Development of an Environmental Impact Model for the Steel Industry in Libya

A thesis submitted in partial fulfilment of the requirements of

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Preface

This thesis is presented as part of the requirements for the fulfilment of the award of the degree of Doctor of Philosophy from Sheffield Hallam University, UK. The reports of research and work carried out by the researcher were supervised by Professor Terrence Perera from the Faculty of Arts, Computing, Engineering and Sciences at Sheffield Hallam University, from October 2009 to July 2012 inclusive.

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Dedication

To my parents and my family who supported me during my study.

Acknowledgments

First of all, I would like to express my gratitude to my parents who gave me confidence to continue my studies. I would also like to thank my wife and my children Bssam, Nizar, Ans and Raghad for their patience and their untiring love.

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Abstract

The global demand for steel is rising due to the infrastructural development of emergent economies in countries such as India, China, Thailand and Libya. Consequently, global steel production has increased dramatically and is expected to grow further in the future.

Processing iron and steel is associated with a number of sustainable development challenges, including various economic, environmental and social issues. The increasing prominence of environmental issues in international and national political discourse, including the developing countries, means that stakeholders demand that manufacturers minimise the negative impacts of their operations.

The steel industry must be able to measure and assess its environmental impacts and demonstrate continuous improvements. This requires an environmental management strategy to manage and minimise impacts on the environment. This study focuses on developing an environmental impacts model in steel industry to investigate the most important environmental parameters and their importance in order to mitigate environmental impacts.

Based on the literature review and the elements that are considered as waste (derived from the waste survey in Libyan iron and steel industry), the potential environmental impacts of the steel industry are identified as criteria and sub-criteria. Then, a model is built using the Analytical Hierarchy Process (AHP) software based on the identified criteria and sub-criteria.

The model also illustrates the overall goal which is creating environmental impacts model for steel industry, in addition, criteria and sub-criteria are listed to clarify the situation and make the analysis clearer and understandable. Pair wise comparisons are used to derive accurate ratio scale priorities.

The results are analysed and presented as prioritised list of environmental impacts. Moreover, a series of sensitivity analyses are conducted to investigate the impact of changing the priority of the criteria on the alternatives' ranking. The validation of the proposed model is carried out to assess its validity and to see this model from the perspectives of the professionals from steel industry.

List of Contents

3. CHAPTER THREE

Research methodology

4. CHAPTER FOUR

Survey and classification of waste generated by the Libyan iron and steel industry

5. CHAPTER FIVE

The proposed model for environmental management in steel industry and analysis

List of Tables

List of Figures

1. CHAPTER ONE

Introduction

1.1 General Introduction

The global demand for steel is rising due to development projects and infrastructural works around the world. Many of these projects are taking place in developing countries such as India, China, Thailand and Libya. As a result, the amount of steel production globally has been increased dramatically due to the high demand, and it is expected to grow further in the future. Most major steel producing countries showed a marked increase in crude steel production between 2008 and 2011. "World crude steel production reached 1,220 million metric tons for the year of 2009. This is a decrease of -8.0% compared to 2008. While World crude steel production reached 1,414 million metric tons (mmt) for the year of 2010. This is an increase of 15% compared to 2009. In addition, World crude steel production reached 1,527 megatonnes (Mt) for the year of 2011. This is an increase of 6.8% compared to 2010 and is a record for global crude steel production" (World Steel Association 2011).

Iron and steel manufacturing is the largest energy-consuming industry in the world. The energy consumption of the iron and steel sector in 1990 accounted for 12% of all world energy consumption. According to World Energy Council, world energy consumption in the steel sector could reach 600 Mtoe by 2020. Hence, the steel industry is considered to be one of the biggest environment polluters (Hidalgo et al. 2005).

Environmental issues are a big concern for customers, suppliers, and the public, particularly for developing countries. As a result, these stakeholders are increasingly demanding that businesses in general, and manufacturing companies in particular, minimize any negative impact of their products and operations on the natural environment (Klassen and Whyark1999).

1.2 Research aim and objectives

Based on the literature, the scale and the diversity of environmental issues in the steel industry have been the subject of many researchers. In the 1970s, researchers focused on minimising production waste and recycling (Barnes and Dhanda 2007). However, from the 1990s onwards, attention was directed to assess wider environmental issues and formulate strategies to minimise industrial impacts on the environment (Singh et al. 2008a, Rennings and Wiggering 1997). In addition, several research works focused on specific areas of steel manufacture and/or specific aspects of environmental impact in steel industry. However, a review of literature pertaining to the subject has revealed that the steel industry still needs more attention to conduct environmental impacts assessment, improve hazardous waste management practices, and make environmental investments at regular intervals.

The aim of this research work is to develop a model for environmental impacts in the steel industry. The primary aim of the model is to investigate the most important environmental criteria and their importance in order to manage the environmental impacts of the steel industry. The following are the main objectives which will help achieve this aim:

1. Conduct a literature review to critically assess research carried out in this area and to identify the research gap.
2. Identify the elements that are considered as waste in steel industry.
3. Develop an environmental impacts model for steel industry using the Analytic Hierarchy Process software to investigate the most important environmental parameters and their importance in order to help to manage the environmental impacts of the steel industry.
4. Prioritise the environmental impacts in order to help to manage the environmental impacts and to maximise opportunities for impacts minimisation.
5. Validate the proposed model using mathematics and questionnaire method.

1.3 Outlines of this thesis

Figure 1.1 illustrates the structure of the thesis. Chapter two, carries out a literature review relevant to this thesis, in order to identify the knowledge gap that are exists and highlight the gaps, which this thesis tries to address. This chapter also includes an overview of steel industry. Chapter three then describes the methodologies employed in this research to achieve the research aims and objectives. Chapter four gives a brief overview of Libyan iron and steel companies and reports the work done during the first phase of the research programme. It also includes conducting a survey and waste classification according to their source in the Libyan iron and steel industry. Chapter five presents the proposed model for environmental impacts in steel industry. After developing the model for the environmental impacts of the steel industry and indicating the most important criteria and sub-criteria, the derived model is validated in chapter six. Chapter seven reviews the main findings of the research, outlines the contribution to the knowledge, limitations and future research work. Figure 1.1 illustrates the structure of this thesis.

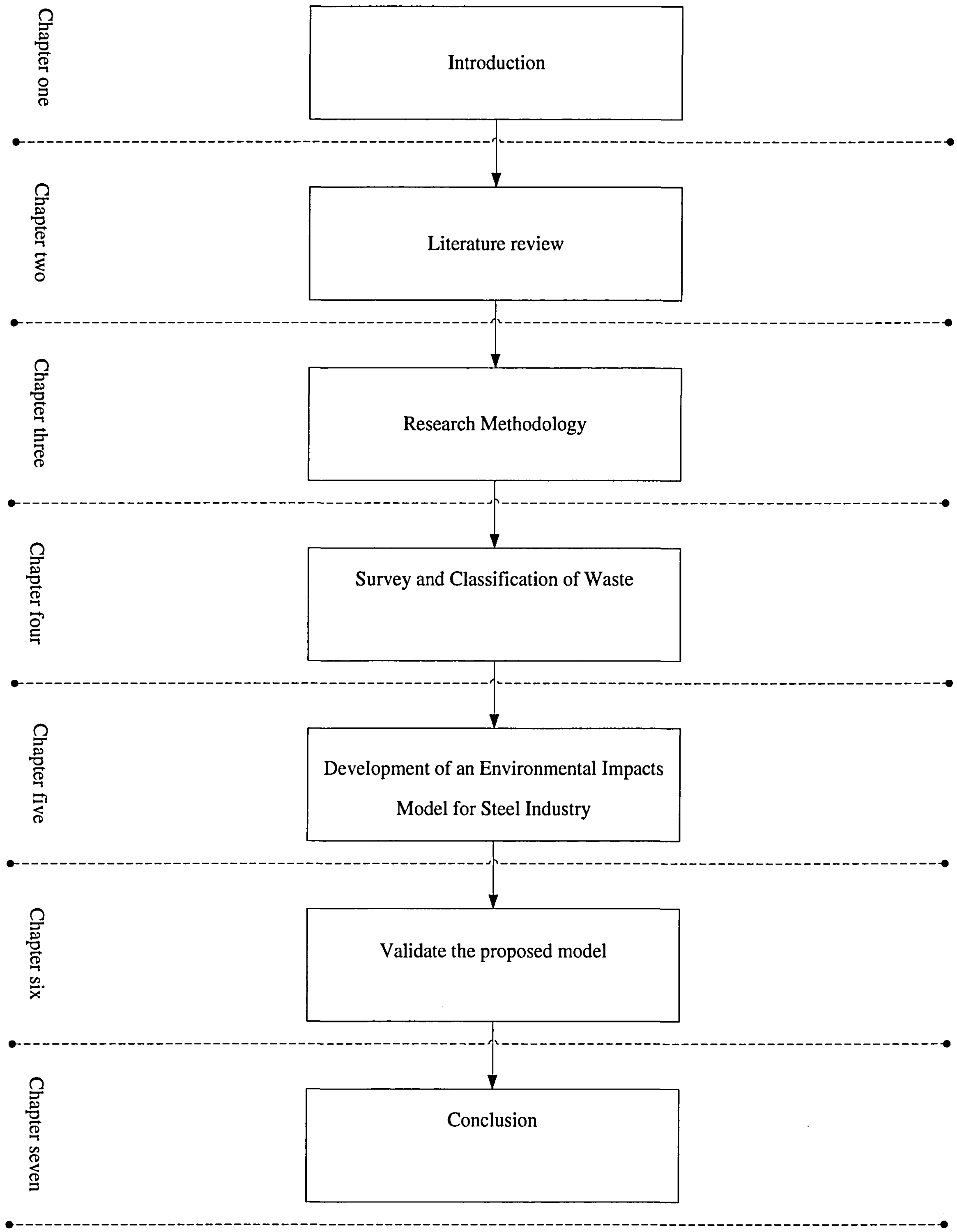

Figure 1.1 The structure of the thesis

2. CHAPTER TWO

Literature Review

2.1 Introduction

An extensive literature review has been carried out to understand the scale and the diversity of environmental issues in steel industry. The sections of this chapter outline a brief overview of the steel industry and its impact on the environment, followed by review of studies related to environmental issues in the steel industry and gap identification.

2.2 Steel industry overview

Iron and steel are essential to everyday life, making up numerous products we all use. As a result, steel manufacturing is expanding in most major steel producing countries (World Steel Association 2010). World crude steel production for 9 regions (65 countries) reporting to the World Steel Association (worldsteel) was 118,756 million metric tons (mmt) in June 2010. This is 18% higher than in June 2009. World crude steel production in the first six months of 2010 was 705,823 mmt, 27.9% higher in comparison with the same period of 2009. Most regions showed increased crude steel production during the first half of 2010 compared to the first half of 2009 (Appendix A). Figure 2.1 illustrates crude steel production in 9 regions.

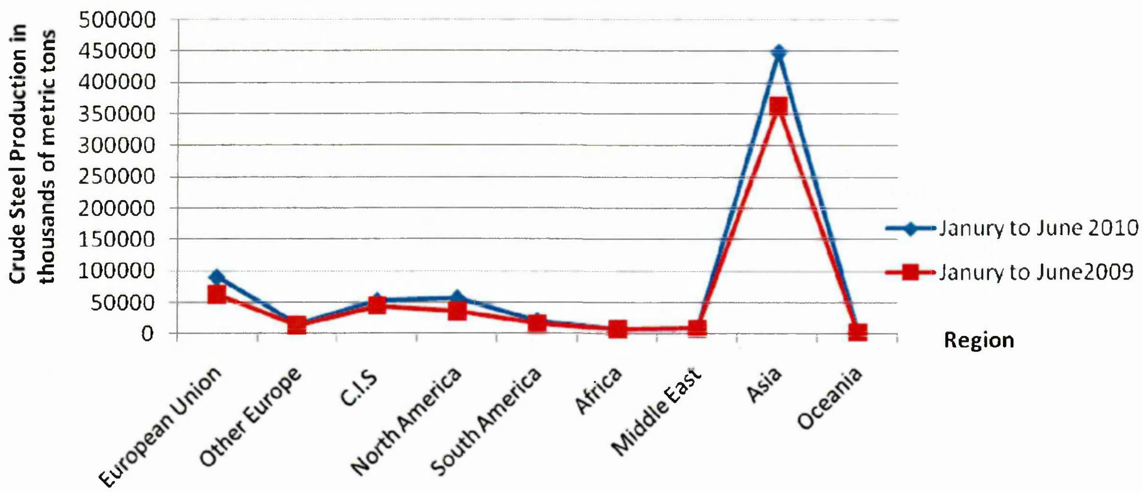

Figure 2.1 Crude steel production in 9 regions (World Steel Association 2010)

Processing of iron and steel are associated with a number of sustainable development challenges, including various economic, environmental and social issues. For example, the steel industry is an important source of employment and wealth creation. On the other hand, "the steel industry consistently leads to a variety of environmental impacts, such as depletion of non-renewable resources, disturbance of the landscape and detrimental effects on the health and safety of workers and the general public" (Singh et al. 2007).

These and the other issues have driven the steel industry to engage in the sustainability debate and start developing strategies for responding to the challenge of sustainable development. In addition, the industry in general is now also starting to recognise that corporate sustainability can bring business benefits such as the following (Singh et al. 2007):

- Lower labour and health costs by providing safe and healthy working environments.
- Cost savings due to cleaner production methods and innovation.
- Easier access to lenders, insurers, loans and insurance rates.
- Best practice influence on regulation.
- Higher value for goodwill on the balance sheet.
- Market advantages created by a socially responsible approach to business.

However, in addressing sustainability, the steel industry also faces a number of challenges. The main challenge for this sector is to clearly demonstrate that it contributes to the welfare and wellbeing of the current generation, without compromising the potential of future generations to pursue a better quality of life. Achieving this objective requires environmental management strategy, such as a comprehensive framework to manage and minimise environmental impacts.

2.3 The impact of the steel industry on the environment

The impact on the environment by steel industry is large. The steel industry is the largest energy consuming industry in the world. Barnes and Dhanda (2007) stated that the steel production process in the US consumes more electricity than the collective electricity consumption of all US households. According to World Energy Council, world energy consumption in the steel sector is expected to reach 600 Mtoe by 2020 (Hidalgo et al. 2005). As a result, the steel industry is one of the most important sources of pollutants. Different types of pollutants result from the different steps in steel production (Table 2.1).

2.3.1 Emissions to air

Major air pollutants include emissions of the gases CO, CO_2 and SO_x. The steel industry produces significantly high CO_2 emissions; it produced 1425 Mt of the gas in 1990, expected to grow to 1700 Mt CO_2 by 2020. (Hidalgo et al. 2005). According to Mathiesen and Mcestad (2004), an integrated steel mill produces on average 2.5 tonnes of CO_2 per tonne of steel. Globally, the steel industry produces 1.7 tonnes of CO_2 per tonne of steel and uses 19.1 GJ of energy per tonne of steel produced, based on figures from the International Iron and Steel Institute (IISI) (Peaslee 2008). Roughly 1.6 tons of CO_2 for every ton of steel produced. This amounts to roughly 1.6 billion tons of carbon dioxide out of total world emissions of roughly 25 billion tons, comprising between 5-10% of all emissions (Barnes and Dhanda 2007).

2.3.2 Solid waste

Solid waste includes slag, metal scrap, scales etc. Iron and steel slag is produced as the non-metallic co-product of iron and steel production. There are three types of steel industry slag, each named for the process from which it is produced: Blast Furnace (BF) iron slag, Basic Oxygen Furnace (BOF) steel slag, and Electric Arc Furnace (EAF) steel slag. Approximately 21 million tons of steel industry slag is produced each year in the US (Shen and Forssberg 2003).

2.3.3 Emissions to water

In the steel manufacturing process, high volumes of water are used to cool the steel. The principal sources of water pollution in the steel industry lies in coke oven gas washing and cooling, blast furnace gas washing, and steel rolling and finishing operations (Patterson and Cheng 1975). This contact or direct cooling water becomes contaminated with high levels of suspended solids and mill scale along with oil and grease. Because of the quantity of water required, it is necessary to cool this water and reuse it.

2.3.4 Noise pollution

Noise is a common occupational hazard in a large number of workplaces, particularly in heavy industry such as iron and steel production. Noise-induced hearing loss is one of the most prevalent occupational diseases. The basic mechanism of noise generation can be due to mechanical noise, fluid noise and/or electromagnetic noise. The sound pressure level generated depends on the type of the noise source, distance from the source to the receiver and the nature of the working environment.

In this respect industry in general and the steel industry in particular must be able to measure and assess its environmental impacts and to demonstrate continuous improvements over the long term.

