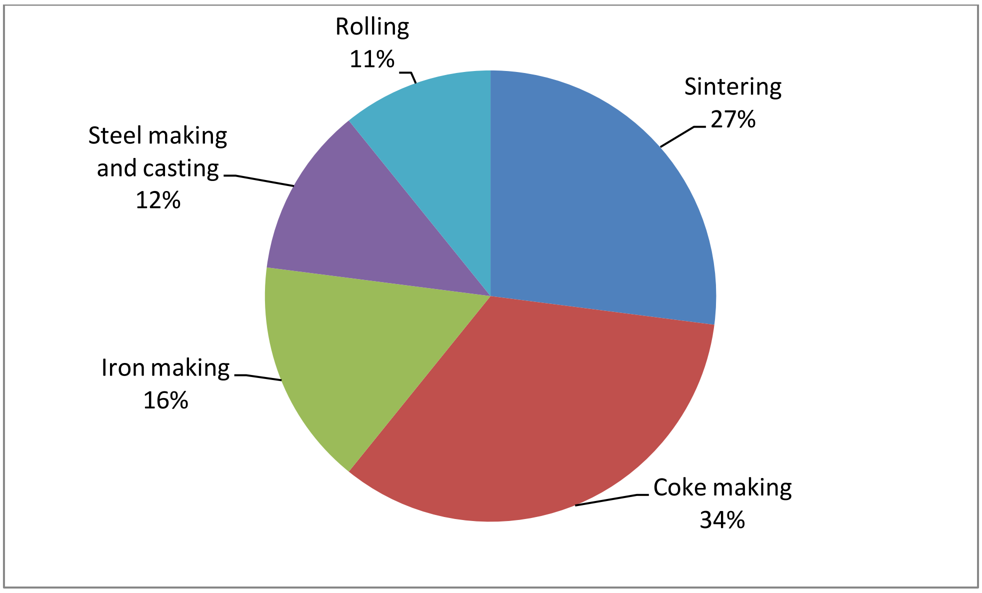


Figure 5.13. Percentile distribution of total BAT alternatives based o sub-processes

On the other hand, looking at the applicabilities of total BAT measures for the facilities, it is realized that among 74 alternatives, 31 BAT measures have already been applied, seven alternatives are not applicable to the facility and the remaining 36 measures are suggested to the facility. The percentile distribution of these values is presented in Figure 5.14 below.

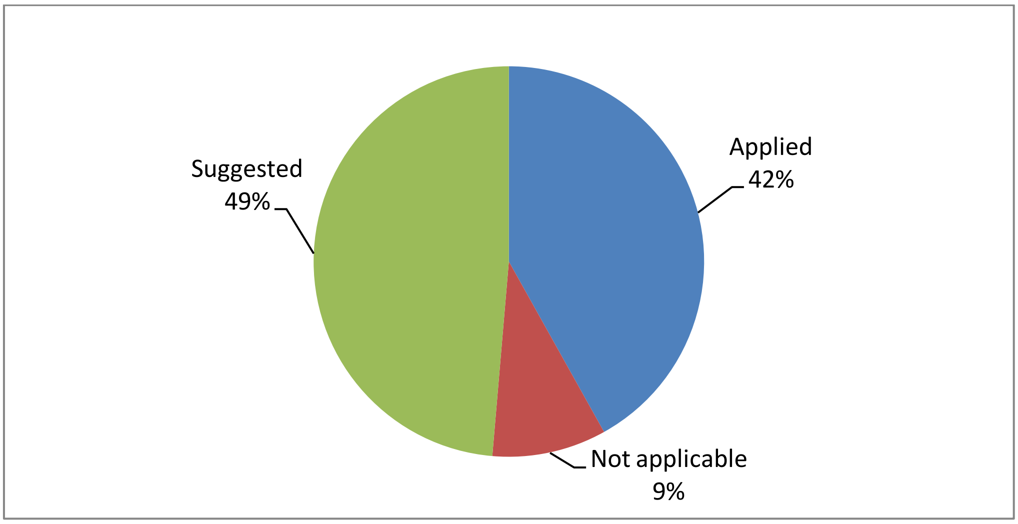


Figure 5.14. Percentile distribution of total BAT alternatives based on applicabilities

Finally, graphical representation of number of BAT alternatives for every sub-processes deduced from Table 5.24 is shown in Figure 5.15. As can be seen from this figure, number of suggested alternatives of sintering process is more than others, on the other side, the largest number of measures that have already been applied belongs to coke making process.

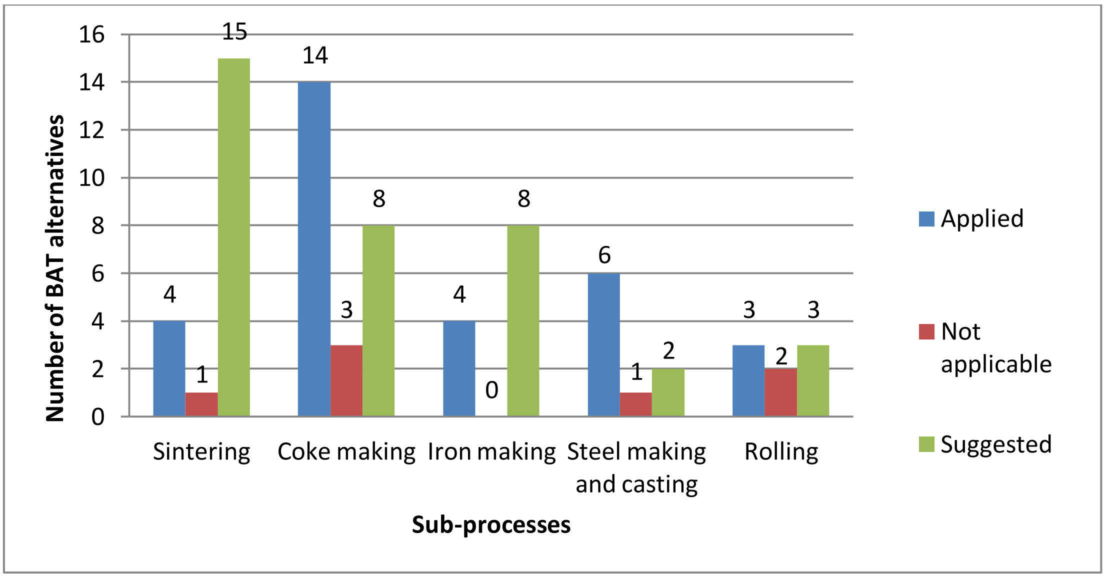
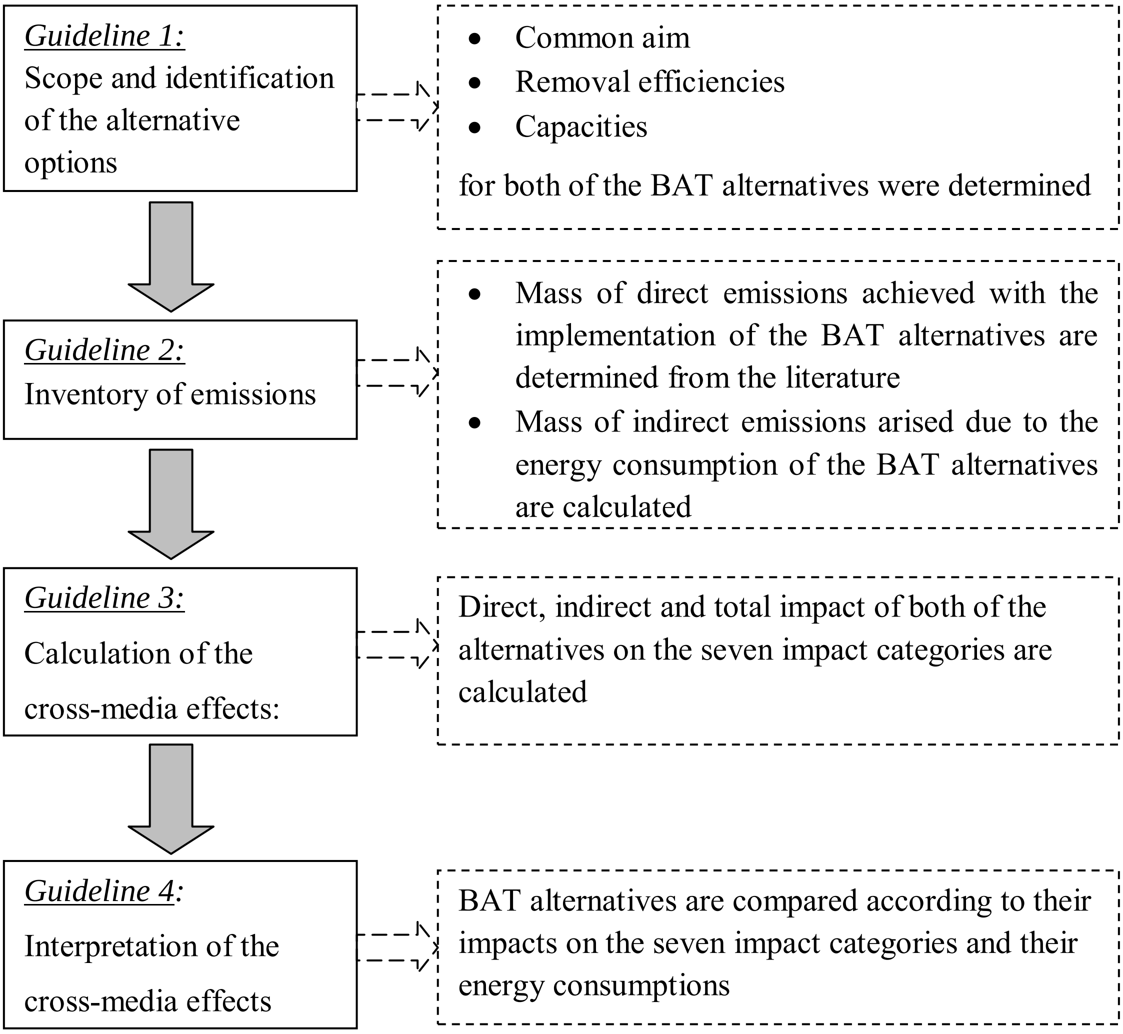


Figure 5.15. Number of BAT alternatives and their applicabilities for sub-processes

5.5 Step 5 – Calculation of Cross-Media Effects of Selected BAT Alternatives

In Section 5.4, all possible BAT alternatives were evaluated and 36 alternatives having different targets were suggested for the facility. In this section, two of the BAT alternatives were selected and cross-media effects of these alternatives are calculated by means of the method described in BREF Document on Economics and Cross-Media Effects (CME), and compared with each other. The procedure of calculation of CME was explained in Section 4.5. Moreover, scematic representation of this procedure is presented in Figure 5.16 below.