Table 2.1 Pollutant releases and potential environmental impacts of steel industry (Barton, J. 1999).

Process stage	Potential pollutant release	Potential environmental impact
Raw materials handling.	Dust.	Localized deposition.
Coke production.	Dust (particulate matter less than 10 microns in diameter), Nitrogen oxides (NOx), Volatile organic compounds (VOCs), methane, dioxins, metals, radioactive isotopes Hydrogen chloride (CHI), and solid waste.	Air, soil and water contamination, acid rain, ground-level ozone, global warming, and odour.
Scrap storage/processing.	Oil, heavy metals.	Soil and water contamination and noise.

Table 2.1 (Continued)

Process stage	Potential pollutant release	Potential environmental impact
Blast furnace.	Dust (particulate matter less than 10 microns in diameter), Hydrogen sulphide (H_2S), carbon monoxide (CO), Carbon dioxide (CO_2), Sulphur dioxide (SO_2), Nitrogen oxides (NOx), radioactive isotopes, and solid waste.	Air, soil and water contamination, acid rain, ground-level ozone, global warming, and odour.
Basic oxygen furnace.	Dust (particulate matter less than 10 microns in diameter), metals (e.g. zinc), carbon monoxide (CO), dioxins, Volatile organic compounds (VOCs), and solid waste.	Air, soil and water contamination, ground-level ozone.
Electric arc furnace.	Dust (particulate matter less than 10 microns in diameter), metals (e.g. zinc, lead, mercury), dioxins, and solid waste.	Air and soil contamination, and noise.

Table 2.1 (Continued)

Process stage	Potential pollutant release	Potential environmental impact
Secondary refining.	Dust (particulate matter less than 10 microns in diameter), metals, and solid waste.	Air and soil contamination, noise.
Casting.	Dust (particulate matter less than 10 microns in diameter), metals, oil, and solid waste.	Air and soil contamination, noise.
Hot rolling.	Dust (particulate matter less than 10 microns in diameter), oil, carbon monoxide (CO), Carbon dioxide (CO_2), Sulphur dioxide (SO_2), Nitrogen oxides (NOx),Volatile organic compounds (VOCs), and solid waste.	Air, soil and water contamination, ground-level ozone, acid rain.

Table 2.1 (Continued)

Process stage	Potential pollutant release	Potential environmental impact
Cold rolling.	Oil, oil mist, carbon monoxide (CO), Carbon dioxide (CO_2), Sulphur dioxide (SO_2), Nitrogen oxides (NOx),Volatile organic compounds (VOCs), acids, and solid waste.	Air, soil and water contamination, and ground-level ozone.
Coating.	Dust (particulate matter less than 10 microns in diameter), Volatile organic compounds (VOCs), metals (e.g. zinc) and oil.	Air, soil and water contamination, ground-level ozone, and odour.
Waste water treatment.	Suspended solids, metals, oil, ammonia, solid waste.	Water/groundwater.
Gas cleaning.	Dust/sludge, metals.	Soil and water contamination.

2.4 A review of the studies related to environmental issues in the steel industry

The scale and the diversity the environmental issues in the steel industry have been the subject of many researchers. In the 1970s, researchers focused on minimising production waste and re-cycling (Barnes and Dhanda 2007). However, from the 1990s onwards, attention has been directed to assessing wider environmental issues and to formulating strategies to minimise impacts (Rennings and Wiggering 1997, Singh et al. 2008a). The following sections review research works related to environmental issues in the steel industry.

2.4.1 Environmental impact assessment of the steel industry

Several authors have focused on the environmental impacts of the steel industry. Szekely (1996) presented a brief review of the evolution of the steel industry over 25 years and formulated some basic definitions, such as of industrial ecology, advanced materials and green materials. In addition, he discussed the environmental problems associated with steel processing technologies, touching on pollution control, waste minimisation and recycling.

Zhou et al. (2002) discussed the environmental problems and impacts of the steel industry in China. They also discussed in detail the environmental conditions and pointed out that it is necessary to reduce the quantity of waste generated by improving the raw materials, energy consumption rate, and reinforcing the waste control and management. At the same time, the relevant mathematical models of environmental impact were set up on the basis of raw material consumption, energy consumption and waste generation and discharge in different technical routes of steelmaking.

Lianexay et al. (2007) conducted a study on the Environmental Impact Assessment (EIA) of the Thai Iron and Steel Factory, which expanded its existing plant to cater for higher demand in downstream industries. Together with the new plant, the total capacity will exceed 100 tons/day, which requires Environmental Impact Assessment according to Thai law. The environmental impacts were assessed during both construction and operation phases. Mitigation measures and a monitoring program were also proposed. During the construction phase, the regular monitoring was carried out to ensure good engineering practices. The 24-hour monitoring of total particulate matter during construction showed the average value of 0.2 mg/m^3, while the standard value was 0.33 mg/m^3. The noise levels measured during the construction were in the acceptable range. During the operation phase, the ambient air quality, indoor air quality and the stack emission were monitored every three months. The maximum total particulate matter value of the ambient air quality, indoor air quality and stack emission were 0.15, 2.5 and 9 mg/m^3, based on 24-hour measuring, while the standard values were 0.33, 15 and 240 mg/m^3 respectively. The monitoring results showed that no single value exceeded the standard value. In their conclusion, the authors confirmed that the

Thai Iron and Steel Factory also made efforts initiate discussions and to establish good relations with local communities and government officials from the inception of the plant, and the response of local communities toward the project was positive, but the study expressed concern about the long-term management of potential environmental impacts.

2.4.2 Sustainable development issues in the steel industry

From the 1990s onwards, researchers began to focus on sustainable development issues in various industries. For example, Spengler et al. (1998) presented a methodology to demonstrate how the planning of integrated by-product management strategies in the iron and steel making industry can be facilitated by the use of flow sheet based simulation and multicriteria based decision support system.

Hilson and Murck (2000) attempted to bridge a major gap in the sustainable development in the corporate mining context by clarifying exactly how sustainable development can be applied in the corporate mining context. In addition, they also presented guidance for mining companies interested in improving the sustainability of their operations. Furthermore, they offered six recommendations to improve the sustainability: improved planning, improved environmental management, cleaner technology implementation, increased stakeholder involvement, formation of partnerships and improved training.

Singh et al. (2007) presented a method for the development of composite sustainability performance index (CSPI) that addresses the sustainable performance of steel industries along all the five pillars of sustainability: economic, environmental, societal, organizational governance and technical aspects. The objective of this paper is to introduce sustainability and to present a conceptual decision model, using analytical hierarchy process (AHP) to assist in evaluating the impact of an organization's sustainability performance. The effectiveness of the proposed model was evaluated in a case study for a major steel company in India.

Kaneko et al. (2006) carried out a study to analyse a clean development mechanism (CDM) project using some analytical methods to introduce energy saving technology from Japan to a small steel manufacturer in China, and conducted a simulation of the quantitative relationships between various technology options and profitability. Based on their results, they examined the environmental and economic significance of technology selection for CDM projects.

Singh et al. (2008b) designed a framework for implementation of Integrated Environmental Management Systems (IEMS) in the steel industry. IEMS aims at the greening of the industry which shall integrate pollution prevention, life cycle assessment, environment management information system, green supply chain, environment performance evaluation, environmental accounting and other environmental management tools to environmental management system (EMS) according to ISO 14001 requirements. The authors noted that this approach allows the steel companies to find and implement profitable and powerful measures that avoid waste generation, reduce environmental pollution, and improve consumption of natural resources.

2.4.3 Life cycle analysis (LCA)

Having identified wider issues in the sector, researchers then focused on whole life cycle analysis. Life cycle assessment stands as the pre-eminent tool for estimating environmental effects caused by products (or services) and processes from 'cradle to grave' or 'cradle to cradle' (i.e. from the initial extraction and processing of raw materials to final disposal) (Reap et al. 2008). Harceag et al. (1999) conducted a study on pollution prevention in the Romanian iron and steel industry. They stated that many Romanian industrial plants and technologies are either old and inefficient or not well operated and they need to be modernised through process modification by increases in the efficiency of equipment, operation and maintenance procedures or by undergoing complete technological change to reduce its impact on natural environment. Therefore, the authors presented characteristics of the iron and steel industry, a case study of Life Cycle Assessment in a Romanian iron and steel plant. LCA is a technical tool to use to identify and evaluate opportunities to reduce the environmental effects related with a specific product, production process, or activity. They also presented some resultant pollution prevention measures.

Scaife et al. (2002) presented a summary of results for life cycle analysis studies for a range of steelmaking routes, including conventional and emerging technologies. Although consideration of the whole value chain is essential for minimising the overall greenhouse gas emissions (GGE) for steel, they focused on the processes from raw materials in the ground through to cast steel. In addition, they recommended that while GGE is still the major concern, it must also be recognised that other impacts of the steel production chain will increasingly need to be taken into account.

Emi and Min (2005) reviewed the strategies and achievements in the Asian steel industry (Japan, Korea and China) in constructing an industrial ecological chain. They discussed practical measures to enhance the linkage and cooperation between these countries for effectively promoting reduction, reuse and recycling. In addition, they emphasised the development of a resource recycling system for the minimisation of various wastes and emissions of greenhouse gases, toxic gases and polluting particulates. Their minimisation strategy involved: rationalisation of iron- and steel-making processes; implementation of available relevant measures; life cycle assessment in designing steel; reduction, reuse and recycling of materials; and energies-utilisation of competent core technologies to process wastes.

Dahlström and Ekins (2006) presented a methodology of value chain analysis developed for a study which combined a material flow analysis of the UK iron and steel sector. This methodology to map the current value chain of iron and steel flows through the UK noted the high value of scrap arising at different stages of the production and use chain, and the high cost of disposing waste products from iron and steel production, and sought to examine the residual outputs generated by this industry and the value of applying industrial ecology principles. The study contrasted the environmental impacts of different categories of materials with their values and discussed the findings in terms of the global environmental burden of this sector of the economy, with particular attention to international trade aspects. Their findings showed that value chain analysis is a good methodology for exploring various aspects of the economy environment interface, and a useful complement to material flow or life cycle analyses.

2.4.4 Environmental strategies

Clemens (2001) studied the changing environmental strategies over time in an empirical study of the steel industry in the US. The study addressed some environmental typologies which were developed by several authors, namely Logsdon (1983), Oliver (1991), Klassen and Whybark (1999), Hillman and Hitt (1999), Prakesh (1999), Sharma (2000), and Bansal and Roth (2000). In addition, the study recommended that Oliver's (1991) typology is the most appropriate, because it is a comprehensive and broadly applicable typology not particular to any specific industry or situation, in contrast to the typologies employed by the other authors. Oliver's typology was not designed to address environmental strategies, but it incorporates the components necessary to understand them. Oliver developed an expanded typology of 15 tactics and five strategies that organizations use to address regulatory interventions.

Singh et al. (2008a) conducted a study to identify and assess the environmental strategies for a typical steel industry using Importance Performance Analysis (IPA). IPA has been used to present recommendations about priorities and resource allocation for ensuring continual improvement in environmental performances. Furthermore, they tried to identify and evaluate the environmental strategies that may be able to facilitate the incorporation of environmental concerns into corporate strategic management. The major findings of their study indicated that the industry needs to develop a robust methodology to monitor Environment Performance Indicators and perform benchmarking with competitors, conduct environmental risk assessment, improve hazardous waste management practices, and make environmental investments at regular intervals.

In addition to the above studies, several research works focused on specific areas of steel manufacture and/or specific aspects of environmental impacts. The following sections review research works related to specific aspects of the environmental impacts of the steel industry.

2.4.5 Emissions to air & material and energy consumption

As mentioned above, the iron and steel industry is the largest energy-consuming industry in the world as well as one of the most important sources of CO_2

emissions and other pollutants. CO_2 is emitted at a variety of points in the iron and steel production process. Taking all emissions into account, the iron and steel industry accounted for an estimated 4.1% of total world CO_2 emissions and about 3.2% of all greenhouse gases (GHGs) in 2000. The steel industry accounted for about 15% of all manufacturing emissions in the 2000s (Wang et al. 2007). The amount of CO_2 is expected to grow further in the future, primarily due to increasing steel production.

A series of studies have been conducted by several authors about CO_2 emissions and material and energy consumption in steel manufacturing. Nippon Steel implemented environmental measures for steel production processes and promoted the development of various environmentally friendly products to meet the requirements of diverse consuming industry. Kawal (2000) introduced the initiatives launched by Nippon Steel in the development of environmentally friendly steel products for specific consuming industries. These environmental initiatives can be considered in three main categories, namely: reduction in CO_2 emissions and energy consumption' recycling and waste reduction; and environmental protection and environmental improvement. The main industries targeted are: automobiles; household electric appliances and electric machinery; electric power and energy; building and construction and civil engineering; and ships and railroads. In his conclusion, Kawal stated that global environmental problems such as global warming and air pollution are the most pressing and important issues for all people and all industries will no longer be able to carry out corporate activities without considering the environment.

Panigrahi (2001) presented an overview on processing of low carbon steel plate and hot strip. The study addressed various issues of hot processing of low carbon steel plate and hot strip to arrive at optimum structure and properties for specific applications. This study concluded that reheating temperature, finishing rolling temperatures, coiling temperatures, and process parameters have influences on microstructure, mechanical properties, final product properties, product quality and hence on the natural environment.

Gielen and Moriguchi (2002) developed a new linear programming model for the analysis of CO_2 emission reduction potentials in the Japanese iron and steel industry. This model is named Steel Environmental Strategy Assessment Program. The model can be used to analyse the impact of CO_2 taxes on technology selection, iron and steel trade and product demand for the next three decades.

Kim and Worrell (2002) analysed trends in CO_2 emissions in the iron and steel industry in China, South Korea, Brazil, China, India, Mexico and the US by using physical indicators. They found big differences in energy efficiency among these countries. In most countries increased/decreased production was the main contributor to changes in CO_2 emissions, while energy efficiency was the main factor reducing intensities in almost all countries. In addition, they stated that structural change in the product mix and changes in power generation also contributed to changing emission characteristics in some countries.

Ozawa et al. (2002) analysed energy use and carbon dioxide emissions for the Mexican iron and steel industry from 1970 to 1996 to assess the trends in energy use and carbon dioxide emissions. The authors stated that the steel production growth drove up primary energy use by 211% between 1970 and 1996, while structural changes (production and process mix) decreased primary energy use by 12% and energy efficiency changes drove down energy use by 51%.

Gielen (2003) studied the possibility of CO_2 removal in the iron and steel industry. He found that CO_2 removal in iron and steel production has received little attention, and he analysed this option in more detail. The results suggest that a CO_2 capture system, based on a shift reaction and physical absorption, in combination with underground or oceanic carbon storage, could be attractive. In addition, he confirmed that global CO_2 emissions could be reduced by 4%, and Japanese CO_2 emissions could be reduced by 6.5% (80 Mt/yr) if this option were applied to its full extent by the iron and steel industry. The author noted that the use of this option is still limited by uncertainties regarding CO_2 storage potentials in deep aquifers and the environmental impacts of oceanic storage. Finally, he recommended studying these issues in more detail.

Hidalgo et al. (2005) presented the Iron and Steel Industry Model (ISIM). This model is able to analyse the evolution of the industry from 1997 to 2030, focusing on steel production, demand, trade, energy consumption, CO_2 emissions, technology dynamics, and retrofitting options.

In the context of the Kyoto Protocol on climate change, the potential impacts of a CO_2 emission market are also addressed. Oda et al. (2007) evaluated CO_2 emission reduction potentials and the minimum cost of technological options in the iron and steel sector by region across the world.

In order to assess the CO_2 abatement potential and energy consumption of China's steel industry, Wang et al. (2007) developed a model using LEAP software to generate three different CO_2 emission scenarios for the industry from 2000 to 2030. LEAP is a scenario-based software tool for integrated energy-environment and greenhouse gas mitigation analysis developed by the Stockholm Environment Institute (SEI). The analytical procedure in the LEAP model can be summarised as five steps: sectoral production projection, corresponding energy demand, CO_2 emissions, total cost calculation, energy savings and CO_2 abatement potential calculation. The abatement potentials of different scenarios were compared, and their respective feasibilities were assessed according to the cost information. High priority abatement measures were then identified. The results show that the average CO_2 abatement per year in the recent policy scenario and in the new policy scenario compared with the reference scenario are 51 and 107 million tons respectively. It is concluded that there is great potential for CO_2 abatement in China's steel industry.

Based on an intensive and in-depth survey of steel producing facilities and energy efficient technologies, Demailly and Quirion (2008) studied the European Emission Trading Scheme (ETS) and competitiveness as a case study on the iron and steel industry. The goal of their study was to assess the competitiveness impact and the environmental effectiveness of the EU ETS in the iron and steel sector, while testing the robustness of the results to key assumptions: marginal abatement cost curve, price elasticity of demand, price elasticity of trade, pass-through rates and allocation updating rules. They addressed two dimensions of competitiveness: production and profitability.

Tridech and Cheng (2008) discussed the concepts of low carbon manufacturing (LCM) and developed theoretical models with initial models by using the theory from supply chain modelling and linear programming solutions. The models show that the relationship of resource utilizations and related variables for LCM in two levels: shop-floor and extended supply chain, also the pilot implementations of LCM are discussed with two approaches: desktop or micro machines and devolved manufacturing.

Melinte et al. (2008) presented system for the assessment and the control of the CO_2 emissions released into atmosphere, in iron and steel industry, especially for the burning processes. The system is composed by two components: a off-line component, for the calculation of the CO_2 emissions amounts, produced in technological and combustion processes in iron and steel, based on a specific software; a on-line component, for the optimisation and control of the CO_2 emissions released during the combustion of a gas fuel into a furnace, by using a loop with a fuzzy regulator, for the adjustment of the oxygen concentration in the flue gases.

Hanrot et al. (2009) proposed an option to mitigate CO_2 emissions in steelmaking. The option proposed is based on using charcoal and plastics waste as reducing agents and secondary raw materials. The results of this study showed that this option can be implemented if local conditions and quality criteria allow it, like the availability of biomass grown and charcoal production in a sustainable way, and the quality criteria of plastic wastes.

Zeng et al. (2009) carried out study in order to promote GHG reduction action in the Chinese iron and steel industry. This study interprets the important role that the Chinese iron and steel industry may play in managing emissions. Through an investigation of the key sources of greenhouse gas emissions in the Chinese iron and steel industry, a comparison of the current Chinese and international situations, and a survey of the technology and methods available for reducing greenhouse gas emissions, and their application in China, the authors analysed the major issues faced by the Chinese iron and steel industry, and proposed the following four approaches through which the industry might reduce its GHG emissions: 1- encouragement of clean development mechanism (CDM) projects, mainly involving secondary energy reuse, to provide capital and technology for greenhouse gas reduction activities in China; 2- stimulation of the social responsibility-based voluntary carbon market (VCM) to increase the long-term benefits for the Chinese iron and steel industry from emission reductions; 3- strict energy auditing is the foundation for steel enterprises to establish appropriate emission reduction targets and formulate reasonable plans; 4- promotion of emission reduction-oriented investment within the industry to obtain profits from project operation, while at the same time gaining extra compensation for emission reductions.

2.4.6 Steel slag

Steel slag is a by-product of steel-making operations, with an estimated 12 million tons generated annually in Europe (Shen and Forssberg 2003). Approximately 21 million tons of steel industry slag are produced each year in the US (Proctor et al. 2000). However, because slag contains heavy metals at concentrations that are higher than in most soil, questions have been raised regarding the need to evaluate the potential human health and environmental hazards associated with current applications. To enhance general understanding of the physical and chemical characteristics of this material, slag samples from 58 active mills with blast furnaces, basic oxygen furnaces and electrical arc furnaces were examined by Proctor et al. (2000). Their study presented the major and minor constituents of slag from each furnace type and the most complete characterisation of steel industry slag produced in North America.

Motz and Geiseler (2001) studied the possibility of utilising steel slag as a road construction material in different European countries. They stated that to reduce some environmental impact in steel manufacture, steel slag has been used successfully in different European countries as a road construction material because of its advantageous technical properties. Also, Reddy et al. (2006) studied the possibility of the utilisation of basic oxygen furnace (BOF) slag in the production of a hydraulic cement binder.

Matei et al. (2007) studied the physical and chemical characteristics to two types of steel wastes; basic oxygen furnace slag (BOF) and electric arc furnace slag (EAF) using the leaching test. They observed that the wastes from the iron and steel industry are not hazardous wastes on the environment, but the risk of the appearance of some heavy metal ions appearance is possible, this being a reason for time-to-time testing of these waste types, bearing in mind the influence of these heavy metals on the environment and life.

Branca et al. (2009) presented a case study on the reduction of potential ladle furnace (LF) slag environmental impacts, because of its intrinsic physicochemical properties. During the handling and cooling of LF slag, it disintegrates into a powder due to instability of the dicalcium silicate, causing an increase in dust emissions to the environment. The aim of the study was to reduce this phenomenon in order to achieve a more sustainable solution in term of reduction of powder dispersion in the environment, of costs saving.

Minett (2009) stated that major steel plant on the east coast of Sweden installed a new rolling mill. In conjunction with this, they introduced the principle of 100% recycling of both the process water and slag resulting from the cooling process. As part of their efforts to implement this, they installed a Dyna Sand filtration plant.

2.4.7 Exposure to noise

Pandya and Dharmadhikari (2002) carried out a comprehensive environmental noise exposure study in and around a major iron and steel works. The works was located in the central part of the city and was surrounded by residential, commercial, and sensitive receptors. Traffic activity near the plant was significant and added to the background noise level. Considering the variety of noise sources in the plant area and in the neighbourhood, a practical approach to measure noise equivalent level in the plant and in the residential, industrial, commercial and silence zone was adopted. A modular precision integrating sound level meter with statistical analyser module were used during the measurements. The day and night levels were determined, and worker exposure was assessed by determining the speech interference level and noise rating level at one of the major sources located in the power plant of the steel works. The results indicated that the impact on the community is significant, as observed from day and night levels.

2.5 Conclusion and comments

From the above it is clear that the scale and the diversity of environmental issues in the steel industry have furnished subjects for many researchers. Several authors have focused on environmental issues in the steel industry. In the 1970s, researchers focused on minimising production waste and re-cycling. From the 1990s onwards, attention has been directed to assess wider environmental issues and to formulating strategies to minimise impacts. However, the steel industry still needs more attention to conduct environmental impacts assessment, to improve hazardous waste management practices, and to make environmental investments at regular intervals.

3. CHAPTER THREE

Research Methodology

3.1 Introduction

This chapter gives a brief description of the methodologies that have been pursued in this research. The general definition of 'methodology' furnished by the Shorter Oxford English Dictionary is "the branch of knowledge that deals with method and its application in particular field. Also the study of empirical research or the techniques employed in it". Collis and Hussey (2003) stated that the term methodology refers to the overall approaches and perspectives to the research process as a whole, while a research method refers only to the various specific tools or ways data can be collected and analysed (e.g. questionnaire, interview, and data analysis software). The following paragraph reviews the problem, which has been tackled in this research.

As mentioned earlier, this research work is aiming to develop a model related to the environmental impacts of the steel industry. The aim of the model is to investigate the most important environmental criteria and their ranking in order to manage the environmental impacts of the steel industry. A questionnaire and Analytical Hierarchy Process (AHP) techniques are applied to achieve the aim of this research work.

For this research the questionnaire was conducted for data collection for pairwise comparison between each two criteria or each two sub-criteria to indicate the relative importance of the two factors shown in each question (Appendix B). AHP is chosen to be used as a tool for priority selection of environmental impacts of steel industry according to their importance. Figure 3.1 illustrates the research methodology.

In the first phase of this research programme an extensive literature review was conducted to understand the scale and the diversity of environmental issues in the steel industry. The second phase includes conducting a waste survey of the Libyan steel industry and its classification according to source. Work done in the previous two phases will form the foundation for next work packages in the research programme, which includes creating the structure of the environmental impacts model for steel industry. The model consists of the overall goal, which is creating an environmental impacts model for steel industry, using four criteria derived from the literature review and waste survey in the Libyan steel industry. Each criterion has numbers of sub-criteria to be able to illustrate the situation and make the analysis clear and understandable. Then the questionnaire is used for pairwise comparison between each two criteria or each two sub-criteria to indicate the relative importance of the two factors shown in each question. Once the environmental impacts of the steel industry have been determined as objectives (main criteria) and alternatives (sub-criteria) and the data has been entered into AHP software. The AHP can be used to build the model to investigate the most important environmental parameters and their importance in order to help to manage the environmental impacts of steel industry.

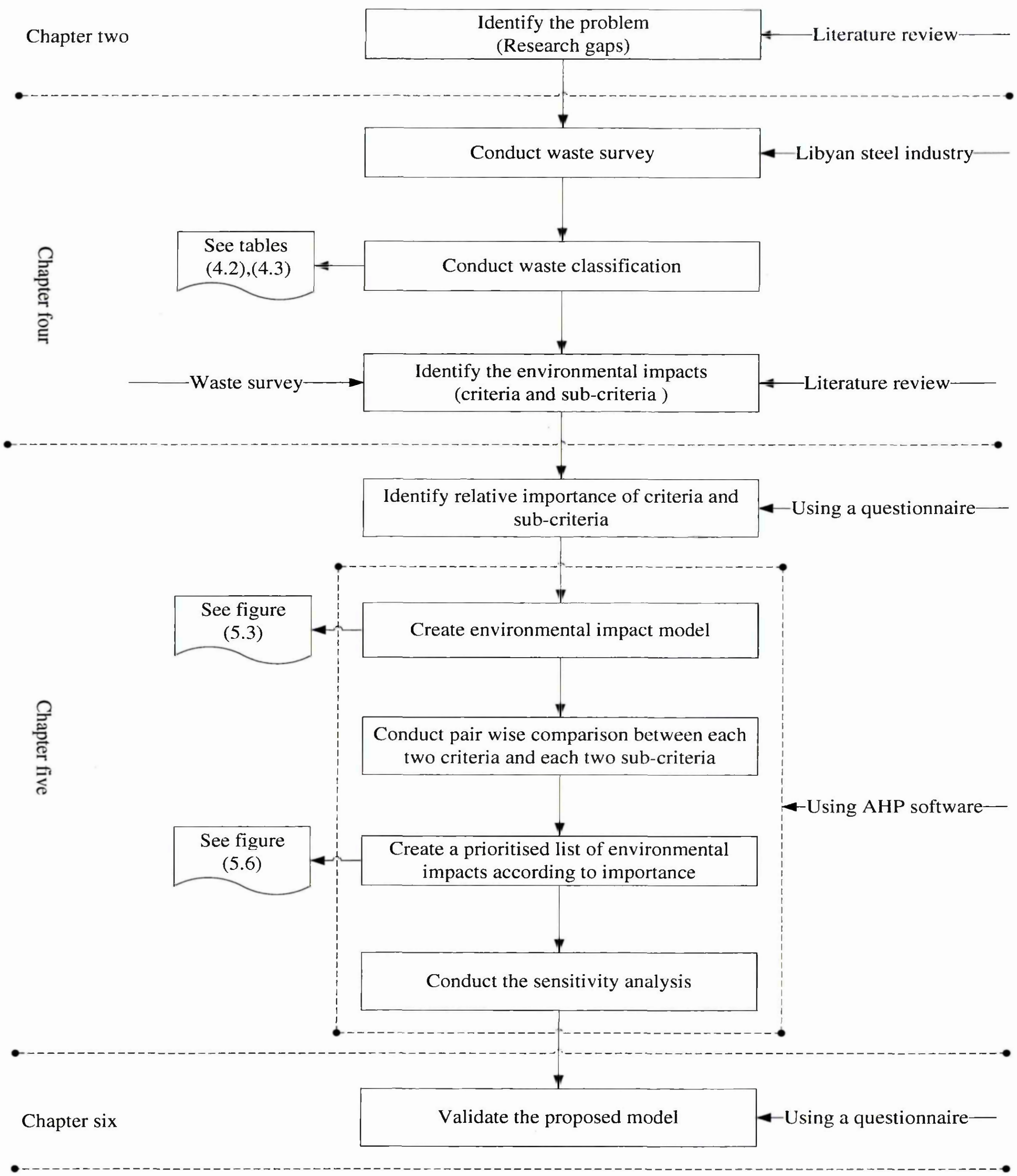

Figure 3.1 Research Methodology

Then, a series of sensitivity analyses were conducted to investigate the impact of changing the priority of the criteria on the alternatives' ranking. After developing the model and indicating the most important criteria and sub-criteria, the derived model needs to be validated. The last phase of this research programme deals with this problem. As mentioned earlier, this research focuses on the application of two main methodologies, namely questionnaire and AHP. The following sections elucidate these methodologies.

3.2 Questionnaire

According to Kumar (2011), a questionnaire is a written list of questions, the answers to which are recorded by respondents, who read the questions, interpret what is expected and then write down the answers. Therefore, it is important that the questions are clear and easy to understand. Also, the layout of a questionnaire should be such that it is easy to read and pleasant to the eye, and the sequence of questions should be easy to follow.

3.2.1 Type of questionnaires

Once it is decided that a questionnaire is the most appropriate data collection method for a study, the researcher must decide whether to construct a closed- or open-ended questionnaire, or a combination of both. In open questions respondents use their own words to answer a question, whereas in closed questions prewritten response categories are provided. When constructing a closed-ended question, all possible answers should be covered (sometimes with the provision 'none of the above' as an answer option, perhaps with the option to define below). Researchers must endeavour not to artificially create opinions by asking leading questions or questions about which respondents are unlikely to have knowledge or opinions.

3.2.2 Designing questionnaires

According to Kumar (2005) the steps required to design and administrate a questionnaire include:

- Defining the objectives of the survey;
- Deciding which questionnaire to use;
- Wording and structure of questions;
- Administering the questionnaire;
- Analysing and interpreting results.

A questionnaire can be administered in different ways, including:

- The mailed questionnaire:

The common approach to collecting data is to send the questionnaire to prospective respondents by mail. One of the major problems with this method is the low response rate.

- Collective administration:

One of the best ways of administering a questionnaire is to obtain a captive audience, such as students in a classroom, people attending a function, participants in a program or any group of people assembled in one place. In such cases the author has personal contact with the study population and can explain the purpose, relevance and importance of the study and clarify any questions that respondents may have. This ensures a very high response rate.

- Administration in a public place:

Sometimes a questionnaire can be administered in a public place such as a shopping centre, hospital or school. Of course this depends upon the type of study population and where desired respondents are likely to be found (Kumar 2005).

3.2.3 Developing questions

The foundation of all questionnaires is the questions. The questionnaire must translate the research objectives into specific questions; answers to such questions will provide the data for hypothesis testing (Nachmias 2004). In this respect, Dawson (2009) stated that the researcher should bear in mind the following:

- Questions should be kept short and simple.
- Questions should not contain some type of prestige bias. This refers to questions which could embarrass respondents or force them into giving a false answer.
- Use indirect questions for sensitive issues.
- Avoiding leading questions.

- Questions must motivate the respondent to provide the information being sought.
- Keep the questionnaire as short as possible.

3.2.4 Pilot questionnaire

Once the questionnaire is constructed, it should be piloted in order to ascertain its utility in obtaining desired results (i.e. pertinent to the study). There are a number of reasons why it is important to pilot a questionnaire, including to test how long it takes to complete, to check that the questions are not ambiguous, to check that the instructions are clear, and to allow the revision or elimination of questions that do not yield usable data.

A questionnaire should be piloted using respondents not involved in its construction in order to identify any ambiguities which those who construct the questionnaire may not notice.

Once this has been done, questions can be revised or deleted accordingly, and then sent out to a cohort of people who meet the criteria of desired respondents for participation in the main survey. These participants should be made aware that it is a pilot test and they should be asked to forward any comments they may have about the length, structure and wording of the questionnaire. Each response should be analysed and evaluated carefully, noting comments and answers to the questions to discover whether there are still ambiguities (Dawson 2009).

3.2.5 Advantages of a questionnaire

- Questionnaire can be used to collect large amounts of information at a low cost per respondent.
- Questionnaire is convenient for respondents, who can answer when they have time (thus improving response rate).

3.2.6 Limitations of a questionnaire

- Questionnaire takes longer to complete than telephone or personal interview.
- Questionnaire response rate is often very low.

Based on literature findings, a questionnaire was designed (Appendix B). The questionnaire was divided into: the first part of the questionnaire, including the personal data of respondents; the second part of the questionnaire, a list of pairwise comparison between the criteria and sub-criteria to indicate the relative importance of the two factors shown in each question; and the third part of the questionnaire, which presents some questions related to this research work.

To pairwise comparison between each two criteria or each two sub-criteria to indicate the relative importance of the two factors shown in each question and to validate the proposed model, fifty questionnaires were distributed by the author when visiting Libya to some experienced managers and engineers in different plants in the Libyan iron and steel industry. Thirty respondents completed the questionnaires, giving an overall response rate of 60%.

3.3 Analytic Hierarchy Process (AHP)

Udo (2000) defined Analytic Hierarchy Process as a mathematically based, multi objective decision-making tool which was developed by Thomas L. Saaty in the 1970s and has been extensively studied and refined since then.