Guideline 1:
Scope and identification of the alternative options

- Common aim
- Removal efficiencies
- Capacities

for both of the BAT alternatives were determined

Guideline 2:
Inventory of emissions

- Mass of direct emissions achieved with the implementation of the BAT alternatives are determined from the literature
- Mass of indirect emissions arised due to the energy consumption of the BAT alternatives are calculated

Guideline 3:
Calculation of the cross-media effects:

Direct, indirect and total impact of both of the alternatives on the seven impact categories are calculated

Guideline 4:
Interpretation of the cross-media effects

BAT alternatives are compared according to their impacts on the seven impact categories and their energy consumptions

Figure 5.16. Flowsceme of the cross-media effects calculation procedure

In order to perform an appropriate comparison, alternatives aiming the same issue should be selected. Moreover, in this study the alternatives were selected considering the most important problems in the facility. As stated in Section 5.3, considering outputs, the most significant and common problem in the facility is the dust emission. In addition, it was found that sintering is the most problematic sub-process in the facility. In sintering process, beside dust, other emissions of SO_2, NO_2 and heavy metals cause nuisance having emission values outside the limits, especially heavy metal emissions are significantly higher (41000%) than upper limit. Moreover, in order to solve the emission problems of the facility, the methods should be selected such that their applicabilities and efficiencies are proven. Considering above mentioned selection criteria, "*Bag Filter-combined or integrated reduction of solid and gaseous pollutants*" and "*Advanced Electrostatic Precipitator (ESP)*" are selected to be considered (After this point of the text, the first method is called as IBFS- *Integrated Bag Filter System* and the second one as *ESP* for convenience) for the CME analysis.

In the following parts of this section, calculation and comparison of these two BAT measures will be presented step by step according to the cross-media guidelines described before in Section 4.5.

Guideline 1-Scope and identification of the alternative options:

In this stage, both of the BAT alternatives are identified as follows:

ESP: By means of an electrostatic field generated, dust in the stack gas of sinter plant is precipitated. Two types of this method are present, wet and dry electrostatic precipitators. In order to increase the efficiency three or four ESP's are placed and connected in series. Beside dust, other emissions also minimized such as SOx, NOx, HCl, HF, heavy metals and PCDD/F. ESP is a common dust removal method being in use. Scematic representataion of ESP is presented in Figure 5.17.

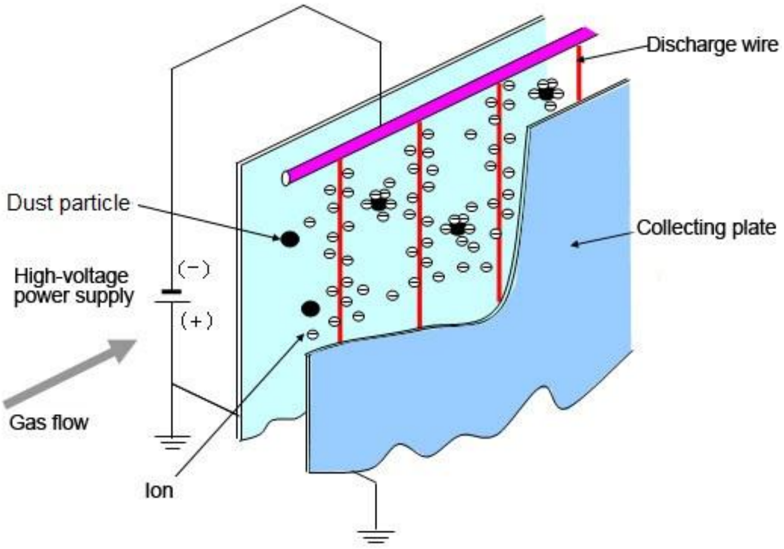


Figure 5.17. Scematic representataion of ESP

IBFS: It is an alternative dust removal method. IBFS is an integrated and quite more complex system comparing to ESP. In this method, a bag filter is placed downstream to an ESP or Cyclone. By injection of some adsorbents removal of PCDD/F, PCB, HCB or PAH, moreover by using slaked lime or sodium bicarbonate solutions, HCl, HF and SOx removal is achieved. Moreover NOx can be removed efficiently. It is a more complex method comparing to ESP, and removal efficiency of dust, heavy metals and other emissions is quite high. Flowsceme of IBFS method is presented in Figure 5.18.

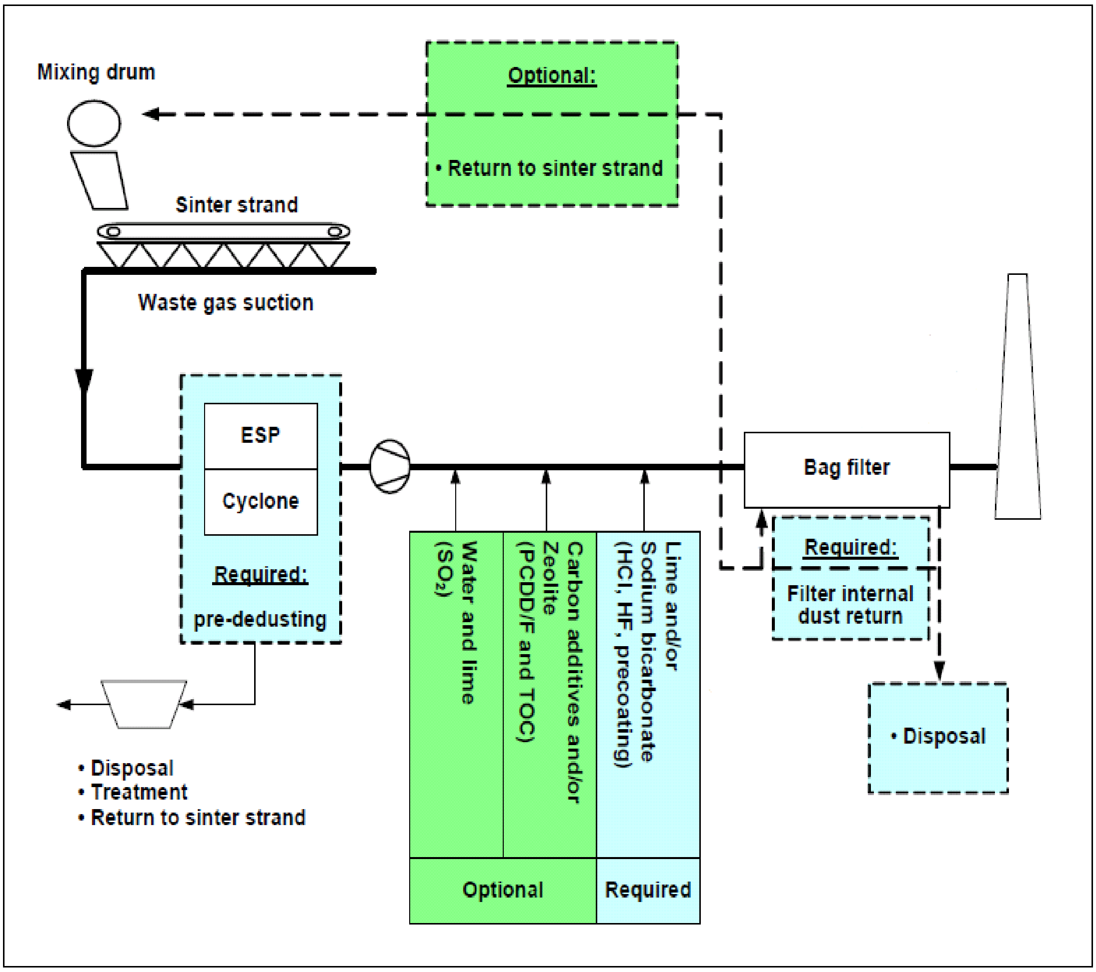


Figure 5.18. Flowsceme of IBFS

As stated above, the major aim of both of the measures is dust removal. In addition they also remove SO_2, NOx and heavy metals which are crucial problems for the sintering process of the facility. Calculations will be performed for a sintering process having 1,000,000 m^3/hr waste gas flow compatible with this sintering process. The dust removal efficiencies are taken as 97% and 95% for IBFS and ESP respectively [8].

Guideline 2- Inventory of emissions:

In determination of “inventory emissions”, both direct and indirect emissions arise from the implementation of BAT measures were considered. Direct emissions are stack gas air emissions that can be achieved after the implementation of BAT measures to the facility. Indirect emissions, on the other hand, can be described as emissions arised due to the consumption of energy. In other words, emissions generated because of the generation of this energy are also taken into account. In BREF Document on Economics and Cross-Media Effects, it is also stated that this indirect harm to the environment should be considered.

Initially, direct emissions of the BAT measures were estimated. Direct emissions of IBFS and ESP are presented in Table 5.25. These values are average achieved stack gas air emissions of the integrated iron and steel plants in Europe which have been applying IBFS or ESP in their sintering units. For instance, in an iron and steel plant implementing IBFS, 0,9 mg/m^3 dust emission was achieved; whereas in another one implementing ESP 36 mg/m^3 emission was achieved. The values in Table 5.25 are specific values for iron and steel production and they are taken from literature.

Emission concentrations are converted to annual mass of emission. As shown in this table, for all parameters IBFS achieves lower emission values.

Table 5.25. Direct emissions of both of the alternatives [8]

Emissions	**IBFS**		**ESP**	
	mg/m^3 (1)	**kg/yr (2)**	**mg/m^3 (1)**	**kg/yr (2)**
dust	0.9	7,884	36	315,360
NOx	240	2,102,400	400	3,504,000
SO_2	263	2,303,880	311	2,724,360
HF	0.2	1,752	0.7	6,132
HCl	2	17,520	17.4	152,424
Cd	0.002	17.52	0.04	350
As	0.001	8.76	0.18	1,577
Hg	0.001	8.76	0.025	219
Cr	0.002	17.52	0.008	70
Pb	0.002	17.52	1.98	17,345
PCDD/F	0.05	438(g/yr) (3)	0.13	1,138(g/yr) (3)

(1) Taken from literature

(2) = (1) * 1,000,000 m^3/hr waste gas flow * 24 hr/d * 365 d/yr /1,000,000 mg/kg

(3) = (1) * 1,000,000 m^3/yr waste gas flow * 24 hr/d * 365 d/yr /1,000 g/kg

Secondly, indirect emissions of the BAT measures were calculated. Both of the alternatives compared in this study consume electricity as energy source. The emissions of electricity can be calculated with respect to the table given in Annex 8 of this BREF Document, presenting CO_2, SO_2 and NO_2 emissions arise from 1GJ of electricity consumption. However it is also stated there that if the data on local use of primary energy for electricity generation is achievable, using of this data rather than the one presented in BREF Document gives more reliable results, since the emissions are highly dependent on the primary energy of electricity generation.

In 2010, 1,586,448 MWh electricity is consumed for the operation of all units whereas 1,175,767 MWh is produced by means of recovered energy in the facility. The remaining 410,681 MWh electricity is supplied from the network. In the facility, electricity produced in the power plant and electricity supplied from the network are transmitted to the units by separated lines. In this study, it is assumed that the needed electricity for the suggested BAT measures which will be implemented (IBFS and ESP), will be supplied from the network.

According to the information obtained from the personel communication with the staff of the institution responsible from the transmission of electricity in Turkey (TEIAS), national electricity grid is operated with an interconnected system. It means that, which electricity production plant feeds a certain region is not known. Therefore, in this part of this thesis, general electricity supply in Turkey is used in the following calculations.