AHP uses deduction and induction as a means of decomposing complicated problems into a hierarchy of simple factors and sub factors, and then makes the corresponding measurements according to comparisons (Saaty 1980). AHP is a mathematical, objective decision-making tool that enables the solution of decision-making problems involving uncertainty and multiple criteria characteristics (Udo 2000, Lin and Wu 2008).

AHP is a multi-criteria decision-making (MCDM) method that helps the decision-maker facing a complex problem with multiple conflicting and subjective criteria (e.g. location or investment selection, projects ranking etc.) (Ishizaka and Labib 2009).

Vaidya and Kumar (2006) illustrated that AHP is a multiple criteria decision-making tool that has been used in almost all applications related to decision-making. Also, they classified AHP as a multiple criteria decision-making tool and they argued that most decision-making applications used it as a tool for priority selection, for the reason that it has such a prominent reputation.

As an MCDM, AHP uses an Eigen value approach to pairwise comparisons. It also provides a methodology to calibrate the numeric scale for the measurement of quantitative as well as qualitative performances. The scale ranges from 1/9 for 'least valued than', to 1 for 'equal', and to 9 for 'absolutely more important than' covering the entire spectrum of the comparison. AHP incorporates the evaluation of all decision makers in to a final decision by pairwise comparisons of the alternatives (Saaty, 1980).

Basically, AHP consists of three main operations: hierarchy construction, priority analysis and consistency verification. First of all, the decision makers need to break down complex multiple criteria decision problems into component parts, of which every possible attribute is arranged into multiple hierarchical levels. Then, the decision makers have to compare each cluster in the same level in a pairwise fashion based on their own experience and knowledge. For instance, every two criteria in the second level are compared at each time with respect to the goal, whereas every two attributes of the same criteria in the third level are compared at a time with respect to the corresponding criterion. Since the comparisons are carried out through personal or subjective judgments, some degree of inconsistency may occur. To guarantee the judgments are consistent, the final operation (called consistency verification and regarded as one of the chief advantages of AHP) is performed, in order to measure the degree of consistency among the pairwise comparisons by computing the consistency ratio. If it is found that the consistency ratio exceeds the limit, the decision makers should review and revise the pairwise comparisons. Once all pairwise comparisons are carried out at every level, and are proved to be consistent, the judgments can then be synthesized to find out the priority ranking of each criterion and its attributes (Ho et al. 2006, Ho 2008). The overall procedure of AHP is shown in Figure 3.2.

AHP has been studied extensively and used in numerous applications over recent decades (Zahedi 1986, Golden et al. 1989, Shim 1989, Vargas 1990, Saaty and Forman 1992, Forman and Gass 2001, Ramanathan 2001, Kumar and Vaidya 2006, Omkarprasad and Sushil 2006, Ho 2008, Liberatore and Nydick 2008). It has been adopted in many applications, including project selection, healthcare, marketing, transportation, evaluation, auditing, business performance and public policy (Udo 2000). In addition, Vaidya and Kumar (2006) pointed out that some research papers have used AHP as a tool to study many topics, including priority, ranking and decision making.

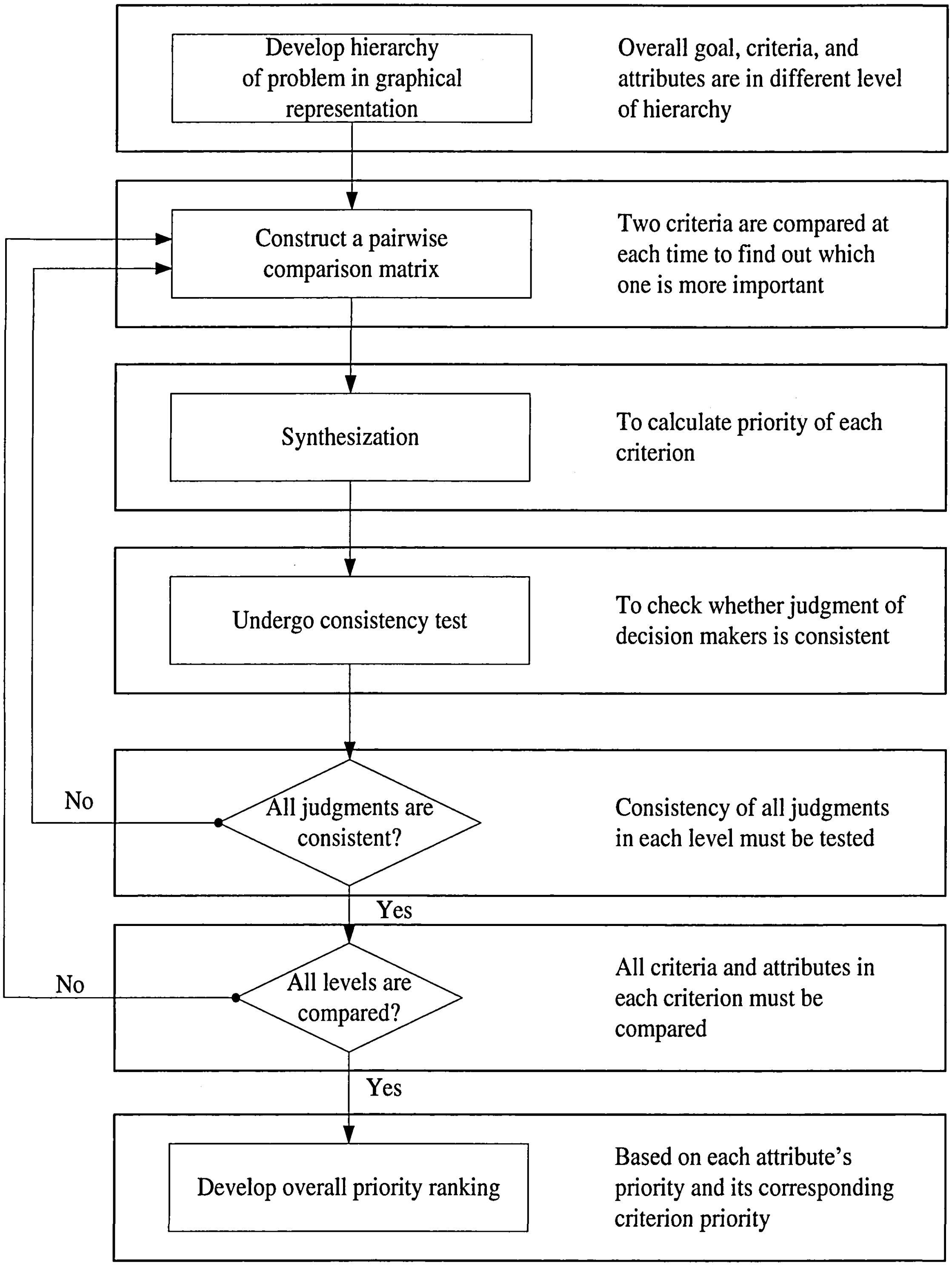

Figure 3.2 the flowchart of the Analytic Hierarchy Process (Ho 2008)

3.3.1 Advantages of Analytic Hierarchy Process

The advantages of AHP over other multi-criteria methods, as often cited by its proponents, are its flexibility, intuitive appeal to decision-makers (experts and stakeholders), and its ability to check the inconsistencies in judgments (Saaty 2000). Also, the technique is simple and thorough in handling difficult real-life problems (Udo 2000). In addition, AHP is easy to operate and the opinions of experts and decision makers can be easily integrated into it (Lin and Wu 2008).

A brief discussion of AHP is provided in this section. More detailed description and application issues can be found elsewhere (Saaty 1980, 2000).

3.3.2 The usefulness of Analytic Hierarchy Process for Environmental Impact Assessment (EIA)

AHP can be potentially useful for environmental impact assessment in many ways. It can provide an ideal framework for environmental impact assessment which also involves trade-offs among various environmental problems and development. AHP helps to elicit the complex judgements of different experts in a common platform. It also ensures accuracy in the sense that it has an inbuilt method to check the inconsistency of judgements. This ensures that the judgements are provided only with sufficient care and the error due to negligence is thus minimised.

- Aggregation of many expert opinions

Environmental Impact Assessment (EIA) requires expert opinions from multiple actors in terms of multiple criteria. Typically, there will be more than one expert who will be consulted in each field of impact (e.g. air, water, land, noise etc.), and there are typically several such groups of experts from different fields. Consulting more experts minimises bias that may be present when the judgements are considered from a single expert. When judgements from many experts are considered, it is necessary to aggregate them suitably. Several methods are available in AHP for performing aggregation, including the geometric mean method and arithmetic mean method (Ramanathan and Ganesh 1994, Peniwati 1996, Saaty 2000, Ramanathan 2001).

- Necessity to consider different groups of experts

"EIA requires consideration of expert opinion from many different fields. In such a case, it is important to study the opinions of experts from different fields on a common platform. Sometimes, weights have to be assigned to the opinions of groups of experts belonging to different fields. Conventional methods such as checklists cannot synthesise such diverse information. AHP possesses some models for this purpose, which can be advantageously used. For example, suppose that several groups of experts are involved in assessing a particular project, and that it is desired to assign weights to the groups. Assignment of such weights is quite difficult, as no group will accept those fixed by an external agency" (Ramanathan 2001). However, Ramanathan and Ganesh (1994) stated that a participatory approach can be adopted. This approach derives the weights of the different groups using intrinsically derived ratings of each group, which compares itself with the other groups. The method has been applied to compare different groups of experts when choosing the most appropriate energymix for urban households (Ramanathan 2001).

- Participation of stakeholders

The recent disputes on environmentally sensitive projects have led to the necessity to consider all the stakeholders (i.e. key actors) of a project, such as the authorities, local and affected people, engineers and others. Several studies on environmentally and socio-economically sensitive projects considered such stakeholder analysis (Grimble and Chan 1995, Grimble and Wellard 1997). The stakeholders and their interests in the project should first be identified. Proper corrective actions, if needed, should be carried out in time to ensure smooth execution of the project. For example, the opinions of the people affected directly by the project on the impacts they are likely to face when the project goes on-stream should be seriously considered. Any misconception on the part of local people in this regard should be rectified. Timely corrective actions should be taken, so that local people feel positive about the project. Several methods such as ranking are possible to elicit the subjective opinions of the stakeholders on the different impacts of the project. However, AHP can be a very valuable tool for the purpose, as it can be devised to capture the feelings of laymen and convert their feelings to a numerical scale that reflects their thinking. As the thoughts of laymen may not be very structured, it is necessary to verify the accuracy of their judgements. This verification is possible when AHP is used, as the inconsistencies of judgments can be easily identified (Ramanathan 2001).

The above discussion of AHP's wide applicability in many fields indicates that it can be used not only to set priorities, but it could be combined with other methodologies to come up with precise analysis and outcome.

Based on the above we conclude that AHP can be a useful tool for systematically analysing the opinions of several groups of experts belonging to diverse fields in an EIA study.

3.4 Conclusion

In this chapter a brief description about the methodologies used in this research were presented. Two main methodologies are discussed, including questionnaire and AHP, and their strengths and advantages were emphasised in order to demonstrate how they can be applied to help in problem solving.

4. CHAPTER FOUR

Survey and Classification of Waste Generated by the Libyan Iron and Steel Industry

4.1 Introduction

This chapter gives a brief overview of the Libyan iron and steel industry. It also reports the work done during the first phase of the research programme. It includes conducting a waste survey and waste classification according to their source, in addition to the environmental impacts of the Libyan iron and steel industry.

4.2 Libyan iron and steel industry overview

4.2.1 Historical background

- The importance of the Libyan Iron and Steel Company (LISCO) greatly increased from 1970 onwards. Extensive studies were undertaken to establish whether a Libyan iron and steel enterprise was possible based on the technical and economic situation of Libya and the requirements of such industries.
- In December 1974, Act No. 101/74 was issued to establish the General Institution of Iron and Steel Projects (GIISPs).
- In October 1975 the contract was signed with a consultant to prepare firstly a report on the project and secondly to give details of the planning to carry out this project.

- In February 1977 the details of general scheme were approved to begin the first stage with the Midrex Direct Redaction/Electric Arc Furnace method, utilising natural gas.
- In September 1979 the cornerstone was laid to establish the complex in Misurata, the first heavy industry in Libya.
- LISCO is situated near the coastal city of Misurata, about 210 km east of Tripoli in an area of 1,200 hectares. LISCO is one of the largest companies in Libya with an annual designed capacity of 1,324,000 tons of liquid steel.
- In 1980, GIISPs started to sign contracts with some global companies to carry out the first stage of the complex, with 30 contracts worth about 1497 million dinars (about 2993 million GBP).
- In September 1989 the company entered the production stage.

4.2.2 The technology used in the Libyan iron and steel industry

In steel industry, there are three types of furnaces used in large-scale production: Electric Arc Furnace (EAF), Electric Induction Furnace (EIF) and Basic Oxygen Furnace (BOF). The Libyan iron and steel industry uses the former (EAF) because the raw material used is direct reduction iron and steel scrap. The basic purpose of the EAF is to re-melting sponge iron, melting scrap, its main inputs, to produce finished steel.

4.2.3 Production facilities of Libyan Iron and Steel Company

LISCO comprises numerous production facilities; the manufacturing layout of LISCO is shown in Fig 4.1. Table 4.1 illustrates the products of production facilities in LISCO.

4.2.3.1 Direct reduction plant:

The plant consists of three direct reduction modules, two of which are for Direct Reduction Iron (DRI) production, with a total annual capacity of 1,100,000 tons, and one module for producing Hot Briquetted Iron (HBI), with a capacity of 650,000 tons annually.

4.2.3.2 Steel melt shop no. 1

The shop consists of three electric arc furnaces 90 tons each, two billet casters and a bloom caster. The shop has a design capacity of 630,000 tons/year of billets and blooms.

4.2.3.3 Steel melt shop no. 2

The shop consists of three electric arc furnaces 90 tons each, and two slab casters. The shop has a design capacity of 611,000 tons/year of slabs.

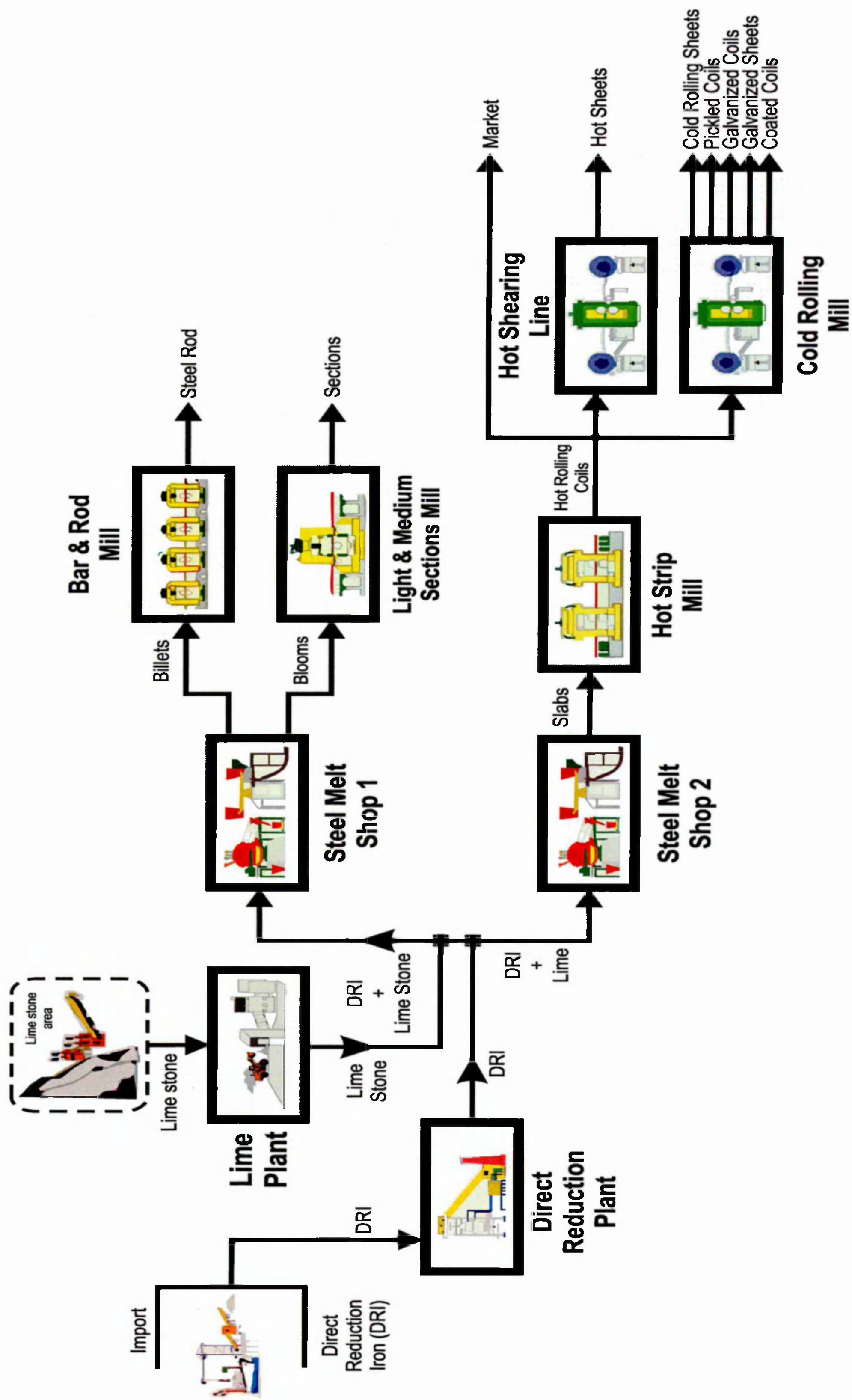

Figure 4.1 manufacturing layout of Libyan iron and steel company

Table 4.1 The products of LISCO

No.	The plant	Products
1	Direct reduction plant	Direct reduction iron (DRI)
2	Calcining plant	Lime stone Dolomite
3	Steel melt shop no. 1	Billets Blooms
4	Steel melt shop no. 2	Slabs
5	Bar and rod mill	Bars Rods
6	Light and medium section mill	Light sections Medium sections
7	Hot strip mill	Hot rolled coils Hot rolled sheets
8	Cold rolling mill	Cold rolled coils Cold rolled sheets Galvanized coils Galvanized sheets Coated coils Coated sheets

4.2.3.4 Bar and rod mills

It consists of two mills for producing bars and a double strand wires and a rod mill. It has a design capacity of 800,000 tons/year of bars and rods.