In Turkey, 45.9% of the electricity is generated from natural gas, followed by coal, hydraulic energy, fuel oil, wind and geothermal& biofuel in 2010, having the shares of 25.3%, 24.5%, 2.5%, 1.35%, 0.47% respectively as presented in Table 5.26. Furthermore, in this table average emissions arising from the use of these primary energies for 1 MWh electricity generation is shown.

Table 5.26. Turkish electricity supply distribution and emissions released for 1 MWh electricity generation [49],[50]

Type of primary energy	**% (2010)**	**CO_2 (kg)**	**SO_2 (kg)**	**NO_2 (kg)**	**H_2S (kg)**	**Cd (mg)**	**Hg (mg)**
Natural gas	45.9	751	-	-	550	0.2	0.35
Coal	25.3	902	4.71	1.95	-	4.65	37.5
Hydraulic energy	24.5	15	-	-	-	0.03	-
Fuel oil	2.5	893	-	-	814	43.3	9
Wind	1.35	21	-	-	-	-	-
Geothermal energy and biofuel	0.47	477	0.08	-	407	-	-

In order to calculate the indirect emissions for 1GJ electricity consumption for the facility, share of primary energy distribution is multiplied by the unit emissions given in the table above, summed up and converted to kg/GJ. As an example, CO_2 emission for 1 MWh electricity production was calculated as follows;

$$CO2\left(\frac{kg}{Mwh}\right) = \frac{45.9}{100} * 751 + \frac{25.3}{100} * 902 + \frac{24.5}{100} * 15 + \frac{2.5}{100} * 893 + \frac{1.35}{100} * 21 + \frac{0.47}{100} * 477 = 601$$

After calculation of emissions of other substances as above, a table is prepared (Table 5.27) and given below.

Table 5.27. Average emissions released to generate 1 GJ electricity in Turkey

	MWh	**GJ**
CO_2 (kg)	601	2,165
SO_2 (kg)	1.2	4.3
NO_2 (kg)	0.5	1.8
H_2S (kg)	275	989
Cd (mg)	2.4	8.5
Hg (mg)	9.9	35.5

Electricity power requirement of IBFS and ESP for 1 million m^3 waste gas flow were taken from literature as [8] 300-400 kW and 1,000 kW respectively. Since electricity power need for ESP is given as range, average of this range is taken and this value is assumed to be 350 kW. Afterwards, power requirement is converted to energy consumption by multiplying 24 and 365, since the facility is working full time in a day. Finally, power is converted from kWh/yr to GJ/yr as presented in Table 5.28 below.

Table 5.28. Electricity consumption of BAT alternatives

	Power requirement (kW)		**Energy consumption**	
	Range	**Assumed**	**kWh/yr** (1)	**GJ/yr** (2)
IBFS	-	1,000 [8]	8,760,000	31,536
ESP	300-400 [8]	350	3,066,000	11,038

(1) = Assumed power * 24h/d * 365d/yr

(2)= Energy (kWh) * 0.0036 (GJ/kwh)

Total mass of emission released with the consumption of electricity by the use of IBFS and ESP are calculated by multiplying electricity consumptions (GJ/yr) of the BAT alternatives (Table 5.28) with the unit emission values presented in Table 5.27 and listed in Table 5.29.

Table 5.29. Mass of indirect emission released with the consumption of electricity by IBFS and ESP

Emission type	**Calculated indirect emission amount (kg/year)**	
	IBFS	**ESP**
CO_2	68,274,894	23,897,270
SO_2	135,604	47,463
NO_2	56,764	19,868
H_2S	31,188,854	10,916,582
Cd	0.268	0.094
Hg	1.119	0.392

All calculations for the amount of emissions arised due to the electricity consumptions of IBFS and ESP are summarized and presented in Table 5.30.

Table 5.30. Calculations for the amount of indirect emissions arised due to the electricity consumptions of IBFS and ESP

	% (2010) (1)	CO_2 (kg) (2)	SO_2 (kg) (3)	NO_2 (kg) (4)	H_2S (kg) (5)	Cd (mg) (6)	Hg (mg) (7)	CO_2 (kg) (8)	SO_2 (kg) (9)	NO_2 (kg) (10)	H_2S (kg) (11)	Cd (mg) (12)	Hg (mg) (13)
Natural gas	45.9	751	-	-	550	0.2	0.35	344.7	-	-	252.4	0.092	0.16
Coal	25.3	902	4.71	1.95	-	4.65	37.5	228.2	1.19	0.49	-	1.177	9.48
Hydraulic energy	24.5	15	-	-	-	0.03	-	3.67	-	-	-	0.0074	-
Fuel oil	2.5	893	-	-	814	43.3	9	22.32	-	-	20.3	1.08	0.23
Wind	1.35	21	-	-	-	-	-	0.28	-	-	-	-	-
Geoth. En. and biofuel	0.47	477	0.08	-	407	-	-	2.24	0.00037	-	1.9	-	-
TOTAL (kg/MWh) (14)								**601**	**1.2**	**0.5**	**275**	**2.4**	**9.9**
TOTAL (kg/GJ) (15)								**2165**	**4.3**	**1.8**	**989**	**8.5**	**35.5**
Calculated emissions for IBFS (kg/year) (16)								**68,274,894**	**135,604**	**56,764**	**31,188,854**	**0.268**	**1.119**
Calculated emissions for ESP (kg/yr) (17)								**23,897,270**	**47,463**	**19,868**	**10,916,582**	**0.094**	**0.392**

(8) = (1)*(2)
(9) = (1)*(3)
(10) = (1)*(4)
(11) = (1)*(5)
(12) = (1)*(6)
(13) = (1)*(7)
(15) = (14) * 3.6 (MWh/GJ)
(16) = (15) * 31,536 GJ/year (for Cd and Hg result is devided by 1.000.000 mg/kg)
(17) = (15) * 11,038 GJ/year (for Cd and Hg result is devided by 1.000.000 mg/kg)

Guideline 3- Calculation of the Cross-Media Effects:

As in Chapter 3, the effects of different pollutants released to the environment by the selected alternatives should be calculated with respect to seven impact categories; *human toxicity, global warming, aquatic toxicity, acidification, eutrophication, ozone depletion, photochemical ozone creation*. However, since neither of these BAT alternatives target wastewater discharge or ozone depleting substances, it is assumed that they do not have environmental impact on aquatic toxicity, eutrophication and ozone depletion. Therefore in this part, only human toxicity, global warming acidification and photochemical ozone creation potentials were calculated and evaluated. In calculation of the total effect on every impact category, the factors given in Annexes of BREF Document on Economics and Cross-Media Effects are placed in the relevant equation presented in Table 4.1of Chapter 4. The indirect effects of emissions arising from the electricity consumption (i.e. indirect emissions) (Table 5.29) and the direct effect arising from direct emissions (Table 5.25) provided by the application of the BAT measures are initially evaluated separately, then they are summed up in order to calculate total effect.

Human toxicity effect of both of the alternatives as *"kg/yr lead equivalent"* is estimated by installing the human toxicity factors given in *"Annex 1-Table of Human Toxicity Factors"* of BREF Document on Cross-Media Effect and mass release of the emission parameters calculated before in to the equation 1 presented Table 4.1. Estimated total human toxicity values for both of the alternatives are given in Table 5.31. As it can be seen from this table, quite a few emission parameters affect the total human toxicity.

Table 5.31. Human toxicity impacts of IBFS and ESP

emission		**human toxicity factor**	**IBFS**		**ESP**	
			mass release (kg/yr)	**human toxicity (kg/yr lead eq.)** (3)	**mass release (kg/yr)**	**human toxicity (kg/yr lead eq.)** (4)
Indirect impact due to elect. use	SO_2	13	135,604 (1)	10,431	47,463 (1)	3,651
	NO_2	95	56,764 (1)	598	19,868 (1)	209
	H_2S	140	31,188,854 (1)	222,778	10,916,582 (1)	77,976
	Cd	0.15	0.268 (1)	1.787	0.094 (1)	0.627
	Hg	0.1	1.119 (1)	11.19	0.392 (1)	3.92
			Total indirect	**233,819**	**Total indirect**	**81,840**
Direct impact due to emiss.	As	1	8.76 (2)	8.76	1,577 (2)	1,577
	Cd	0.15	17.52 (2)	116.80	350(2)	2,333
	HCl	80	17,520 (2)	219	152,424 (2)	1,905
	Pb	1	17.52 (2)	17.52	17,345 (2)	17,345
	Hg	0.1	8.76 (2)	87.60	219 (2)	2,190
	V	5	61.32 (2)	12.26	-	-
	SO_2	13	2,303,880 (2)	177,222	2,724,360 (2)	209,566
	NO_2	95	2,102.400 (2)	22,131	3,504,000 (2)	36,884
			Total direct	**199,814**	**Total direct**	**271,801**
			TOTAL	**433,633**	**TOTAL**	**353,641**

(1) Taken from Table 5.29

(2) Taken from Table 5.25

(3) Human toxicity factor/mass release of IBFS

(4) Human toxicity factor/mass release of ESP

The total direct, total indirect and overall total impacts are compared by means of a graph presented below in Figure 5.19. As it can be seen clearly from this graph, indirect emission of IBFS caused by electricity consumption is higher than ESP, whereas the direct emission of this BAT alternative is lower due to its higher emission removal efficiency. In consequence, total emission of IBFS is more than the one of ESP, in other words considering human toxicity impact potential, ESP is the preferable BAT alternative.

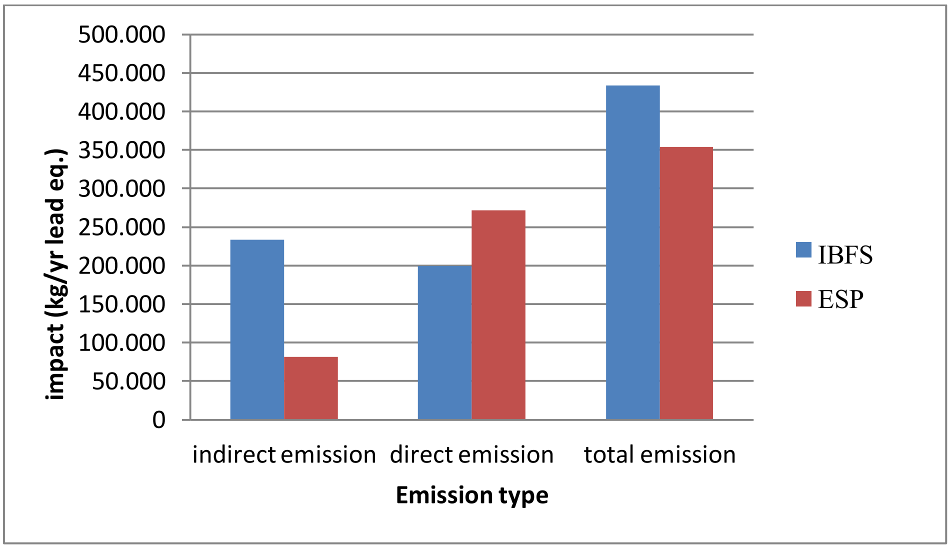


Figure 5.19. Total, indirect and direct human toxicity impacts of IBFS and ESP

Calculation of global warming potential is performed by using the values of global warming potential numbers given is *"Annex 2-Table of Global Warming Factors"* of BREF Document on Cross-Media Effect and mass release of related emission parameters calculated before, and the equation 2 given in Table 4.2. Table 5.32 shows the calculated global warming impacts as *"kg CO_2 equivalent"* of both of the BAT alternatives. It can be noticed from this table that the only emission parameter affecting the global warming potential is CO_2.

Table 5.32. Global warming impacts of IBFS and ESP

emission		**global warming potential**	**IBFS**		**ESP**	
			mass release (kg) (1)	**global warming effect (kg CO_2 eq.) (2)**	**mass release (kg) (1)**	**global warming effect (kg CO_2 eq.) (3)**
Indirect impact	CO_2	1	68,274,894	68,274,894	23,897,270	23,897,270
			TOTAL	68,274,894	**TOTAL**	23,897,270

(1) Taken from Table 5.29
(2) Global warming potential*mass release of IBFS
(2) Global warming potential*mass release of ESP

Since neither of these BAT alternatives causes direct CO_2 emission, there is no direct impact on global warming of both these BAT alternatives. Hence, only indirect impacts are compared as it can be seen from the graph in Figure 5.20. It can be noticed from this graph that IBFS has more impact on global warming since it consumes more electricity than ESP. More electricity consumption causes more CO_2 production, consequently, more global warming effect arises. As a result, if global warming is an important issue to be considered, ESP should be selected.

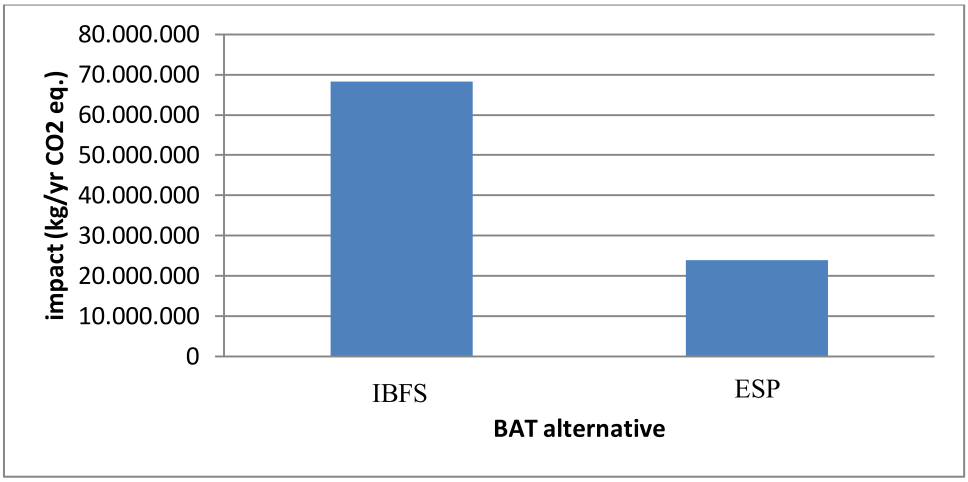


Figure 5.20. Global warming impacts of IBFS and ESP

In order to determine the total effect of IBFS and ESP on acidification, acidification potentials of related emission parameters given in *"Annex 4-Table of acidification potentials"* of BREF Document on Cross-Media Effect and estimated mass released of these emission parameters are placed into the equation 4 mentioned in Table 4.2. Total acidification effect is calculated as *"kg SO_2 equivalent"*. Among the emission of both of the alternatives, only SO_2 and NO_2 are related emission parameters according to the Table of Acidification potentials. The result table (Table 5.33) of acidification impacts of IBFS and ESP is presented below.

Table 5.33. Acidification impacts of IBFS and ESP

emission		**acidification potential**	**IBFS**		**ESP**	
			mass release (kg)	**acidification effect (kg SO_2 eq.) (3)**	**mass release (kg)**	**acidification effect (kg SO_2 eq.) (4)**
Indirect impact	SO_2	1	135,604 (1)	135,604	47,463 (1)	47,463
	NO_2	0,5	56,764 (1)	113,529	19,868 (1)	39,737
			Total indirect	**249,132**	**Total indirect**	**87,200**
Direct impact	SO_2	1	2,303,880 (2)	2,303,880	2,724,360 (2)	2,724,360
	NO_2	0,5	2,102,400 (2)	4,204,800	3,504,000 (2)	7,008,000
			Total Direct	**6,508,680**	**Total Direct**	**9,732,360**
			TOTAL	**6,757,812**	**TOTAL**	**9,819,560**

(1) Taken from Table 5.29
(2) Taken from Table 5.25
(3) Acidification potential * mass release of IBFS
(4) Acidification potential * mass release of ESP

In the graph presented in Figure 5.21 the total direct, total indirect and overall total impacts are compared. According to this graph, it can be noticed, indirect emission of IBFS caused by electricity consumption is higher than ESP, whereas the direct emission of this BAT alternative is lower due to its higher SO_2 and NO_2 emission removal efficiency. Consequently, total emission of ESP is more than the one of IBFS, since the indirect impacts are negligible comparing to the direct impacts. In conclusion if acidification if impact potential is considered to be more crucial, IBFS is the preferable BAT alternative.

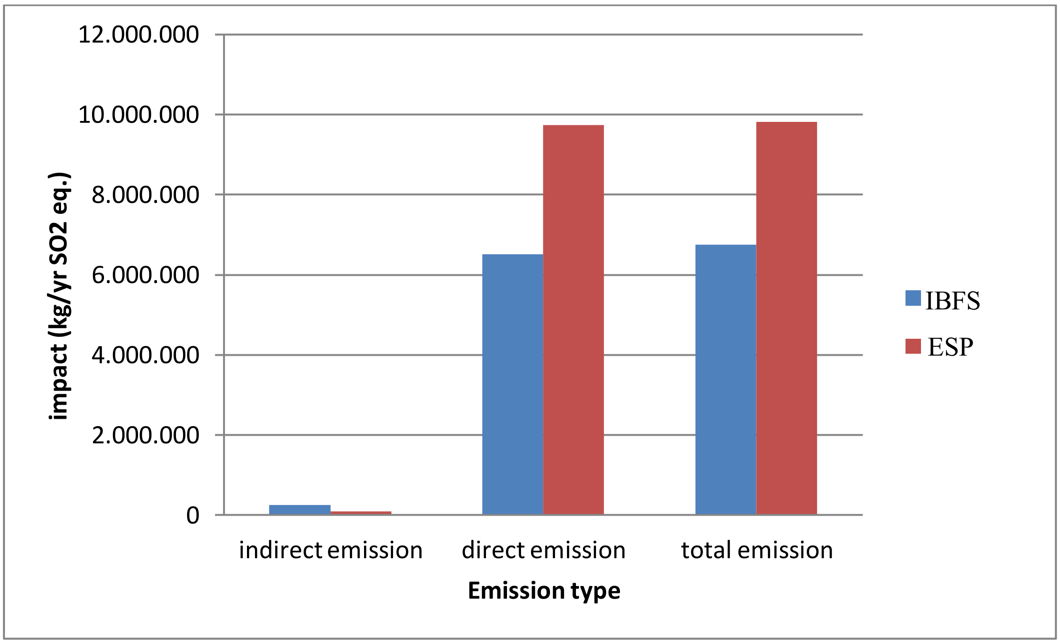


Figure 5.21. Total, indirect and direct acidification impacts of IBFS and ESP

Photochemical ozone creation potentials for IBFS and ESP are calculated by means of equation 7 given in Table 4.2. Photochemical ozone creation potentials of related emission parameters, which are only SO_2 and NO_2, are taken from *"Annex 7-Table of Photochemical Ozone Creation Potentials"* of BREF Document on Cross-Media Effect and mass release of related emission parameters are obtained from Table 5.29. They are inserted to the aforementioned equation and total photochemical ozone creation potentials for both of the BAT alternatives are calculated as *"kg ethylene equivalent"* as presented in Table 5.34.

Table 5.34. Photochemical ozone creation impacts of IBFS and ESP

emission		phot. ozone potential	IBFS		ESP	
			mass release (kg)	**phot. ozone effect (kg ethylene equv.) (3)**	**mass release (kg)**	**phot. ozone effect (kg ethylene equv.) (4)**
Indirect impact	SO_2	0,048	135,604 (1)	2,825,077	47,463 (1)	988,821
	NO_2	3,8	56,764 (1)	14,938	19,868 (1)	5,229
			Total indirect	**2,840,015**	**Total indirect**	**994,049**
emission		**phot. ozone potential**	**IBFS**		**ESP**	
			mass release (kg)	**phot. ozone effect (kg ethylene equv.) (3)**	**mass release (kg)**	**phot. ozone effect (kg ethylene equv.) (4)**
Direct impact	SO_2	0,048	2,303,880 (2)	47,997,500	2,724,360 (2)	56,757,500
	NO_2	3,8	2,102,400(2)	553,263	3,504,000 (2)	922,105
			Total Direct	**48,550,763**	**Total Direct**	**57,679,605**
			TOTAL	**51,390,779**	**TOTAL**	**58,673,655**

(1) Taken from Table 5.29
(2) Taken from Table 5.25
(3) Photochemical ozone creation potential*mass release of IBFS
(4) Photochemical ozone creation potential*mass release of ESP

Total direct, total indirect and overall total impacts are compared in the graph presented in Figure 5.22. As it can be noticed from this graph, indirect emission of IBFS caused by electricity consumption is higher than ESP, whereas the direct emission of this BAT alternative is lower due to its higher SO_2 and NO_2 emission removal efficiency. In consequence, as the indirect impacts are negligible comparing to the direct impacts, total emission of ESP is more than the one of IBFS. In other words, with respect to photochemical ozone creation potential, IBFS is the preferable BAT alternative rather than ESP.

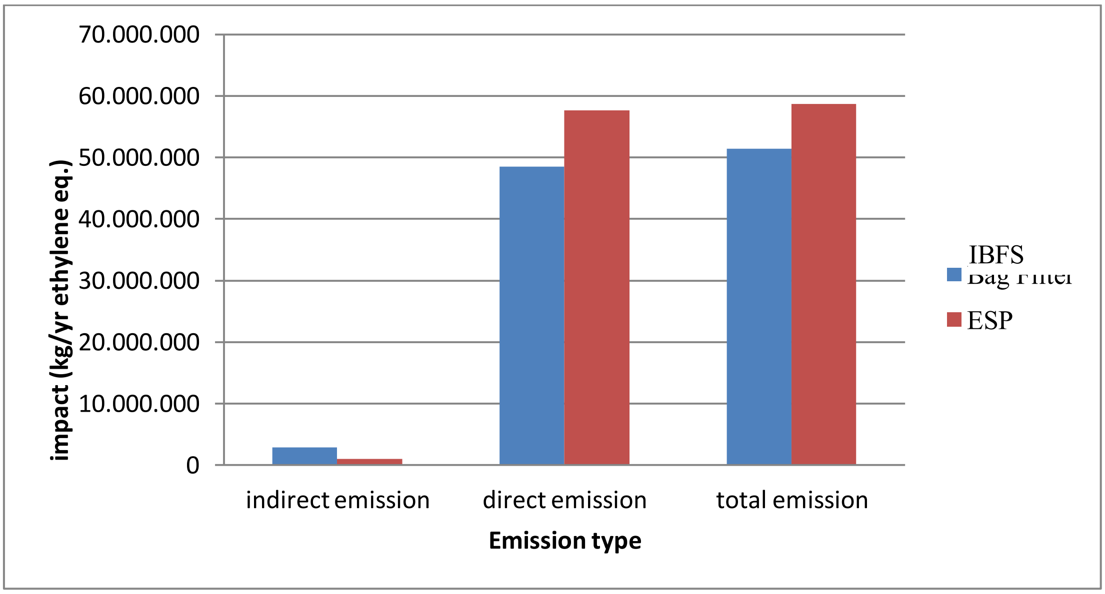


Figure 5.22. Total, indirect and direct photochemical oxygen creation impacts of IBFS and ESP

<u>Guideline 4- Interpretation of the cross-media effects:</u>

In this step, a selection is made with respect to the environmental effects of both of the alternatives on the seven impact categories, whose quantities were calculated above and the energy consumption. The comparison table is presented below (Table 5.35). The alternative having less environmental impact and less energy consumption is preferred and marked with check sign (√) whereas the impact categories that are not valid for these BAT alternatives are signed with NA implying *"not applicable"*.