4.2.3.5 Light and medium section mill

The plant has a design capacity of 120,000 tons/year of light and medium sections.

4.2.3.6 Hot strip mill

The plant has a design capacity of 580,400 tons/year of hot rolled coils and sheets.

4.2.3.7 Cold rolling mill

The plant has a design capacity of 140,000 tons/year of cold rolled coils and sheets. A galvanizing line was added to the mill to produce 80,000 tons/year of galvanized coils and sheets, and a colour coating line was also added to produce 40,000 tons/year of coated coils and sheets.

4.2.4 Auxiliary and supporting facilities of Libyan iron and steel company

The company comprises of several auxiliary and supporting facilities, which include:

- Power and desalination plant.
- Water and gas unit services.

- Computer, systems and communications unit.

- Electrical networks unit.

- Electrical and electronic maintenance workshop.

- Quality control laboratories.

- Mechanical maintenance workshop.

- Civil maintenance unit.

- Planning and manufacturing spare parts unit.

- Transportation unit.

- Training centre.

4.3 Waste Survey Generated by Libyan Iron and Steel Industry

Waste survey in Libyan iron and steel industry included two main stages:

4.3.1 Designing information model

An information model was designed (figure 4.2) to capture all essential data.

4.3.2 Populating the information model

The elements that are considered as waste were identified by the author when visiting Libya and used to populate the information model (Appendix C).

4.3.3 Waste classification according to source

The waste products were classified according to their source, namely; waste in production facilities (table 4.2) and waste in auxiliary and supporting facilities (table 4.3).

Development of an Environmental Impact Model for the Steel Industry

Mansur Salem Zaghinin

PhD Student at Sheffield Hallam University

Waste name:			
Description of the waste	**Source**	**Chemical properties**	**Physical properties**
Annual quantity	**Current disposal or treatment methods**	**Notes**	

Figure 4.2 An information model waste survey generated by Libyan Iron and Steel Industry

Table 4.2 Waste generated by production facilities in Libyan iron and steel company

Potential pollutants release	Source							
	DRP	CP	SMS1	SMS2	BRM	LMSM	HSM	CRM
Batteries			√	√	√	√		
Belts dust	√		√	√				
Belts residues	√	√	√	√				
Carbon dioxide (CO_2)							√	√
Carbon monoxide (CO)		√					√	√
Carbon electrodes			√	√				
Cardboard boxes and plastic			√	√				
Consumed electronic parts	√	√	√	√	√	√	√	√
Consumed greases	√	√	√	√	√	√	√	√
Consumed oils	√	√	√	√	√	√	√	√
Consumed spare parts	√	√	√	√	√	√	√	√
Emulsion cooling			√	√	√	√	√	√

Table 4.2 (Continued)

Potential pollutants release	Source							
	DRP	CP	SMS1	SMS2	BRM	LMSM	HSM	CRM
Filters		√	√	√				
Furnaces dust	√		√	√				
Furnace slag			√	√				
Grinding and Turning waste			√	√				
Hydrogen chloride (HCl)								√
Industry wastewater	√		√	√	√	√	√	√
Iron oxide powder	√							
Iron powder after reduction	√							
Metal drums	√	√	√	√	√	√	√	√
Nitrogen oxides (NO_x)	√	√	√	√	√	√		√
Oxides Treatment								√
Powder lime and dolomite		√						

Table 4.2 (Continued)

Potential pollutants release	Source							
	DRP	CP	SMS1	SMS2	BRM	LMSM	HSM	CRM
Refractory bricks	√		√	√	√	√	√	√
Remnants of the slabs				√			√	
Scales			√	√	√	√	√	√
Scrap bar and rod					√			
Scrap rollers			√	√	√	√	√	√
Scrap slabs							√	
Sludge	√							
Sulphate dioxide (SO_2)								√
Sulphate oxides (SO_x)	√	√	√	√	√	√		
Thermal wool	√	√	√	√	√	√	√	
Tyres - shredded			√	√				
Waste spreaders			√	√				

Table 4.2 (Continued)

Potential pollutants release	Source							
	DRP	CP	SMS1	SMS2	BRM	LMSM	HSM	CRM
Wood			√	√				
Zinc slag								√

DRP - Direct Reduction Plant

CP - Calcining Plant

SMS1 - Steel Melt Shop1

SMS2- Steel Melt Shop2

BRM - Bar and Rod Mill

LMSM - Light and Medium Sections Mill

HSM - Hot Strip Mill

CRM - Cold Rolling Mill

Table 4.3 Waste generated by auxiliary and supporting facilities in Libyan iron and steel company

Potential pollutants release	Source											
	P&D	EN	WGU	QC	CSC	PMSP	EEM	MM	CM	TU	TC	ADF
Acetone			√									
Batteries										√		
Cardboard boxes and plastic	√			√								
Consumed electronic devices					√		√					
Consumed electronic parts	√	√	√		√		√	√		√	√	
Consumed greases	√	√	√			√		√		√		
Consumed oils	√	√	√			√		√		√		
Consumed spare parts	√		√					√				

Table 4.3 (Continued)

Potential pollutants release	Source											
	P&D	EN	WGU	QC	CSC	PMSP	EEMW	MM	CMU	TU	TC	ADF
Emulsion cooling				√		√		√			√	
Granules carbon	√											
Grinding and Turning waste						√		√			√	
Industrial wastewater	√		√									
Insulating substance			√									
Liquids associated with natural gas			√									
Metal drums	√	√	√			√		√		√		
Photocopying toners												√

Table 4.3 (Continued)

Potential pollutants release	Source											
	P&D	EN	WGU	QC	CSC	PMSP	EEM	MM	CMU	TU	TC	ADF
Plastic drums	√		√									
Printing inks												√
Remnants of building materials									√			
Residues of the aluminium samples				√								
Thermal wool	√		√									
Tires										√		
Trash												√
Waste paper (consumed paper)												√

Table 4.3 (Continued)

Potential pollutants release	Source											
	P&D	EN	WGU	QC	CSC	PMSP	EEM	MM	CMU	TU	TC	ADFC
Wastewater												√
Wood	√											

P&DP - Power & Desalination plant
ENU - Electrical Networks Unit
WGUS - Water and Gas Unit Services
QCL - Quality Control Laboratoires
CSCU - Computer, Systems and Communications Unit
PMSPU - Planning and Manufacturing Spare Parts Unit
EEMW - Electrical and Electronic Maintenance Work
MMW - Mechanical Maintenance Workshop
CMU - Civil Maintenance Unit
TU - Transportation Unit
TC - Training Centre
ADFC-All departments & facilities of the company

In general the waste was classified into three types, namely:

- Waste that could be used within the company: this kind of waste is used as scrap metal in steel melt shops such as production rejected by steel shops, hot strip mill, cold rolling mill and foundries workshops.
- Waste sold periodically: such as iron oxide powder, wood, oils consumed, zinc and aluminium. This type of waste results from production processes in the Company's factories.
- Waste with no use within the company: for example, slag, sludge, scals, oxides, limestone, and some liquids that are discharged through the sewage system.

4.4 The environmental impacts of the Libyan iron and steel industry

The environmental impacts of any industry depend mainly on the waste generated by the industry itself. As mentioned above, the impact on the environment by the steel industry is immense. The steel industry is still one of the biggest energy users and one of the biggest polluters. Different types of pollutants result from the different steps in steel production"

- Air emissions

The steel industry is a very large consumer of energy, and as such is the largest source of air emissions.

- Wastewater

Wastewater generated from the processes of steel industry has high contaminant levels, requiring extensive removal and treatment before disposal.

- Solid waste

Solid waste generated by the steel industry presents problems due to the volume of the waste generated.

- Noise

Noise is one of the physical environmental factors affecting health in today's world. Noise is generally defined as unpleasant sounds which disturb human beings physically and physiologically, and cause environmental pollution by destroying environmental properties. It has been observed that there are high noise levels in some process of Libyan steel industry.

The wastes outlined above have significant impacts on the working environment and natural environment.

4.5 Conclusion

This chapter has presented a brief overview of the Libyan iron and steel industry, waste survey and waste classification according to source. In addition, the environmental impacts of the Libyan iron and steel industry have been outlined. Work done so far will form the foundation of the next stage in the research programme.

5. CHAPTER FIVE

The Proposed Model for Environmental Impacts in the Steel Industry and Analysis

5.1 Introduction

This chapter develops a model related to the environmental impacts of the steel industry. Some important criteria are selected and some sub-criteria are chosen to help to clarifying and building the model by using the AHP.

As mentioned previously, the aim of this model is to investigate the most important environmental parameters and their importance in order to help to manage the environmental impacts of the steel industry.

Judgments/pairwise comparisons are used to derive priorities for the objectives with respect to the goal and for the alternatives with respect to each objective. Fifty questionnaires were distributed by the author when visiting Libya to some experienced managers and engineers in different plants in the Libyan iron and steel industry. Thirty valid responses were obtained, giving an overall response rate of 60%. In addition, sensitivity analysis was applied to see how the priority list would be affected when the weight allocated to each criterion changed.

5.2 The structure of the environmental impacts assessment model for the steel industry

Based on the literature review and the elements that are considered as waste (which were derived from the waste survey in the Libyan iron and steel industry), the potential environmental impacts of the steel industry were identified. Figure 5.1 illustrates the structure of the environmental impacts model for the steel industry.

The model consists of the overall goal, which is creating an environmental impact model for the steel industry, criteria and sub-criteria. The following set of 26 sub-criteria was accepted and grouped into four criteria to be able to illustrate the situation and make the analysis clear and understandable. These criteria and sub-criteria are as follows:

1. Resources consumption:
   - Raw materials consumption.
   - Auxiliary material consumption.
   - Energy consumption.
   - Fuel consumption.
2. Waste generated:
   - Emissions to air.
   - Emissions to water.
   - Solid waste.
   - Noise.
   - Odour.

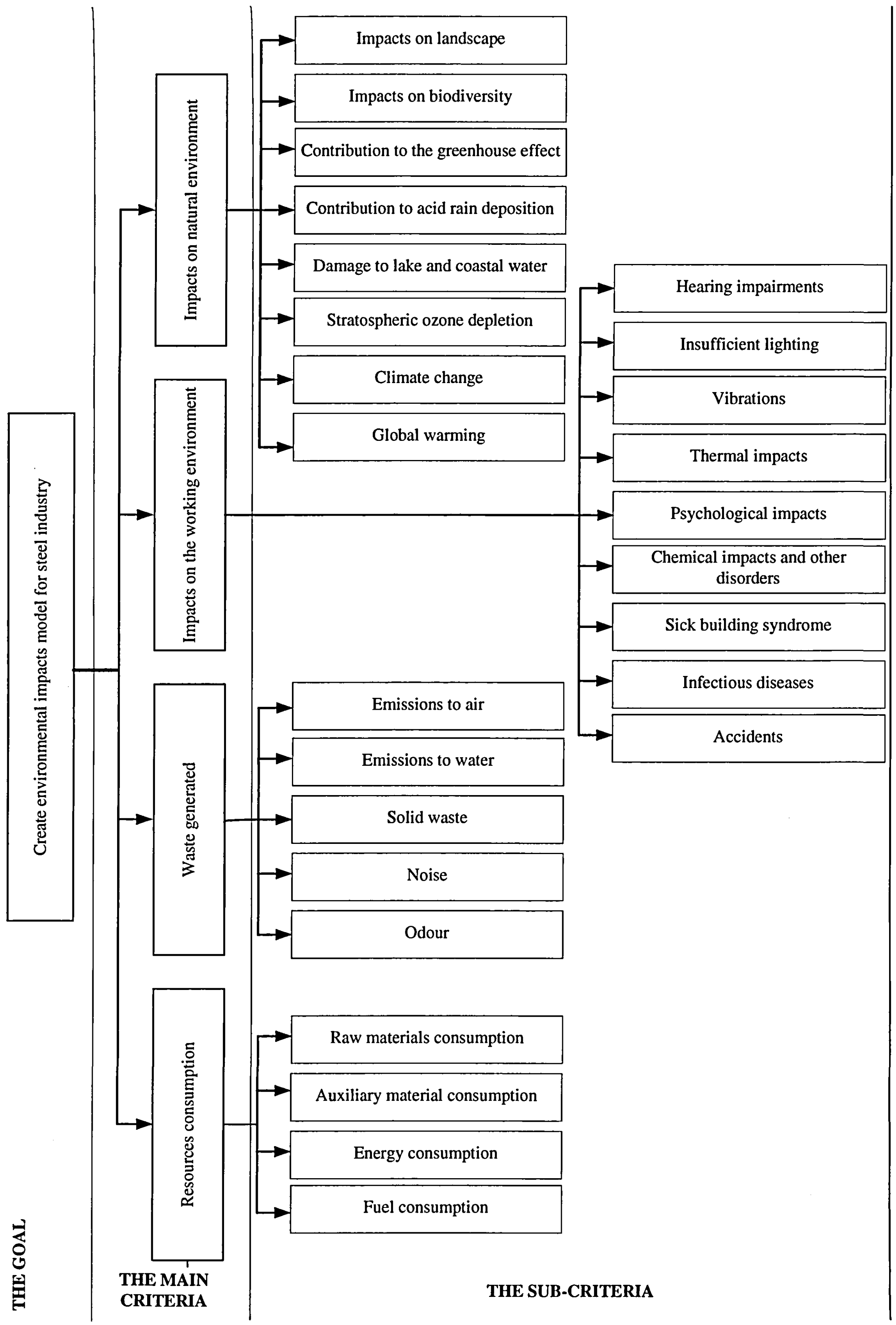

Figure 5.1 The structure of environmental impacts model for steel industry

3. Impacts on the working environment:
   - Hearing impairments.
   - Insufficient lighting.
   - Vibrations.
   - Thermal impacts.
   - Psychological impacts.
   - Chemical impacts and other disorders.
   - Sick building syndrome.
   - Infectious diseases.
   - Accidents.
4. Impacts on the natural environment:
   - Impacts on landscape.
   - Impacts on biodiversity.
   - Contribution to the greenhouse effect.
   - Contribution to acid rain deposition.
   - Damage to lake and coastal water.
   - Stratospheric ozone depletion.
   - Climate change.
   - Global warming.

These are the criteria and sub-criteria that could affect the decision-making process, which were derived from the literature review and the waste survey of the Libyan iron and steel industry. These sub-criteria will be ranked in descending order according to their score, to enable senior management to choose the highest score. It is expected that the highest would be chosen as an initial project, after which the rest could be scheduled for future consideration to help in evaluating and managing the environmental impacts.

5.3 The statistical analysis of the responses

After the completed questionnaires were returned, the author started to analyse the respondents' responses. A spreadsheet was created to calculate the frequencies of the respondents of different criteria and sub-criteria. Then the average of respondents' frequency using the geometric mean technique was calculated and rounded up to the nearest integer figure. The geometric mean may be more appropriate than the arithmetic mean (Expert Choice 2000).

5.4 Selecting a suitable software for analysis

According to the goal of this research work, which clearly concerns the decision-making process, several methods are available for use in the MCDM, along with a number of software packages in priority selection. Table 5.1 lists some of them.

Table 5.1 Some software used in priority selection

Product	Vendor	Address
Expert choice 2000	Expert Choice	www.expertchoice.com
Folio Priority System	Folio Technologies LLC	www.foliotechnologies.com
VIP Task Manager	VIP Quality Software	www.vip-qualitysoft.com
Genius Project	Genius Inside Inc.	www.geniusinside.com
Priority System Software	Lee Merkhofer Consulting	www.prioritysystem.com

The software Expert Choice 2000, which is based on AHP, is one of the most popular MCDM methods. The AHP method was introduced by Professor Thomas Saaty (Saaty 1980, Saaty 1994, Saaty and Vargas 2000) as a multi-criteria decision support methodology and it has been widely used in practical decision making problems in a variety of fields. This decision-making method can help people set priorities and choose the best options by reducing complex decision problems to a system of hierarchies. Since its inception, it has evolved into several different variants and has been widely used to solve a broad range of multi-criteria decision problems (Vaidya and Kumar 2006).

The AHP has some advantages over some other methods, including the following:

- Unity - the AHP provides a single, easily understood, flexible model for a wide range of unstructured problems.
- Complexity - the AHP integrates deductive and systems approaches in solving complex problems.
- Interdependence - the AHP can deal with the interdependence of elements in a system and does not insist on linear thinking.
- Hierarchical structuring - the AHP reflects the natural tendency of the mind to sort elements of a system into different levels and to group similar elements in each level.
- Measurement - the AHP provides a scale for measuring intangibles and a method for establishing priorities.
- Consistency - the AHP tracks the logical consistency of judgements used in determining priorities.

- Synthesis - the AHP leads to an overall estimate of the desirability of each alternative.
- Trade-offs - the AHP takes into consideration the relative priorities of factors in a system and enables people to select the best alternative based on their goals.
- Judgment and consensus - the AHP does not insist on consensus but synthesises a representative outcome from diverse judgements.
- Process repetition - the AHP enables people to refine their definition of a problem and to improve their judgement and understanding through repetition.

Expert Choice gives the opportunity to hesitant people involved in group discussions to give their opinions and speak up when the discussion drifts from topic to topic. In addition, it is an ideal tool for generating group decision through a cohesive and rigorous process. Furthermore, it provides facilities for performing sensitivity analysis, whereby decision makers can check the sensitivity of their judgements on the overall priorities of contractors by trying different values for their comparison judgements (Al-Harbi 2001).

Sloane et al. (2003) determined many features of Expert Choice 2000 implementation of AHP, such as that it provides a mixture of graphic tools that supplement the numerical computations and it uses a graphical user interface for model development. This allows easy revision of the model's structure during discussions, so that the participants can actually see the impact of their comments.

Sloane et al. (2003) also documented that, it includes integrated sensitivity analysis tools to help interpret how changes on the weights of the criteria or changes on the performance values of the alternatives could affect the ranking results of the decision problems. We needed a methodology that is well supported with powerfully developed software conducive to real-life applications easily understandable by the managers. AHP would be appropriate whenever a goal is clearly stated and a set of relevant criteria and alternatives are available.

Based on the above AHP was chosen for this research as a tool for priority selection of environmental impacts of the steel industry according to their importance, involving multiple criteria as well as expert opinion. The following sections present how the Expert Choice 2000 was used to work out the priority selection (Sloane et al. 2003).

5.5 Building the model using the AHP

Once the environmental impacts for steel industry are determined as criteria and sub-criteria and the statistical analysis of the responses are calculated, data is entered into the AHP software. The AHP software can build the model or the tree view of the model. Figure 5.2 shows the hierarchy block diagram of the environmental impacts for the steel industry that are applied for priority selection, and figure 5.3 shows the environmental impacts model for the steel industry.

Once the model is built, the next step in the modelling process that the AHP software provides is to make judgments/pairwise comparisons to derive priorities for the objectives with respect to the goal and for the alternatives with respect to each objective. This step is one of the major strengths of the AHP and Expert Choice. Pairwise comparison is used to derive accurate ratio scale priorities, as opposed to using traditional approaches of "assigning weights" which can be difficult to justify. A judgment expresses the strength of importance, preference or likelihood of one element over another. As mentioned previously, fifty questionnaires were distributed by the author to some experienced managers and engineers in different plants in the Libyan iron and steel industry. Thirty valid responses were obtained, giving an overall response rate of 60%. Figure 5.4 is a pairwise comparison that shows experts' judgments.

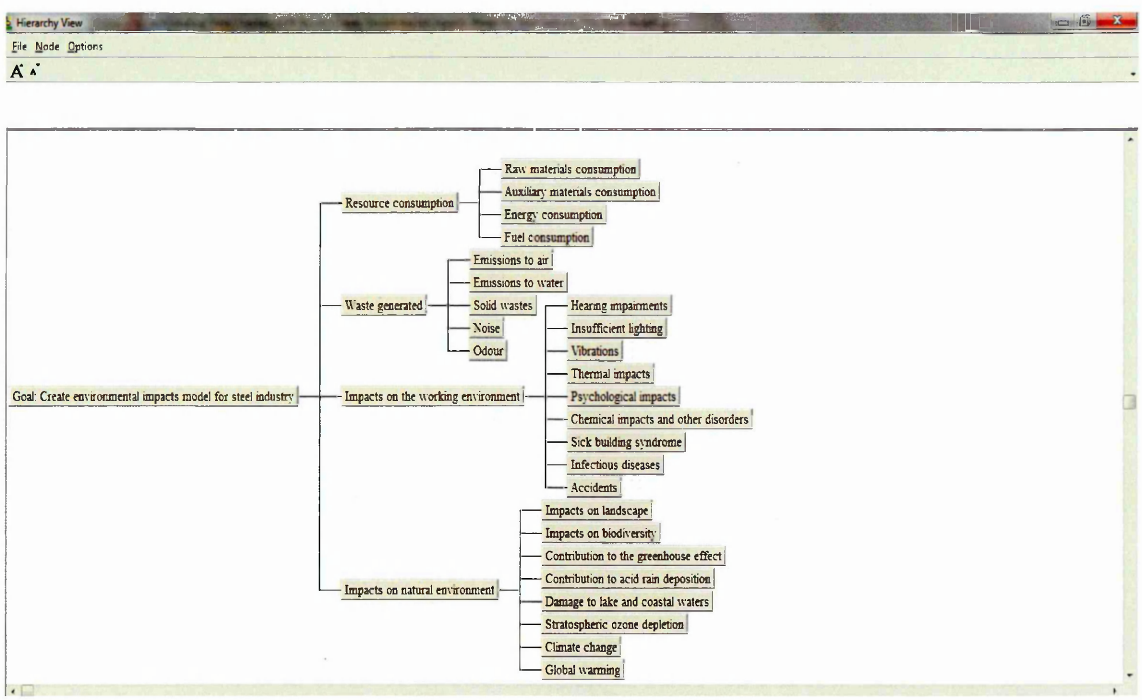

Figure 5.2 The hierarchy block diagram of environmental impacts for steel industry (produced by AHP).

Model Name: Create Environmental Impacts Model for Steel Industry

Treeview

- Goal: Create environmental impacts model for steel industry
  - Resource consumption (L: .127 G: .127)
    - Raw materials consumption (L: .286 G: .036)
    - Auxiliary materials consumption (L: .143 G: .018)
    - Energy consumption (L: .286 G: .036)
    - Fuel consumption (L: .286 G: .036)
  - Waste generated (L: .280 G: .280)
    - Emissions to air (L: .361 G: .101)
    - Emissions to water (L: .272 G: .076)
    - Solid wastes (L: .173 G: .048)
    - Noise (L: .097 G: .027)
    - Odour (L: .097 G: .027)
  - Impacts on the working environment (L: .312 G: .312)
    - Hearing impairments (L: .083 G: .026)
    - Insufficient lighting (L: .069 G: .022)
    - Vibrations (L: .062 G: .019)
    - Thermal impacts (L: .106 G: .033)
    - Psychological impacts (L: .093 G: .029)
    - Chemical impacts and other disorders (L: .139 G: .043)
    - Sick building syndrome (L: .062 G: .019)
    - Infectious diseases (L: .176 G: .055)
    - Accidents (L: .208 G: .065)
  - Impacts on natural environment (L: .280 G: .280)
    - Impacts on landscape (L: .094 G: .026)
    - Impacts on biodiversity (L: .085 G: .024)
    - Contribution to the greenhouse effect (L: .077 G: .022)
    - Contribution to acid rain deposition (L: .122 G: .034)
    - Damage to lake and coastal waters (L: .170 G: .048)
    - Stratospheric ozone depletion (L: .155 G: .043)
    - Climate change (L: .155 G: .043)
    - Global warming (L: .143 G: .040)

Figure 5.3 The environmental impacts model for steel industry

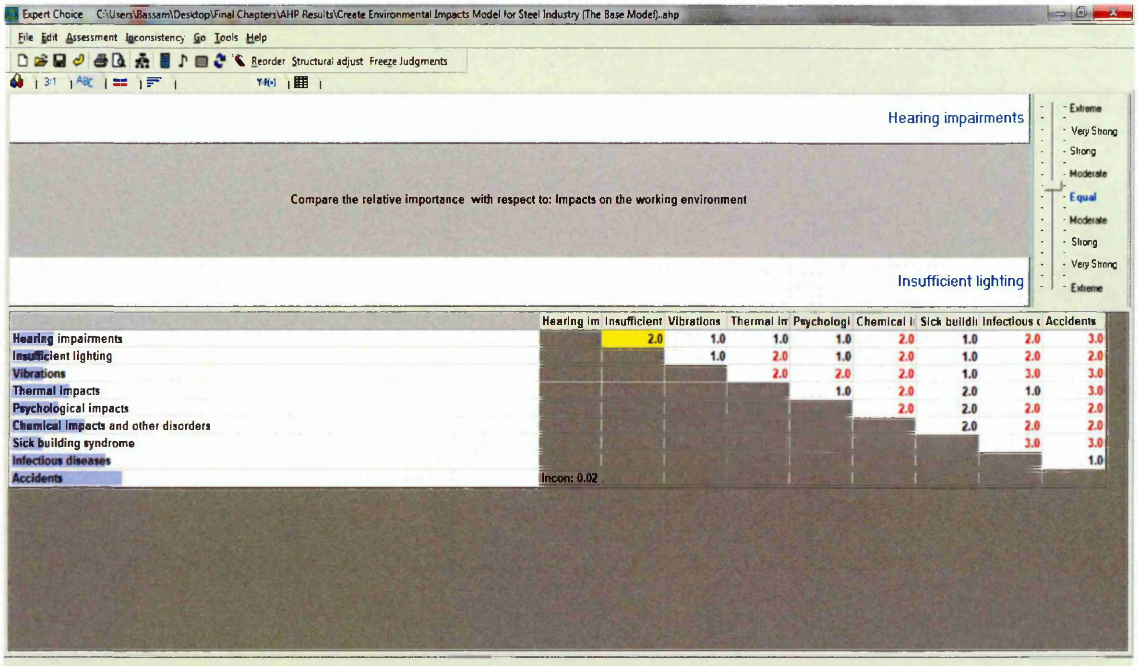

Figure 5.4 Pairwise comparison example.

Once all judgments (pairwise comparisons of alternatives to peers relative to the objectives and the objectives relative to the goal) have been made and priorities have been calculated, a synthesis is automatically performed to produce a report that includes a detailed ranking of each criterion (criteria weight and the criteria significance). The synthesis cannot be completed if any of the pairwise comparisons have an inconsistency greater than ten percent (Expert Choice 2000). In general, a consistency ratio of 0.10 or less is considered acceptable. If the value is higher, the judgements may not be reliable and have to be elicited again (Ramanathan 2001). In this study, consistency ratio is less than 0.1. This indicates that the comparisons of criteria were perfectly consistent and the relative weights were suitable for use in the suitability analysis.

In this research work the AHP is used to determine the most important environmental impacts of the steel industry. The synthesis was conducted using the distributive mode. This mode distributes the priorities of each covering objective among all alternatives, therefore dividing its global priorities proportionately to the priorities the alternatives beneath it. This method is used when all alternatives matter. Figure 5.5 shows the priorities of main criteria with respect to the goal. The reader could note that the impacts of steel industry on the working environment have a value of 0.312, the highest significant weight. The waste generated and impacts on the natural environment both have a value of 0.280, the second-highest. The resource consumption is the last of all, with a value of 0.127.

Table 5.2 The weight of the main criteria with respect to the goal

Criteria name	Weight %
Resources consumption	0.1276785
Waste generated	0.2803571
Impacts on the working environment	0.3116071
Impacts on natural environment	0.2803571
Inconsistency = 0.00776	

Figure 5.5 The priorities of the main criteria with respect to the goal

In addition, findings from the use of this method highlighted the importance of emissions to air, emissions to water, accident, infectious diseases, solid waste and damage to lake and coastal waters, with weights of 0.101, 0.076, 0.065, 0.055, 0.048 and 0.048 respectively (Table 5.3). Other environmental impacts mentioned in this study are less important. Figure 5.6 shows the importance rankings of the environmental impacts of steel industry obtained through pairwise comparisons with respect to the goal.

Table 5.3 The priorities of the sub-criteria.

Rank	Sub-criterion	Weight %
1	Emissions to air	10.1
2	Emissions to water	7.6
3	Accidents	6.5
4	Infectious diseases	5.5
5	Solid waste	4.8
6	Damage to lake and coastal water	4.8
7	Stratospheric ozone depletion	4.3
8	Climate change	4.3
9	Chemical impacts and other disorders	4.3
10	Global warming	4.0
11	Raw materials consumption	3.6
12	Energy consumption	3.6
13	Fuels consumption	3.6
14	Contribution to acid rain deposition	3.4
15	Thermal impacts	3.3
16	Psychological impacts	2.9
17	Noise	2.7
18	Odour	2.7
19	Impacts on landscape	2.6
20	Hearing impairments	2.6
21	Impacts on biodiversity	2.4
22	Insufficient lighting	2.2
23	Contribution to the greenhouse effect	2.2
24	Vibrations	1.9
25	Sick building syndrome	1.9
26	Auxiliary materials consumption	1.8

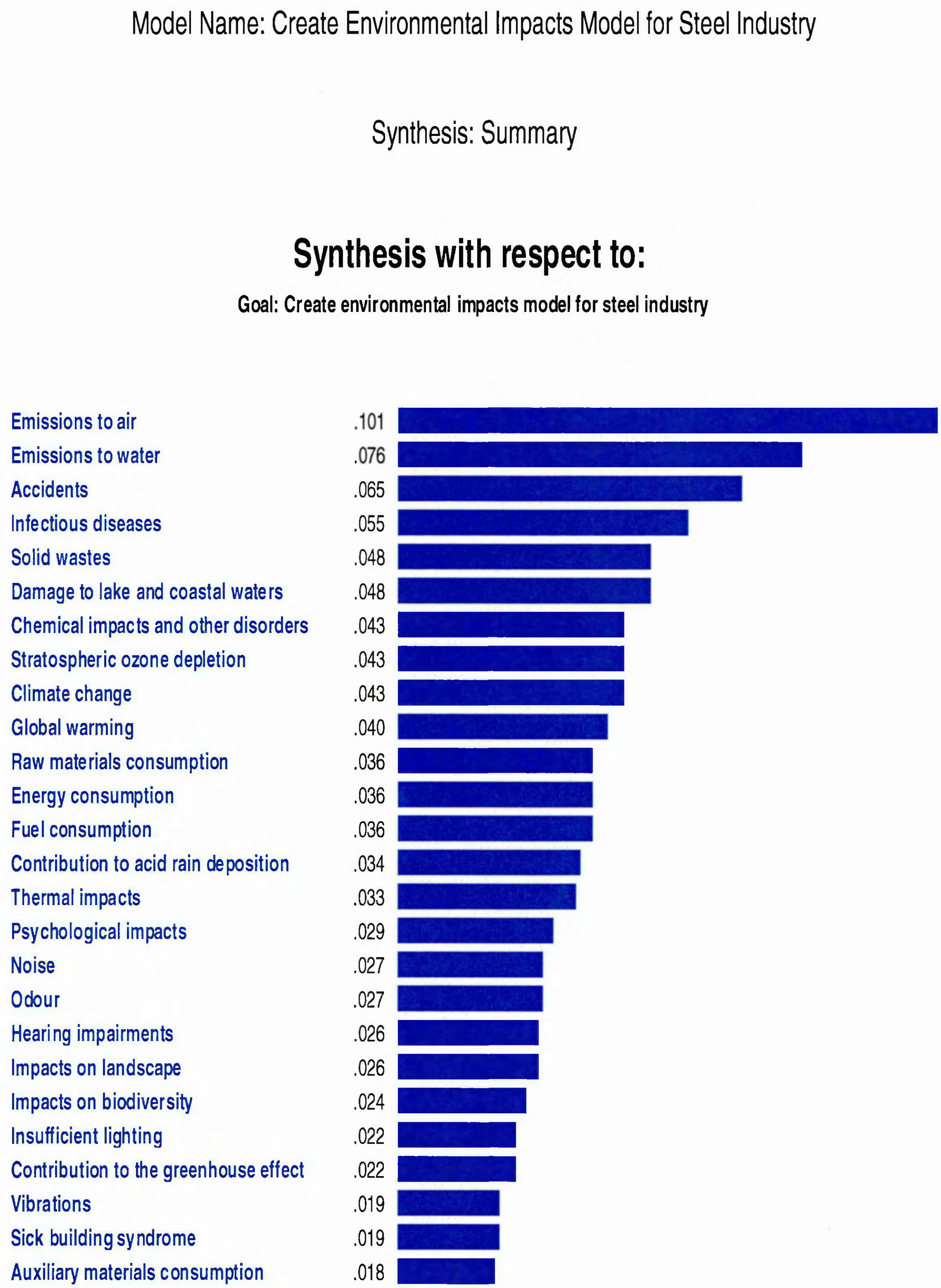

Figure 5.6 Synthesis with respect to the goal

5.6 Sensitivity analysis

Usually, a sensitivity analysis aims to examine how changes in the weights of the criteria or changes in the performance values of the alternatives could affect the ranking results of the decision problems. Sensitivity analysis is used to investigate the sensitivity of the alternatives to changes in the priorities of the objectives. There are five types of sensitivity analysis available within Expert Choice: performance, dynamic, gradient, two-dimensional plot (2-D plot), and head-to-head.