As it can be seen from Table 5.35, according to the three of the five applicable comparison items, ESP is preferred. However, the selection should be made considering the importance of these impact categories for the decision makers.

Table 5.35. Comparison of alternatives with respect to environmental impacts and energy consumption

Impact category	**IBFS**	**ESP**
Human toxicity potential		√
Global warming potential		√
Aquatic toxicity potential	NA	NA
Acidification potential	√	
Eutrophication potential	NA	NA
Ozone depletion potential	NA	NA
Photochemical ozone creation potential	√	
Energy consumption		√

NA: Not Applicable

5.6 Step 6 – Calculation of Cost of Selected BAT Alternatives

Up to now, comparison of BAT alternatives was made considering environmental impacts of the alternative. In this step, economical aspects of them will be considered. Economic analysis is performed according to the methodology described in Section 4.6. Moreover, scematic representation of this procedure is presented in Figure 5.23.

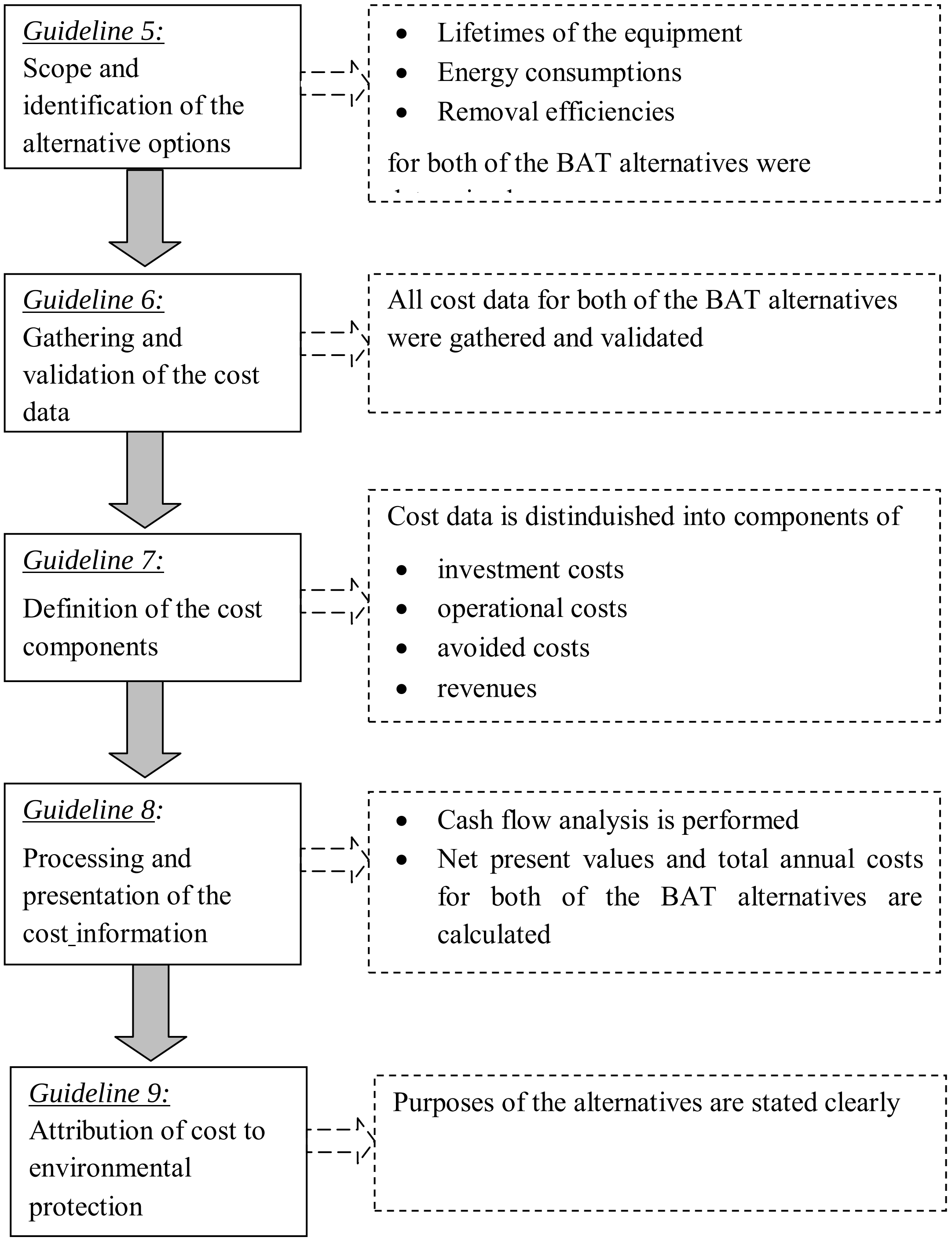


Figure 5.23. Flowsceme of the cost analysis procedure

Guideline 5- Scope and identification of the alternative options:

As it was stated before in Section 4.6., lifetimes of the equipment, energy consumptions and removal efficiencies of the alternatives should be specified. Lifetime of the both of the BAT alternatives is determined as 20 years [51]. Energy consumptions and removal efficiencies of IBFS and ESP have alreay been determined in Section 4.5. Dust removal efficiencies of IBFS and ESP have been specified as 97% and 95% respectively. Energy consumption data will be included in oparetion and maintanance cost.

Guideline 6- Gathering and validation of the cost data:

Intially all cost data is gathered from the literature including operational and maintenance cost of the BAT alternatives. From the literature, the cost values suitable for the facility studied are selected (for 1 million m^3/h waste gas flow). However, the investment and operational cost values are given as ranges rather than unique values. Hence, the averages are taken as investment cost and operational cost for IBFS and ESP. Additionally, as it was stated in Section 4.6, different sources were researched to validate cost data in the literature and from the design companies; any of appropriate information cannot be obtained.

Guideline 7- Definition of the cost components:

In this stage, averages of ranges of investment and operational cost data which is gathered from the literature are taken as a requirement of Guideline 6.

Afterwards, revenues and avoided costs are calculated (revenues and avoided costs are previously defined in Section 4.6). Revenues are price of sinter dust recovered, since sinter dust is an iron bearing material. Unit price of sinter dust is taken as 159$/ton [52] which equals 121 €/ton. As stated above, the assumed dust removal efficiencies are teken as 97% and 95% for IBFS and ESP respectively. Assuming that the waste gas flow of sintering process is 1,000,000 m^3/hr [11] and dust concentration in the inflow of the removal equipment (IBFS or ESP) is 530 mg/m^3 [11], the recycled dust amount is calculated as 4,504 ton/year for IBFS and 4,411 ton/year for ESP (calculation are given in Table 5.36 below) . In addition for IBFS and ESP, price of recycled dust, in other words revenues, are specified as 546,610 €/year and 535,340 €/year respectively. The details of the renevue calculations and the assumptions made are listed in Table 5.36 (The raw numbers given in the 4th column represent the numbers given in the 3rd column. Calculations column shows the details of the calculations).

Table 5.36. Assumed and calculated values in revenue calculation

Parameter		**Unit**	**Value**	**Raw number**	**Calculation**
Assumed	Unit price of sinter dust	$/ton	159 [52]	(1)	-
	Exchange rate[1]	€/$	1.31	(2)	-
	Unit price of sinter dust	€/ton	121	(3)	(1)*(2)
	Dust removal efficien. of IBFS	%	97 [8]	(4)	-
	Dust removal efficien. of ESP	%	95 [8]	(5)	-
	Inflow dust concentration	mg/m^3	530 [11]	(6)	-
	Waste gas flow	m^3/hr	1,000,000 [11]	(7)	-
		m^3/yr	8,760,000,000	(8)	(7) * 24 *hr/d* * 365*d/yr*
Calculated	Mass of recycled sinter dust for IBFS	ton/yr	4,504	(9)	$\frac{((4)/100)*(6)*(8)}{(10^9 mg/kg)}$
	Mass of recycled sinter dust for ESP	ton/yr	4,411	(10)	$\frac{((5)/100)*(6)*(8)}{(10^2 mg/kg)}$
	Price of recycled sinter dust for IBFS	€/yr	546,610	(11)	(9)*(3)
	Price of recycled sinter dust for ESP	€/yr	535,340	(12)	(10)*(3)

[1] as of the date of 02.05.2012

No avoided cost is calculated, since if neither of these alternatives will be applied, no charge will be paid according to the *"Regulation on the Control of Emissions from Industries [53]"*. Instead the emission permission of the facility will be cancelled which causes the shutoff of the production.

The summary table on defined cost components is presented below (Table 5.37).

Table 5.37. Defined cost components

		IBFS		**ESP**	
Parameter	**Unit**	**Range** [8]	**Assumed (1)**	**Range** [8]	**Assumed (1)**
Investment cost	€	16,000,000-35,000,000	25,000,000	5,000,000-7,500,000	6,250,000
Operational cost	€/ton sinter (2)	0.3-0.6	0.45	0.11-0.16	0.135
	€/yr (3)	1,200,000 – 2,400,000	1,800,000	440,000 – 640,000	540,000
Revenues	€/yr (4)	546,610		535,340	

(1) Average of the range
(3) = (2) * 4,000,000 ton/yr sinter production of the facility
(4) Taken from Table 5.36

<u>Guideline 8- Processing and presentation of the cost information:</u>

In this stage, cash flow analysis should be performed in order to be able to calculate net present value (NPV). The procedure of Cach Flow Analysis was described in detail in Section 4.6. Performed cash flow analysis for IBFS and ESP as presented in Table 5.38 and Table 5.39.

Table 5.38.. Cash Flow (€) analysis for IBFS

YEAR	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
Revenues	0	546,610	546,610	546,610	546,610	546,610	546,610	546,610	546,610	546,610
Investment cost	25,000,000	0	0	0	0	0	0	0	0	0
Operating cost	0	1,800,000	1,800,000	1,800,000	1,800,000	1,800,000	1,800,000	1,800,000	1,800,000	1,800,000
Total cost	25,000,000	1,800,000	1,800,000	1,800,000	1,800,000	1,800,000	1,800,000	1,800,000	1,800,000	1,800,000
NET CASH FLOW	-25,000,000	-1,253,390	-1,253,390	-1,253,390	-1,253,390	-1,253,390	-1,253,390	-1,253,390	-1,253,390	-1,253,390
YEAR	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**
Revenues	546,610	546,610	546,610	546,610	546,610	546,610	546,610	546,610	546,610	546,610
Investment cost	0	0	0	0	0	0	0	0	0	0
Operating cost	1,800,000	1,800,000	1,800,000	1,800,000	1,800,000	1,800,000	1,800,000	1,800,000	1,800,000	1,800,000
Total cost	1,800,000	1,800,000	1,800,000	1,800,000	1,800,000	1,800,000	1,800,000	1,800,000	1,800,000	1,800,000
NET CASH FLOW	-1,253,390	-1,253,390	-1,253,390	-1,253,390	-1,253,390	-1,253,390	-1,253,390	-1,253,390	-1,253,390	-1,253,390

Table 5.39. Cash Flow (€) analysis for ESP

YEAR	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
Revenues	0	535,340	535,340	535,340	535,340	535,340	535,340	535,340	535,340	535,340
Investment cost	6,250,000	0	0	0	0	0	0	0	0	0
Operating cost	0	540,000	540,000	540,000	540,000	540,000	540,000	540,000	540,000	540,000
Total cost	6,250,000	540,000	540,000	540,000	540,000	540,000	540,000	540,000	540,000	540,000
NET CASH FLOW	-6,250,000	-4,660	-4,660	-4,660	-4,660	-4,660	-4,660	-4,660	-4,660	-4,660
YEAR	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**
Revenues	535,340	535,340	535,340	35,340	535,340	535,340	535,340	535,340	535,340	535,340
Investment cost	0	0	0	0	0	0	0	0	0	0
Operating cost	540,000	540,000	540,000	540,000	540,000	540,000	540,000	540,000	540,000	540,000
Total cost	540,000	540,000	540,000	540,000	540,000	540,000	540,000	540,000	540,000	540,000
NET CASH FLOW	-4,660	-4,660	-4,660	4,660	-4,660	-4,660	-4,660	-4,660	-4,660	-4,660

In calculation of Net Present Values (NPV) for both of the alternatives, following equation is used, which is also given in Section 4.6.

$$NPV = -(investment\ cost\ of\ ESP\ or\ IBFS) + \sum_{t=0}^{n} \left(\frac{\text{net revenues (t)}}{(1+r)^{t}} \right)$$

Where;

t = year 0 to year n

n = lifetime of ESP of IBSF

net revenues (t) = (revenue – cost) at time t

r = discount rate (Discount rate is the risk-free interrest rate, therefore it is generally taken as the interrest rate of government bonds [54])

Lifetimes of the both alternatives are taken as 20 years [51]. On the other hand, discount rate is selected as 9.70% considering interest rate of government bonds (average of 2012 dated government bonds regardless of duration of the bonds) [55]. “Net revenues” is taken from cash flow analysis Table 5.38 and Table 5.39. Estimated NPV’s of both of the alternatives are shown in Table 5.40 below.

Table 5.40. NPV’s of alternatives

Alternative	**NPV (€)**
IBFS	-33,663,294
ESP	-7,245,078

The larger NPV indicates the more preferable option economically. Hence, considering the NPV results, ESP becomes the more economical alternative.

Furthermore, total annual costs of these alternatives are calculated by using the following equation, which is also given in section 4.1.6.

$$\boxed{total\ annual\ cost = C\left[\frac{r\,(1+r)^n}{(1+r)^n - 1}\right] + OC}$$

Where;

C = investment cost of ESP or IBSF
n = lifetime of ESP or IBSF
r = discount rate
OC = operating and maintenance cost of ESP or IBSF

Calculated total annual cost for both of the alternatives is presented in Table 5.41. According to total annual cost calculations, ESP is evaluated more economical as well since its annual cost is less than the one of IBFS.

Table 5.41. Total annual costs of alternatives

Alternative	**Total Annual Cost (€)**
IBFS	4,676,591
ESP	1,259,148

Guideline 9- Attribution of cost to environmental protection:

In Section 4.6, it was stated that, in this stage the purpose of the alternatives should be transparently distinguished, (1) those to be implemented for reduction or prevention of the environmental pollution, and (2) those for other reasons such as investment expenditure in waste minimization or energy conservation. It is also stated that generally end-of-pipe techniques aim to reduce or prevent emissions. Since both IBFS and ESP are end of pipe techniques, it can be concluded that their common purposes are to reduce and prevent emissions.

5.7 Step 7 – Evaluation of Selected BAT Alternatives

Cost effectiveness of these alternatives are calculated using the equation given in section 4.1.6. Although IBFS and ESP alternatives are selected because of their dust, SO_2, NO_2 and heavy metal removal characteristics, as stated in section 5.5, the main aim of these alternatives are dust removal. As a result, annual reduction term is based on "dust removal" of these alternatives. As it was stated in Section 4.7, CE of the alternatives are calculated by dividing annual cost by annual reduction (Equation 10). Results of cost/effectiveness analysis are presented in Table 5.42. As it can be clearly deduced from this table, ESP is the more preferred alternative with its lower CE value.

Table 5.42. Cost effectiveness of alternatives

Alternative	**Annual Cost (€) [Table 5.41]**	**Annual Reduction (ton) [Table 5.36]**	**CE (€/ton) (annual cost/annual reduction)**
IBFS	4,676,591	4,504	1,038
ESP	1,259,148	4,410	285

5.8 Results Overview for Step 5, Step 6 and Step 7

In these steps, two of the suggested 36 BAT alternatives, IBFS and ESP, were selected to be compared with each other with respect to their cross media effects on the seven impact categories and their cost effectiveness.

In step 5, impacts of both of the alternatives on the four impact categories, human toxicity, global warming, acidification and photochemical ozone creation were calculated numerically, since the rest three categories, aquatic toxicity potencial, eutrophication potencial and ozone depletion potencial were not applicable for these BAT alternatives. Afterwards, BAT alternatives were compared with each other with respect to these four impact categories and their energy concumption. According to human toxicity, global warming and energy consumption, ESP became the preferable option, on the other hand according to acidification and photochemical ozone creation, IBFS became the preferable option. The selection should be made by the authority of the facility considering their priorities. For instance, if the global warming is a more important concern for the facility than the others, ESP should be preferred. If acidification is considered to be more important, IBFS should be preferred by the authority of the facility.

In the next step, Step 6, costs of the alternatives were evaluated considering their investment costs, operational and maintenance costs, avoided costs and revenues. NPVs and annual costs of the alternatives were calculated. NPV of ESP was determined to be considerably higher than IBFS, which means that according to NPV, ESP became the preferable option. On the other hand, annual cost of IBFS was estimated to be four times higher than ESP, which also means that according to annual cost, ESP became the preferable option. In other words, results of Step 6 show that, ESP is the more economical option than IBFS.

Finally, in Step 7, cost effectiveness analysis was performed using the results of Step 5 and Step 6, and the BAT alternatives were compared with respect to their CE values. As a result of this Cost Effectiveness analysis, CE value of ESP was determined to be quite higher than IBFS, which means that ESP is the preferable option.

In conclusion, according to their cross media effects, selection can be alter according to the importance of the impact categories for the authority of the facility, however, if costs and CEs of the BAT alternatives are considered, it can be clearly deduced that, ESP is the more proper option for the facility.

5.9 Step 8 – Evaluation of Economic Viability in the Sector

Iron and steel production sector has a very substantial role in the world considering proliferation of the area of usage, increase of consumption day by day, its production of raw material for other production sectors, and its great potential of export [2].

For Turkish economy, steel production is an important sector as well due to the abovementioned reasons. The export of produced steel in Turkey was 12,3 billion dollars corresponding 11% of the total export of Turkey [2],[56]. Moreover, according to Turkish Statistical Institute, iron and steel sector takes the forth place following textile, food and automotive sector comparing to its industry production index that is an indicator of the greatness of a sector [57].

In Turkey three integrated plants are in activity beside 27 arc furnaces. All f these 30 plants are large scale facilities [58].

The facility is one of the biggest companies in Turkey. According to the research conducted by Istanbul Board of Trade, the facility is considered in the first 10 in the top list of 500 firms with a net sale of more than 3,2 billion TL [59]. Moreover according to World Steel Association it is also in the top steel producers in the world.

The facility has a cleaner production approach to protect the environment. Since the start of the modernization works in the facility in 2004, more than 160 million dollar investment have been performed and these investments are still continuing [60].

Considering the scale of the facility and its approach to environmental protection, it can be easily mentioned that, the facility has affordability and willingness to the make real of selected the BAT alternatives.

In addition, Ministry of Environment and Urbanization have initiated the implementation studies of IPPC Directive in Turkey. A lot of harmonization projects have been completed and plenty of projects have been continuing. The regulations have been being changed according to European Union Regulations. It is stated that, the integrated permission system, which is a major requirement of IPPC, will be passed in 2015, and fully application of permission system will be in 2018 [61]. With the application of IPPC in Turkey, industrial establishments including iron and steel facilities will be encouraged to apply BAT in BREF documents.

CHAPTER 6

CONCLUSION AND RECOMMENDATIONS

In the recent years, due to the decrease of energy sources, raw material and water resources and increase of environmental pollution, sustainable environmental consciousness has been developed throughout the world. As a result, more stringent limitations in legislations force the industry to meet increased energy efficiency, reuse and recycle. One of the most important legislation is Directive on Integrated Pollution Prevention and Control (96/61/EC) of European Union. IPPC strengthen the concept of *"Best Available Techniques (BAT)"* which are most effective, advanced and applicable methods in prevention of environmental pollution and providing of efficient resource use. BAT of different industrial sectors are specified in *"Best Available Techniques Reference Documents (BREF's)"* prepared by European Commission. In these Documents in addition to BAT alternatives, sectoral process information, and specific emission and consumption limit values are presented. Beside sectoral BREF documents, documents general issues were published.

One of these general BREF's is on Economics and Cross-Media Effects describing the methodology on calculation and comparison of cross-media effects and cost-effectiveness' of the BAT alternatives.

There are great amount of BAT studies performed in different countries and industrial sectors such as cement manufacturing, casting industry and textile production. Yet, there is not any study performed on BAT application in iron and steel sector in the literature, although iron and steel sector is one the major environmental polluting and resource depleting industries. This deficiency in environmental concern is filled by this study.

This thesis aims to evaluate the environmental performance of an integrated iron and steel plant in Turkey and to suggest BAT alternatives suitable for this plant, by considering the environmental impacts and cost/ effectiveness of these alternatives. In this context, a case study was undertaken in an integrated iron and steel plant representative for Turkish integrated iron and steel production

In this study, after a comprehensive input-output analysis, specific inputs and outputs of the facility were calculated and compared with the limit values in BREF Documents regarding Iron and Steel Production. Furthermore BAT alternatives for the facility were determined and their applicabilities to the facility were specified. Afterwards, considering BREF on Economics and Cross-Media Effects, two of the applicable BAT options were selected and their cross-media effects were calculated. Finally, cost/benefit analysis for both of the alternatives was performed.