Sensitivity analysis was applied to see how the priority list will be affected when the weight allocated to each criterion is changed. As shown in figure 5.7, the results indicated that emissions to air have the highest environmental impact of the steel industry, with weight of 10.1%, while auxiliary materials consumption is the lowest environmental impact of the steel industry, with weight of 1.8%.

A series of sensitivity analyses were conducted to investigate the impact of changing the priority of the criteria on the alternatives' ranking. Dynamic sensitivity of Expert Choice was ascertained to see how realistic the final outcome is. Dynamic sensitivity analysis is used to dynamically change the priorities of the criteria to determine how these changes affect the priorities of the alternative choices. The impact of changing the priority of four main criteria on overall results was investigated.

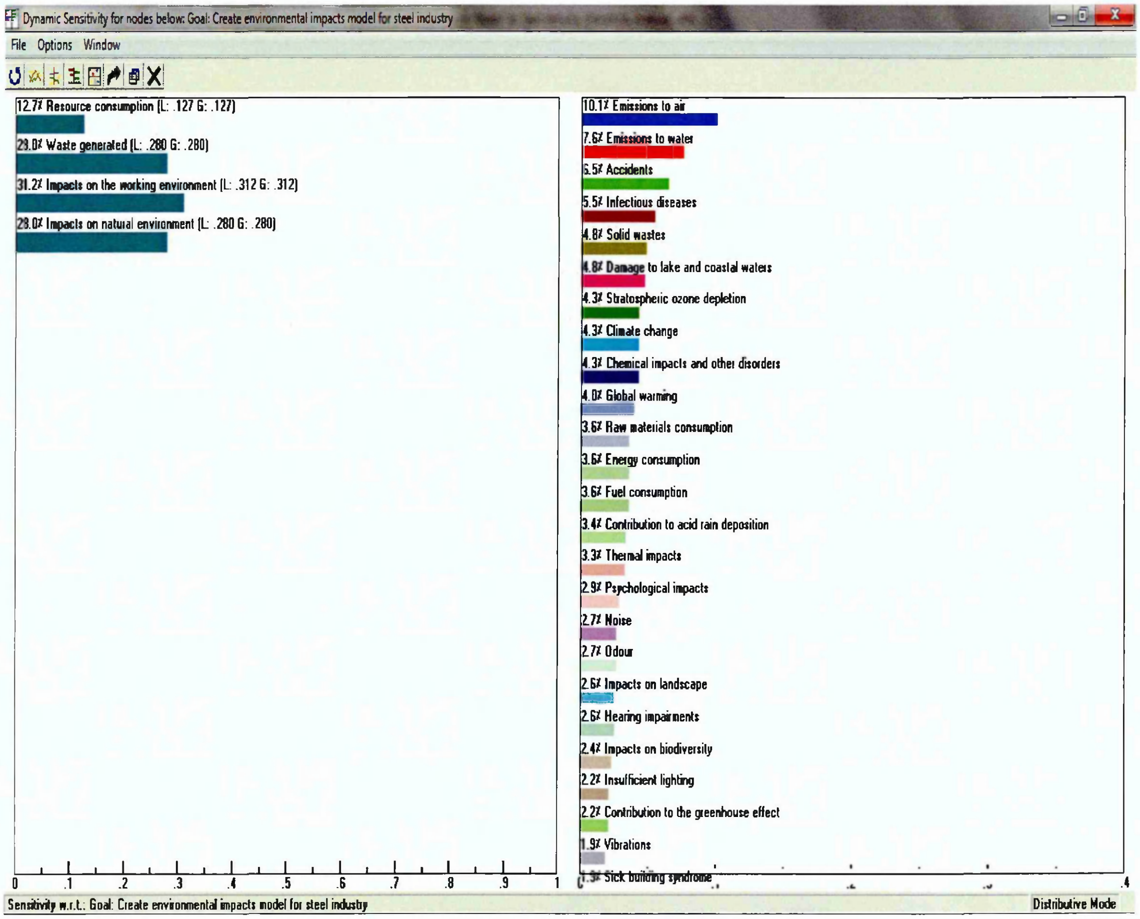

Figure 5.7 Original sensitivity analysis

5.6.1 Sensitivity analysis when the weight of resource consumption was raised

A series of sensitivity analyses were applied to see how the priority list was affected when the weight allocated to resource consumption was raised. Table 5.4 illustrates the priorities of the criteria with respect to the goal and the sensitivity analysis when the weight of resource consumption was raised by 7%. Table 5.5 illustrates the priorities of the criteria with respect to the goal and the sensitivity analysis when the weight of resource consumption was raised by 8%.

Table 5.4 The priorities of different criteria after the weight of resource consumption was raised by 7%.

<table>
<tr><td rowspan="27">Resource Consumption 12.8%

Waste Generated 28%

Impacts on the working environment 31.2%

Impacts on natural environment 28%</td><td>Rank</td><td>Environmental impacts of steel industry</td><td>Weight %</td></tr>
<tr><td>1</td><td>Emissions to air</td><td>10.0</td></tr>
<tr><td>2</td><td>Emissions to water</td><td>7.6</td></tr>
<tr><td>3</td><td>Accidents</td><td>6.4</td></tr>
<tr><td>4</td><td>Infectious diseases</td><td>5.5</td></tr>
<tr><td>5</td><td>Solid waste</td><td>4.8</td></tr>
<tr><td>6</td><td>Damage to lake and coastal water</td><td>4.7</td></tr>
<tr><td>7</td><td>Stratospheric ozone depletion</td><td>4.3</td></tr>
<tr><td>8</td><td>Climate change</td><td>4.3</td></tr>
<tr><td>9</td><td>Chemical impacts and other disorders</td><td>4.3</td></tr>
<tr><td>10</td><td>Global warming</td><td>4.0</td></tr>
<tr><td>11</td><td>Raw materials consumption</td><td>3.9</td></tr>
<tr><td>12</td><td>Energy consumption</td><td>3.9</td></tr>
<tr><td>13</td><td>Fuels consumption</td><td>3.9</td></tr>
<tr><td>14</td><td>Contribution to acid rain deposition</td><td>3.4</td></tr>
<tr><td>15</td><td>Thermal impacts</td><td>3.3</td></tr>
<tr><td>16</td><td>Psychological impacts</td><td>2.9</td></tr>
<tr><td>17</td><td>Noise</td><td>2.7</td></tr>
<tr><td>18</td><td>Odour</td><td>2.7</td></tr>
<tr><td>19</td><td>Impacts on landscape</td><td>2.6</td></tr>
<tr><td>20</td><td>Hearing impairments</td><td>2.6</td></tr>
<tr><td>21</td><td>Impacts on biodiversity</td><td>2.4</td></tr>
<tr><td>22</td><td>Insufficient lighting</td><td>2.1</td></tr>
<tr><td>23</td><td>Contribution to the greenhouse effect</td><td>2.1</td></tr>
<tr><td>24</td><td>Vibrations</td><td>1.9</td></tr>
<tr><td>25</td><td>Sick building syndrome</td><td>1.9</td></tr>
<tr><td>26</td><td>Auxiliary materials consumption</td><td>1.9</td></tr>
</table>

Changes in the weight are highlighted.

Table 5.5 The priorities of different criteria after the weight of resource consumption was raised by 8%.

	Rank	Environmental impacts of steel industry	Weight %
Resource Consumption 13.7% Waste Generated 27.7% Impacts on the working environment 30.9% Impacts on natural environment 27.7%	1	Emissions to air	10.0
	2	Emissions to water	7.5
	3	Accidents	6.4
	4	Infectious diseases	5.4
	5	Solid waste	4.8
	6	Damage to lake and coastal water	4.7
	7	Stratospheric ozone depletion	4.3
	8	Climate change	4.3
	9	Chemical impacts and other disorders	4.3
	10	Global warming	4.0
	11	Raw materials consumption	3.9
	12	Energy consumption	3.9
	13	Fuels consumption	3.9
	14	Contribution to acid rain deposition	3.4
	15	Thermal impacts	3.3
	16	Psychological impacts	2.9
	17	Noise	2.7
	18	Odour	2.7
	19	Impacts on landscape	2.6
	20	Hearing impairments	2.6
	21	Impacts on biodiversity	2.4
	22	Insufficient lighting	2.1
	23	Contribution to the greenhouse effect	2.1
	24	Vibrations	1.9
	25	Sick building syndrome	1.9
	26	Auxiliary materials consumption	2.0

Changes in the weight are highlighted.

As shown in figure 5.8, the sensitivity analysis indicated that the ranking of the alternatives remained stable when the weight of resource consumption was raised by 7%, while the ranking of some alternatives (vibrations, sick building syndrome and auxiliary materials consumption) was a little sensitive to changes in the importance of opportunities when the weight of resource consumption was raised by 8%.

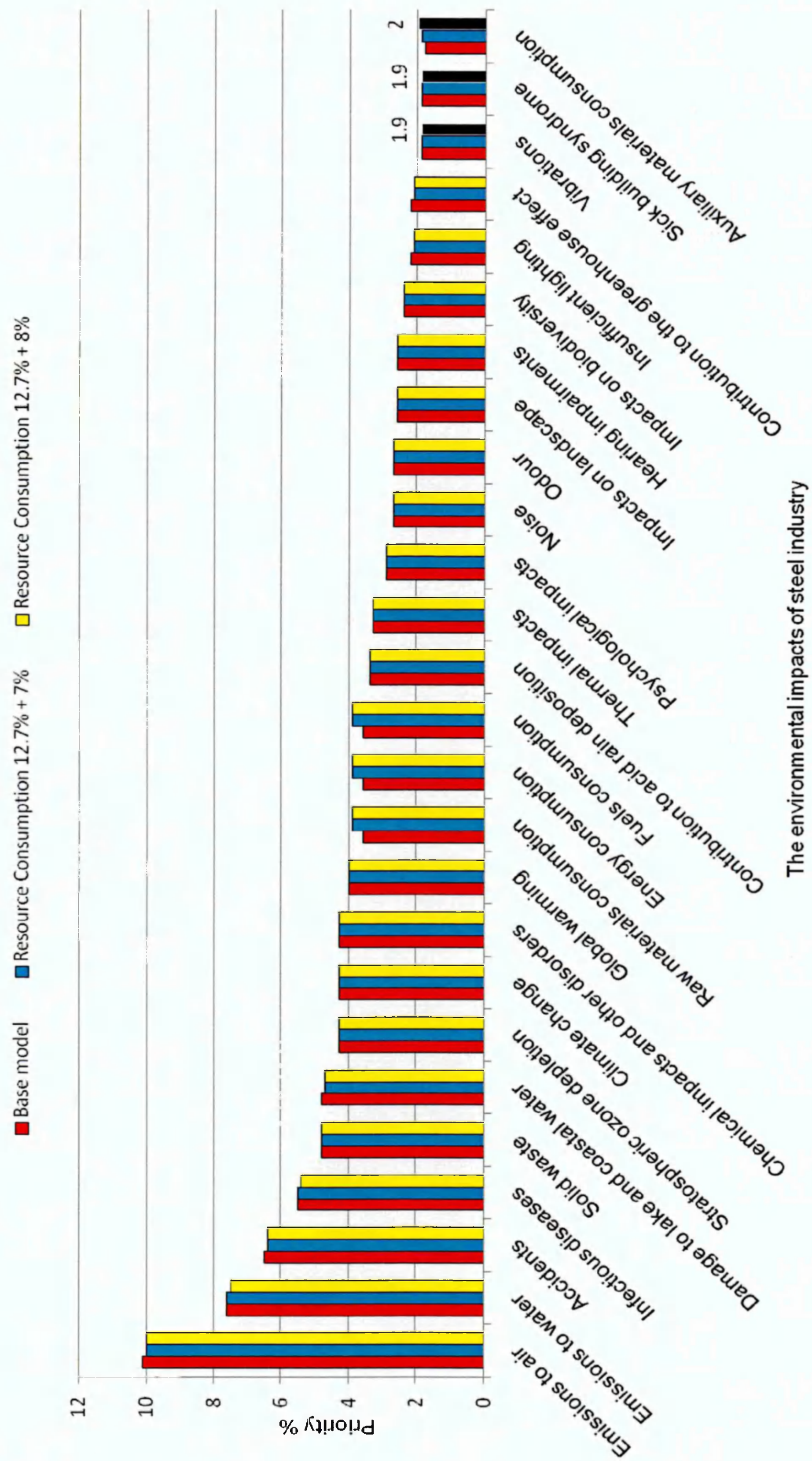

Figure 5.8 Sensitivity analysis when the weight of resource consumption was raised by 7 and 8%

5.6.2 Sensitivity analysis when the weight of resource consumption was reduced

A series of sensitivity analyses was applied to see how the priority list was affected when the weight allocated to resource consumption was reduced. Table 5.6 illustrates the priorities of the criteria with respect to the goal and the sensitivity analysis when the weight of resource consumption was reduced by 4%. Table 5.7 illustrates the priorities of the criteria with respect to the goal and the sensitivity analysis when the weight of resource consumption was reduced by 5%.

The sensitivity analysis indicated that when the weight of resource consumption was reduced by 4%, the ranking of the alternatives remained stable in all cases, while when the weight of resource consumption was reduced by 5% the ranking of some alternatives (raw materials consumption, energy consumption, fuels consumption and contribution to acid rain deposition) was a little sensitive to changes in the importance of opportunities, as shown in figure 5.9.

Table 5.6 The priorities of different criteria after the weight of resource consumption was reduced by 4%.

	Rank	Environmental impacts of steel industry	Weight %
Resource Consumption 12.2% Waste Generated 28.2% Impacts on the working environment 31.4% Impacts on natural environment 28.2%	1	Emissions to air	10.2
	2	Emissions to water	7.7
	3	Accidents	6.5
	4	Infectious diseases	5.5
	5	Solid waste	4.9
	6	Damage to lake and coastal water	4.8
	7	Stratospheric ozone depletion	4.4
	8	Climate change	4.4
	9	Chemical impacts and other disorders	4.4
	10	Global warming	4.0
	11	Raw materials consumption	3.5
	12	Energy consumption	3.5
	13	Fuels consumption	3.5
	14	Contribution to acid rain deposition	3.4
	15	Thermal impacts	3.3
	16	Psychological impacts	2.9
	17	Noise	2.7
	18	Odour	2.7
	19	Impacts on landscape	2.6
	20	Hearing impairments	2.6
	21	Impacts on biodiversity	2.4
	22	Insufficient lighting	2.2
	23	Contribution to the greenhouse effect	2.2
	24	Vibrations	1.9
	25	Sick building syndrome	1.9
	26	Auxiliary materials consumption	1.7

Changes in the weight are highlighted.

Table 5.7 The priorities of different criteria after the weight of resource consumption was reduced by 5%.