In the light of the results of this study, following conclusions can be drawn;

- The common problems related to inputs are energy and steam consumptions of the sub-processes. As energy, electricity is consumed quite higher than the limit values mentioned in BREF Documents.

- Considering electricity consumption, steelmaking and casting process is the most problematic sub-process and it is followed by sintering and coke making processes respectively. Moreover, steel making and casting process exceeds steam consumption limits priorly as well and iron making process exceed slightly less than steel making and casting process, they are followed by coke making process.

- Dust emission is the common problem for the facility among other parameters. Iron making is the leading sub-process by far and following sub-processes are coke making, steel making and casting, sintering and rolling, respectively. It can be deduced that all sub-processes have dust emission problem, among them rolling process exceeds the limits in negligible quantities comparing with the others.

- The amount of heavy metal emissions arising from sintering process is so enormous that dust emissions from this process become negligible. Especially emissions of Ni and Cr are huge comparing to other emissions that are V, Mn, Cu, dust, SO_2 and NOx.

- Comparing the number of parameters outside the limits of each sub-processes of the facility between each other, it can be mentioned that sintering is the most problematic sub-process, especially with respect to its energy consumption and air emissions. The number of parameters outside the limits of sintering process is 13, eight of them being air emissions. Sintering process is followed by steel making-casting processes (5), coke making process (5) and iron making process (4). On the other hand, among all, rolling process is evaluated as the most environmental friendly sub-process comparing with the other ones with only two parameters outside the limits.

- Totally 74 BAT alternatives were evaluated with respect to their applicabilities in the facility. Comparing the number of BAT alternatives, coke is the prior sub-process having 25 BAT possible alternatives, followed by sintering, iron making, steel making and casting, and rolling processes with the number of possible BAT alternatives 20, 12, nine and eight respectively.

- Again among 74 alternatives, 31 BAT measures have already been applied, seven alternatives are not applicable to the facility and the remaining 36 measures are suggested to the facility.

- Number of suggested alternatives of sintering process is more than others, on the other side; the largest number of measures that have already been applied belongs to coke making process.

- The most suitable BAT alternatives to be compared with respect to their cross-media effects and cost/effectiveness' were determined as "Electrostatic Precipitator-ESP" and "Integrated Bag Filter System-IBFS" for Sintering process. Considering cross media effects of the these alternatives, according to human toxicity and global warming potential, and energy consumption of ESP is the preferred alternative, on the other hand according to acidification and photochemical ozone creation potential IBFS is the preferred option.

- According to cost/effectiveness analysis, ESP is the more preferred alternative with its lower CE value.

In recent years, due to the sharp increase of global warming and climate change in the world, emission of greenhouse gases has gained importance in Turkey as well as throughout the world. Therefore, Ministery of Environment and Urbanisation started to work in order to decrease emission of greenhouse gases especially from the industrial activities. Accordingly, it can be said that, among the seven impact categories, global warming impact is the most crucial one for Turkish industrial plants. Moreover, as wellknown, the cost/effectiveness of an implementation is the most important factor for an industrial plant. Considering these, ESP is more suitable option than IBFS since it has less global warming potential and CE value.

The facility where this study was undertaken produces about 50% of the Turkish total integrated iron and steel and it applies the same manufacturing technologies as the other integrated iron and steel plants in Turkey. Moreover environmental performances of all of these three plants are similar. Considering all of these, it can be said that the facility can be considered as representative for Turkish iron and steel production. Therefore, the results of this study can aid decision makers to make environmental initiatives in other iron and steel plants.

Turkey is in the harmonization period in European Union. In this context, Ministery of Environment and Urbanization works on adaptation of IPPC directive to Turkish Legislations. In this framework, the methodology followed in this study is crucial.

Since, after adaptation of IPPC Directive in Turkish Legislations, BAT application in the industries will gain importance.

As it was mentioned before, only two of the BAT alternatives have been compared with CME and CE analysis due to the data limitations. Both of the BAT alternatives aim to decrease dust emissions from the sinter plant of the facility. In the future studies, the methodology used in this study can be applied on the other crucial problem of the facility, inefficient use of energy. Furthermore, the same methodology can be extended for the other subprocesses such as iron making or coke making.

It was stated in Section 3.2.2., there are studies evaluating individual and combinations of BAT alternatives. In this study, individual BAT alternatives are evaluated. As a recommendation, in future studies, combination of BAT alternatives can be asseses with this methodology.

Finally, the lack measurements of in the facility cause some uncertainities in this study. This situation leads to also problems in environmental management in the facility. Therefore, a monitoring program is recommended to the facility. Especially, the media listed below should be monitored by measuring relevant parameters;

- gas treatment sludges,
- gas cleaning waters,
- cooling waters,
- wastewater,
- some other wastes

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APPENDIX A

DETAILED INFORMATION ON APPLICABLE BAT ALTERNATIVES

Table A.1. Explanations of applicable BAT alternatives

	BAT Alternative	**Explanation**	**Ref.**
	Sintering		
1	Lowering the content of volatile hydrocarbons in the sinter feed	The most important reason of hydrocarbon emissions in sinter plant is use of oily mill scale in sinter mix. In order to remove oil content o mill scale two methods are suggested. 1- Solvent utilization 2- Heating of mill scale up to 800°C in order to burn hydrocarbons However, first method brings another problem of oily water, while second method requires extra energy for heating.	[8] [11]
2	Top layer sintering	With the application of top layer sintering, mill scale having oil content up to 3% can be utilized in sintering process without causing any problem. The mixture including oily mill scale is conditioned to nearly 7% of water content and deposited on the main sinter layer. A second ignition hood ignites this second layer. In addition PCDD/F emission is reduced by 60-65%.	[8] [11] [34]

Table A.1. Explanations of applicable BAT alternatives - continued

	BAT Alternative	Explanation	Ref.
3	Waste gas recirculation	Normally combustion in sintering process is provided by clean air. In this method clean air is mixed with waste exhaust gas from sinter machine recirculated to a certain part of the sinter strand. So that the heat of exhaust gas is recovered, moreover sinter strand acts as a filter for particles and particulate emissions to the air decreases. Four different waste gas recirculation methods are described in BREF Documents as follows; 1- Emission optimized sintering (EOS) 2- Low emission and energy optimized sintering process (LEEP) 3- Environmental process optimized sintering (EPOSINT) 4- Recycling of parts of waste gas to other parts of the sinter strand The difference of these methods is the parts of the sinter strand that the exhaust gas is suctioned and recycled onto.	[8] [11] [34] [42]

Table A.1. Explanations of applicable BAT alternatives - continued

	BAT Alternative	Explanation	Ref.
4	Suppression of PCDD/F formation by addition of nitrogen compounds in the sinter mix	With the addition of various additives such as triethanolamine (TEA), monoethanolamine (MEA) and urea into the sinter exhaust gas, PCDD/F emissions can be prevented. Addition of urea also minimizes HCl and HF emissions, however this method has some disadvantages as follows; • Dust removal efficiency of ESP may decrease, • Stack gas of sinter plant may be more visible • Ammonia emission may increase • Dust and micro pollutant emissions may increase due to the abovementioned results	[11] [36]
5	Twin layer charging	Sinter mix is charged into the sinter machine by dividing it into two according to the particle size; Top layer includes small particle size and high coke breeze content providing ignition easily. On the other hand the particle size of bottom layer is large and its coke breeze content is low, so that high permeability and efficient use of fuel is provided. In order to optimize and control moisture content, preheating is required. By means of the implementation of this method higher and more stabilized quality can be achieved.	[34]

Table A.1. Explanations of applicable BAT alternatives - continued

	BAT Alternative	**Explanation**	**Ref.**
6	Intensive mixing and granulation system- IMGS	With the application of this method, several benefits are provided as follows; • No pre-mixing is required • An exactly homogenous sinter mix having high and equal permeability is achieved • High production (> 40 ton/m² x 24 hr) is approached even if iron ore very small in size is consumed • Sinter having high and stabilized quality is produced affecting blast furnace performance positively, electricity consumption decreases • Coke breeze consumption decreases due to the distribution as proper as possible	[34]
7	Advanced electrostatic precipitator (ESP)	By means of an electrostatic field generated, dust in the stack gas of sinter plant is precipitated. Two types of this method are present, wet and dry electrostatic precipitators. In order to increase the efficiency three or four ESP's are placed and connected in series. Dust removal efficiency of ESP is more than 95%. Beside dust, other emissions also minimized such as Sox, NOx, HCl, HF, heavy metals and PCDD/F. ESP is a common dust removal method being in use.	[8] [11]
8	Bag Filter- combined or integrated reduction of solid and gaseous pollutants (IBFS)	An alternative dust removal method is bag filter downstream to an ESP or cyclone (IBFS). By injection of some adsorbents removal of PCDD/F, PCB, HCB or PAH, moreover by using slaked lime or sodium bicarbonate solutions, HCl, HF and SOx removal is achieved. Removal efficiency of dust, heavy metals and other emissions is quite high comparing to other methods.	[8] [11]

Table A.1. Explanations of applicable BAT alternatives - continued

	BAT Alternative	Explanation	Ref.
9	Fine wet scrubber (AIRFINE)	In scrubber system waste gas is treated by means of a liquid. This liquid contaminated by dust is removed from the system in to be treated further as sludge. Conventional scrubber systems are not suitable for sinter plants due to their content of hydrocarbons and very small sized particles. In 1993, this system called AIRFINE was developed. This system includes the following items: • A cyclone or ESP for removal of larger particles • A scrubber for gas cooling • A fine cyclone for smaller particles and simultaneous gas cleaning • Water cleaning unit Unlike dry cleaning methods, removal of pollutants dissolving in water such as alkali chlorides and heavy metal chlorides is possible. In case of NaOH addition acidic compounds such as HF, HCl and SO_2 can be cleaned. Dust emissions can be decreased up to from 40 to 80 mg/Nm^3. Less dust emission values can be achieved according to the situation of the unit. This method provides removal of PCDD/F as well.	[8] [11]
10	Desulphurization	A solution including SO_2 gas, Ca or Mg is sprayed on to the waste gas after cooling, and sulphur in the waste gas is precipitated as $CaSO_4$ or $MgSO_4$. After dewatering, precipitated $CaSO_4$ can be utilized by cement factories as raw material. Wet type of desulphurization can be performed by scrubber as well.	[8] [11]

Table A.1. Explanations of applicable BAT alternatives - continued

	BAT Alternative	**Explanation**	**Ref.**
11	Regenerative active carbon (RAC)	This is a dry sulphur removal method in which sulphur is absorbed by activated carbon and H_2SO_4 is produced as side-product. This method can be added to the normal desulphurization systems in order to increase the removal efficiency. By means of Regenerative Active Carbon, SO_2, HCl, HF, Hg, dust, PCDD/F are achieved. Moreover in case of HN_3 injection NO_X emissions are prevented as well. Since the construction and operational costs of this method are high, this method have not being applied in the recent years in Europe.	[8] [11] [42]
12	Selective catalytic reduction (SCR)	NOx is converted to urea or N_2 and H_2 catalytically by addition of NH_3. Titanium oxide (TiO_2), vanadium pentoxide (V_2O_5) and tungsten oxide (WO_3) are generally used catalysts. Optimum temperature range is 300-400°C. Reactions that take place are as follows; • $4NO + 4NH_3 + O_2 \rightarrow 4N_2 + 6H_2O$ • $6NO_2 + 8NH_3 \rightarrow 7N_2 + 12 H_2O$ The most crucial issue to be careful about is deactivation of catalyst, accumulation of ammonium nitrate being explosive and forming of corrosive SO_3. No wastewater is produced since SCR is a dry method. The only waste produces is the deactivated catalysts which can be recycled the manufacturer. Desulphurisation is required priorly. Additionally waste gas temperature should be more than 300°C. Since the construction and operational costs of this method are high, this method have not being applied in the recent years in Europe.	[8] [11]

Table A.1. Explanations of applicable BAT alternatives - continued

	BAT Alternative	**Explanation**	**Ref.**
13	Reduction of PCDD/F by means of ESP and additives	In order to remove PCDD/F in the waste gas, activated carbon is injected prior to ESP. Waste gas temperature should be smaller than for minimization of fire. The retention time between gas injection point and gas cleaning unit, which should be more than three minutes between 150 and 180°C temperatures.	[11]
14	Biological treatment of oily mill scale	It is proved that oily mill scale is treated biologically. The oil content of the mill scale is reduced from 4.5-5% to 2.7-3% after a decomposition lasting 60 days. This is an economic and environmental friendly method on the contrary to burning and physicochemical methods such as solvent use.	[35]
15	Use of novel filter for dust and heavy metal treatment	Novel filter is an alternative method to ESP and bag filter. ESP cannot work efficiently in case of the smaller dust concentration than 50mg/m^3 in waste gas. On the other hand bag filters has some disadvantages such as being affected from content of moisture and some other substances of waste gas, and being harmed from the high temperature of waste gas. In order to overcome these problems, a method called metallic novel filter is developed. These filters can be cleaned easily and they are long lasting. However, this is a new developed method and there is no sufficient study is present.	[36]

Table A.1. Explanations of applicable BAT alternatives - continued

	BAT Alternative	**Explanation**	**Ref.**
	Coke making		
1	Waste gas recirculation	Similar to the sintering process, waste gas arising form coke oven combustion rooms is mixed with combustion air and given to the system as combustion air. By this method, both waste heat of exhaust gas is recovered and Nox emissions are avolided since the low O_2 and high CO_2 content in the waste gas prevents high flame temperature which causes Nox emissions.	[11]
2	Closed belt conveyors	Transportation of fine particle containing goods such as granular coal or coke minimizes all material emissions, especially dust emissions are prevented.	[11] [43]
3	Stabilized coke wet quenching	This system consists of a quenching tower, quenching water sedimentation tank and a quenching car. It has larger quenching tower than conventional wet quenching towers with the dimensions 16x16x70m.	[11]
4	Preheating of coal, combustion air and fuel	When coal, combustion air and fuel is preheated before being used, energy consumption decreases. For preheating of coal, use of coke oven gas is suggested.	[37]
5	De-NOx of waste gas from coke oven firing (Selective catalytic reduction -SCR)	For NOx removal from coke oven gas, SCR method is used as well as sintering process. Detailed information was given above in BAT alternatives for sintering process.	[8] [11]

Table A.1. Explanations of applicable BAT alternatives - continued

	BAT Alternative	**Explanation**	**Ref.**
6	Coke oven gas desulphurization	The main reason of SO_2 emissions from coke oven plants is the sulphur content of the fuel used. Therefore minimization of sulphur content of the fuel is required which is generally coke oven gas. Two main desulphurization processes are in use that are oxidatif process and absorbing followed by stripping. The tyeps of oxidative processes are Stretford, Takahax, Thylox, Perox, Fumaks Rhodacs and the types of absorbing/stripping processes are ASK, Vacasulf, Sulfibon, desulf. The most common used oxidative process is Stretford while the one of absorbing/stripping is ASK.	[8] [11]
7	Hydrogen and methanol production from COG	Hydrogen and methanol can be produced from coke oven gas after various processes and these side-products can be sold.	[38] [39]
8	Heat recovery from COG	Placing a heat exchanger at the exit point of coke oven gas from coke oven provides both cooling the temperature of coke oven gas from 650-899 °C to 400°C, and waste heat is recovered and evaluated afterwards.	[37]

Table A.1. Explanations of applicable BAT alternatives - continued

	BAT Alternative	**Explanation**	**Ref.**
	Iron making		
1	Direct injection of reducing agents	In blast furnaces, some of the coke can be replaced by other hydrocarbon sources such as heavy oil, oil residues, recovered waste oil, granular or pulverized coal, natural gas or coke oven gas and waste plastics. The most common used ones are coal and oil. By this method, requirement for coke is decreased. Considering that the production of coke is very polluting and expensive, it can be deduced that this method provides minimization of environmental pollution and operational cost. These materials are injected to blast furnaces via tuyeres.	[8] [11]
2	Energy recovery from top gas pressure	The pressure at the exit point of blast furnace gas is quite high and the energy there can be recovered by placing turbine at this point. A top gas pressure of 2-2.5 bar provides 15 MW electricity generation and an energy of 0.4 GJ/ton hot metal produced is recovered.	[8] [11]
3	Use of tar-free runner linings	Use of tar free runner linings in blast furnaces minimizes VOC ve PAH emissions. This type of liners is more resistible to slag and more long-lasting comparing to others.	[8] [11]
4	Gas recovery system from top hopper release	The pressure in the blast furnace is up to 2.5 bar which is more than atmospheric pressure. During the charge of blast furnace, in order to equilibrate the atmospheric pressure with the pressure in the blast furnace, some blast furnace gas is discharge to the atmosphere which causes air emission and waste of energy. With application of this method, this released gas is collected and recovered in order to prevent air emissions and provide energy recovery.	[11]

Table A.1. Explanations of applicable BAT alternatives - continued

	BAT Alternative	Explanation	Ref.
5	De-dusting of tap holes and runners	During casting of liquid iron and slag due to the formation of ferrous oxides such as Fe_2O_3 which causes brown fume. In order to suppress during casting, typically two measures are taken; • Covering the runners with movable lids • Dissipating oxygen from hot metal by using of N_2 gas So that formation of ferrous oxides is prevented.	[8] [11]
6	Fume suppression during casting	This is a more complex and costly method with the same aim of the previous measure. The whole transfer route of the hot metal is enclosed by specially designed sculptures. The space between hot metal is kept minimum and if necessary this space is filled with N_2 gas in order to dissipate oxygen from hot metal.	[8] [11]
7	Hydro-cyclonage of blast furnace sludge	Zinc is present in gas treatment sludge as fine particulate zinc oxides. By means of hydro-cyclonage of this sludge separating these fine particles from larger iron particles. With this method, two different sludges are generated having low and high zinc content. Sludge including low zinc is recycled to the sintering process in order to recover iron in it, whereas the one including high zinc is sent to disposal of zinc recovery plant depending on the zinc enrichment.	[11] [46]
8	Condensation of fume from slag granulation	During slag processing H_2S and SO_2 emissions are generated. Odor problem arised due to H_2S generated is prevented with this method.	[8] [11]

Table A.1. Explanations of applicable BAT alternatives - continued

	BAT Alternative	**Explanation**	**Ref.**
	Steel making and casting		
1	Dust hot briquetting and recycling	Dust from stack gas treatment of basic oxygen furnaces are heated up to 750°C in a hot briquetting plant and then they are shaped as briquettes with the help of a cylindrical press machine. These briquettes are fed in to basic oxygen furnaces in order to recycle of iron in the briquettes. This process continues, in time the zinc content of the briquettes enriches. When the zinc content of the briquettes reaches up to a certain level, it is sent to zinc recover plants.	[8] [11] [47] [48]
2	Treatment of wastewater from continuous casting	Cooling water generated during countinuous casting is separated from the oily mill scale my means of settling tanks as well as sand filters.	[8] [11]
	Rolling		
1	Regenerative burner system	This is an alternative method to racuperators which is currently in use in the facility, aiming to recover the heat of exhaust gas arising from heating furnaces. In regenerative burner two sets of heat exchangers are present including brick pieces or ceramic balls. When one of the burner is in firing mode, regenerator of other burner is heated by direct contact with exhaust gas. After a certain time, flow is switched to reverse of the process. In this type of systems preheated air temperature can be achieved up to 1100-1300°C, which provides a quite high amount of energy recovery in the furnace.	[9]

Table A.1. Explanations of applicable BAT alternatives - continued

	BAT Alternative	**Explanation**	**Ref.**
2	External flue gas recirculation (FGR)	Flue gas recirculation is a NOx emission reduction system, limiting peak flame temperatures. Waste gas from the furnaces is recirculated by mixing the air, so that flame temperature is decreased due to the reduction of oxygen content in the air to 17- 19%. This provides both minimization of NOx emission and energy recovery. Similar systems were mentioned above in sintering and coke making processes.	[9]
3	Selective catalytic reduction (SCR)	For NOx removal from coke oven gas, SCR method is used as well as sintering process. Detailed information was given above in BAT alternatives for sintering process.	[9]

APPENDIX B

DETAILED INFORMATION ON NON-APPLICABLE BAT ALTERNATIVES

Table B.1. Reason why BAT alternative is not applicable to the facility

	BAT alternative	**Reason**	**Ref.**
	Sintering		
1	Lowering the sulphur content of the sinter feed	It is stated that, iron ore having low sulphur content and coke breeze smaller in size should be consumed in order to decrease the sulphur emissions. In the facility, previously a feasibility study had been conducted comparing the cost of construction of a desulphurization system for stack gas and the cost of purchase of low sulphur containing iron ore consumption. The results had shown that purchase of iron ore with low sulphur content is not feasible. In addition, by using coke breeze very small in size, completely combustion cannot be provided and combustion efficiency decreases.	[8] [11]
	Coke Making		
1	Emission reduction during coke oven firing	Reducing of coking temperature in coke ovens is suggested aiming decrease of NOx emissions. However, a temperature decrease in coke ovens will lead to an increase in coking time, causing a decrease in production efficiency.	[8] [11]

Table B.1. Reason why BAT alternative is not applicable to the facility- continued

	BAT alternative	**Reason**	**Ref.**
2	Large coke oven chambers	As stated in BREF document, this method cannot be applied in existing coke oven plants.	[8] [11]
3	Non-recovery coking	As stated in BREF document, this method cannot be applied in existing coke oven plants.	[8] [11]
	Steel Making and Casting		
1	Lowering the zinc-content of scrap	Only unpainted and ungalvanized scrap includes low zinc, who cannot be found easily in the market.	[8] [11]
	Rolling		
1	Limiting air preheating temperature	Air preheating is a method providing energy efficiency in furnaces and preventing CO_2 and SO_2 emissions. Limiting air preheating provides NOx reduction however it causes increase in energy consumption in furnaces and CO_2 and SO_2 emissions.	[9]
2	Selective non-catalytic reduction (SNCR)	In order to decrease the NOx emission, providing a reaction in flue gas of furnaces reducing NOx to N_2 is suggested. However this reaction requires 850-1100°C temperature and flue gas of furnaces should be heated up to this temperature. This consumes huge amount of energy, in other words, this method is not feasible.	[9]