	Rank	Environmental impacts of steel industry	Weight %
Resource Consumption 12% Waste Generated 28.3% Impacts on the working environment 31.5% Impacts on natural environment 28.3%	1	Emissions to air	10.2
	2	Emissions to water	7.7
	3	Accidents	6.6
	4	Infectious diseases	5.5
	5	Solid waste	4.9
	6	Damage to lake and coastal water	4.8
	7	Stratospheric ozone depletion	4.4
	8	Climate change	4.4
	9	Chemical impacts and other disorders	4.4
	10	Global warming	4.0
	11	Raw materials consumption	3.4
	12	Energy consumption	3.4
	13	Fuels consumption	3.4
	14	Contribution to acid rain deposition	3.5
	15	Thermal impacts	3.3
	16	Psychological impacts	2.9
	17	Noise	2.7
	18	Odour	2.7
	19	Impacts on landscape	2.6
	20	Hearing impairments	2.6
	21	Impacts on biodiversity	2.4
	22	Insufficient lighting	2.2
	23	Contribution to the greenhouse effect	2.2
	24	Vibrations	2.0
	25	Sick building syndrome	2.0
	26	Auxiliary materials consumption	1.7

Changes in the weight and in the priority are highlighted.

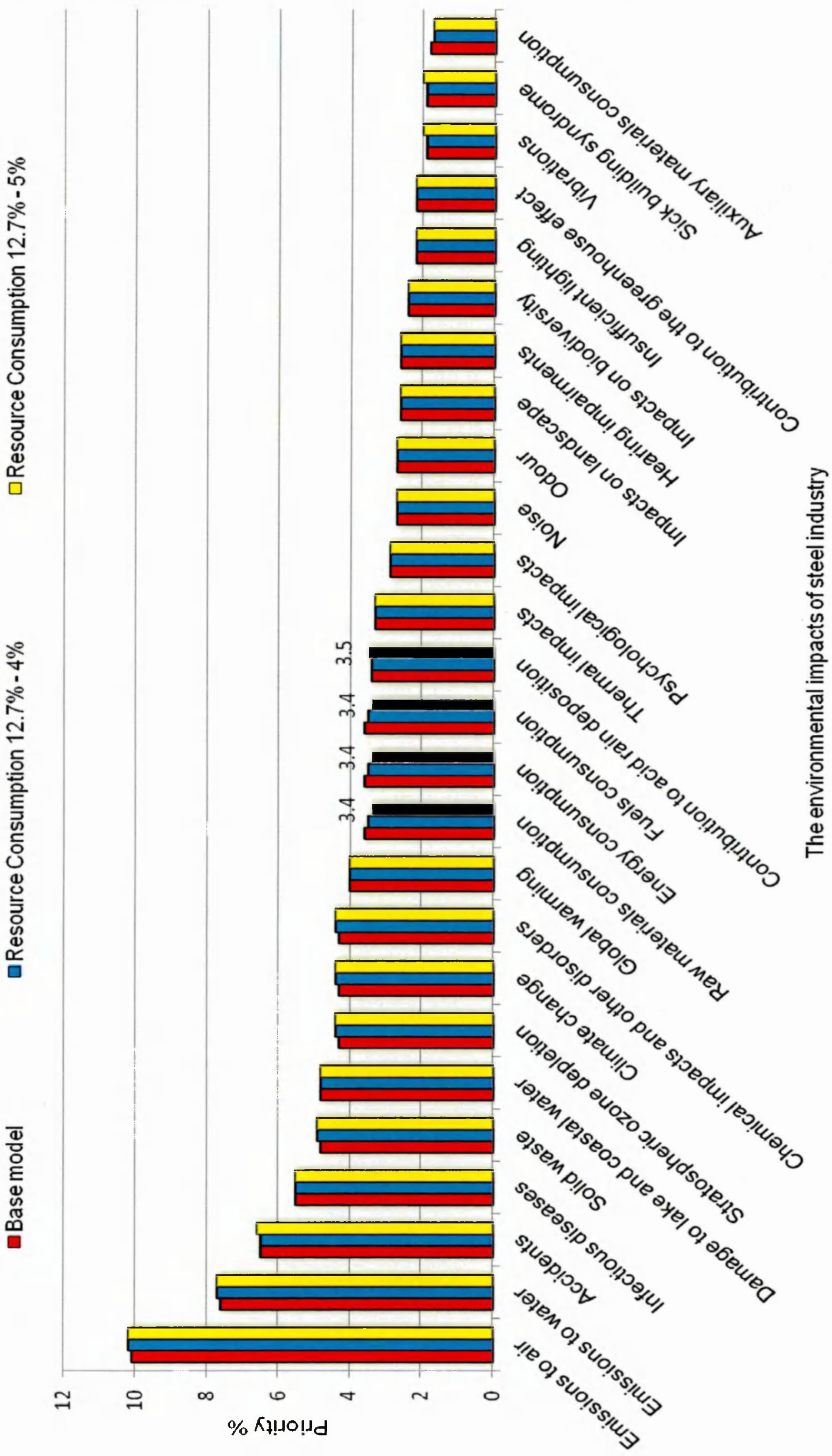

Figure 5.9 Sensitivity analysis when the weight of resource consumption was reduced.

■ Changes in the priority are highlighted

5.6.3 Sensitivity analysis when the weight of waste generated was raised

Table 5.8 illustrates the priorities of the criteria with respect to the goal and the sensitivity analysis when the weight of waste generated was raised by 4%. Table 5.9 illustrates the priorities of the criteria with respect to the goal and the sensitivity analysis when the weight of waste generated was raised by 5%.

The sensitivity analysis indicated that when the weight of waste generated was raised by 4%, the ranking of the alternatives remained stable in all cases, while the ranking of some alternatives (psychological impacts, noise and odour) was a little sensitive to changes in the importance of opportunities when the weight of waste generated was raised by 5%, as shown in figure 5.10.

Table 5.8 The priorities of different criteria after the weight of waste generated was raised by 4%.

	Rank	Environmental impacts of steel industry	Weight %
Resource Consumption 12.5% Waste Generated 29.1% Impacts on the working environment 30.7% Impacts on natural environment 27.6%	1	Emissions to air	10.5
	2	Emissions to water	7.9
	3	Accidents	6.4
	4	Infectious diseases	5.4
	5	Solid waste	5.0
	6	Damage to lake and coastal water	4.7
	7	Stratospheric ozone depletion	4.3
	8	Climate change	4.3
	9	Chemical impacts and other disorders	4.3
	10	Global warming	4.0
	11	Raw materials consumption	3.6
	12	Energy consumption	3.6
	13	Fuels consumption	3.6
	14	Contribution to acid rain deposition	3.4
	15	Thermal impacts	3.3
	16	Psychological impacts	2.9
	17	Noise	2.8
	18	Odour	2.8
	19	Impacts on landscape	2.6
	20	Hearing impairments	2.6
	21	Impacts on biodiversity	2.3
	22	Insufficient lighting	2.1
	23	Contribution to the greenhouse effect	2.1
	24	Vibrations	1.9
	25	Sick building syndrome	1.9
	26	Auxiliary materials consumption	1.8

Changes in the weight and in the priority are highlighted.

Table 5.9 The priorities of different criteria after the weight of waste generated was raised by 5%.

	Rank	Environmental impacts of steel industry	Weight %
	1	Emissions to air	10.6
	2	Emissions to water	8.0
	3	Accidents	6.4
	4	Infectious diseases	5.4
	5	Solid waste	5.1
Resource Consumption 12.5%	6	Damage to lake and coastal water	4.7
	7	Stratospheric ozone depletion	4.3
	8	Climate change	4.3
	9	Chemical impacts and other disorders	4.2
Waste Generated 29.4%	10	Global warming	3.9
	11	Raw materials consumption	3.6
	12	Energy consumption	3.6
	13	Fuels consumption	3.6
Impacts on the working environment 30.6%	14	Contribution to acid rain deposition	3.4
	15	Thermal impacts	3.3
	16	Psychological impacts	2.8
	17	Noise	2.9
	18	Odour	2.9
Impacts on natural environment 27.5%	19	Impacts on landscape	2.6
	20	Hearing impairments	2.6
	21	Impacts on biodiversity	2.3
	22	Insufficient lighting	2.1
	23	Contribution to the greenhouse effect	2.1
	24	Vibrations	1.9
	25	Sick building syndrome	1.9
	26	Auxiliary materials consumption	1.8

Changes in the weight and in the priority are highlighted.

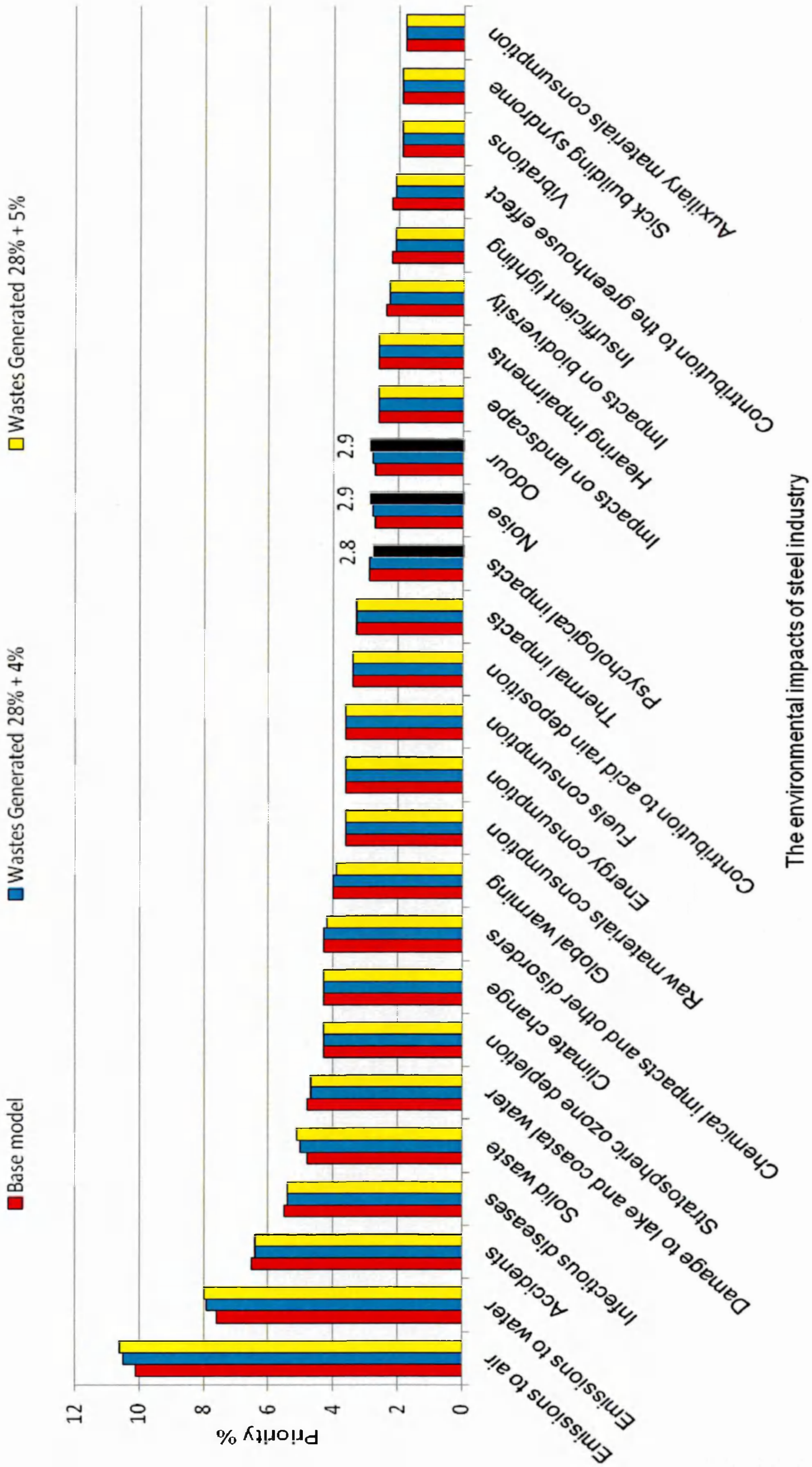

Figure 5.10 Sensitivity analysis when the weight of waste generated was raised.

■ Changes in the priority are highlighted

5.6.4 Sensitivity analysis when the weight of waste generated was reduced

Table 5.10 illustrates the priorities of the criteria with respect to the goal and the sensitivity analysis when the weight of waste generated was reduced by 1%. Table 5.11 illustrates the priorities of the criteria with respect to the goal and the sensitivity analysis when the weight of waste generated was reduced by 2%.

As shown in figure 5.11, the ranking of the alternatives remained stable when the weight of waste generated was reduced by 1%, while the ranking of the alternatives was a little sensitive to changes in the importance of opportunities when the weight of waste generated was reduced by 2%. It is clear that the ranking of damage to lake and coastal water switches with the ranking of solid waste.

Table 5.10 The priorities of different criteria after the weight of waste generated was reduced by 1%.

<table>
<tr><th></th><th>Rank</th><th>Environmental impacts of steel industry</th><th>Weight %</th></tr>
<tr><td rowspan="26">Resource Consumption 12.8%

Waste Generated 27.8%

Impacts on the working environment 31.3%

Impacts on natural environment 28.1%</td><td>1</td><td>Emissions to air</td><td>10.0</td></tr>
<tr><td>2</td><td>Emissions to water</td><td>7.6</td></tr>
<tr><td>3</td><td>Accidents</td><td>6.5</td></tr>
<tr><td>4</td><td>Infectious diseases</td><td>5.5</td></tr>
<tr><td>5</td><td>Solid waste</td><td>4.8</td></tr>
<tr><td>6</td><td>Damage to lake and coastal water</td><td>4.8</td></tr>
<tr><td>7</td><td>Stratospheric ozone depletion</td><td>4.4</td></tr>
<tr><td>8</td><td>Climate change</td><td>4.4</td></tr>
<tr><td>9</td><td>Chemical impacts and other disorders</td><td>4.3</td></tr>
<tr><td>10</td><td>Global warming</td><td>4.0</td></tr>
<tr><td>11</td><td>Raw materials consumption</td><td>3.6</td></tr>
<tr><td>12</td><td>Energy consumption</td><td>3.6</td></tr>
<tr><td>13</td><td>Fuels consumption</td><td>3.6</td></tr>
<tr><td>14</td><td>Contribution to acid rain deposition</td><td>3.4</td></tr>
<tr><td>15</td><td>Thermal impacts</td><td>3.3</td></tr>
<tr><td>16</td><td>Psychological impacts</td><td>2.9</td></tr>
<tr><td>17</td><td>Noise</td><td>2.7</td></tr>
<tr><td>18</td><td>Odour</td><td>2.7</td></tr>
<tr><td>19</td><td>Impacts on landscape</td><td>2.6</td></tr>
<tr><td>20</td><td>Hearing impairments</td><td>2.6</td></tr>
<tr><td>21</td><td>Impacts on biodiversity</td><td>2.4</td></tr>
<tr><td>22</td><td>Insufficient lighting</td><td>2.2</td></tr>
<tr><td>23</td><td>Contribution to the greenhouse effect</td><td>2.2</td></tr>
<tr><td>24</td><td>Vibrations</td><td>1.9</td></tr>
<tr><td>25</td><td>Sick building syndrome</td><td>1.9</td></tr>
<tr><td>26</td><td>Auxiliary materials consumption</td><td>1.8</td></tr>
</table>

Changes in the weight and in the priority are highlighted.

Table 5.11 The priorities of different criteria after the weight of waste generated was reduced by 2%.

	Rank	Environmental impacts of steel industry	Weight %
Resource Consumption 12.8% Waste Generated 27.5% Impacts on the working environment 31.5% Impacts on natural environment 28.3%	1	Emissions to air	9.9
	2	Emissions to water	7.5
	3	Accidents	6.6
	4	Infectious diseases	5.5
	5	Solid waste	4.7
	6	Damage to lake and coastal water	4.8
	7	Stratospheric ozone depletion	4.4
	8	Climate change	4.4
	9	Chemical impacts and other disorders	4.4
	10	Global warming	4.0
	11	Raw materials consumption	3.7
	12	Energy consumption	3.7
	13	Fuels consumption	3.7
	14	Contribution to acid rain deposition	3.5
	15	Thermal impacts	3.3
	16	Psychological impacts	2.9
	17	Noise	2.7
	18	Odour	2.7
	19	Impacts on landscape	2.6
	20	Hearing impairments	2.6
	21	Impacts on biodiversity	2.4
	22	Insufficient lighting	2.2
	23	Contribution to the greenhouse effect	2.2
	24	Vibrations	2.0
	25	Sick building syndrome	2.0
	26	Auxiliary materials consumption	1.8

Changes in the weight and in the priority are highlighted.

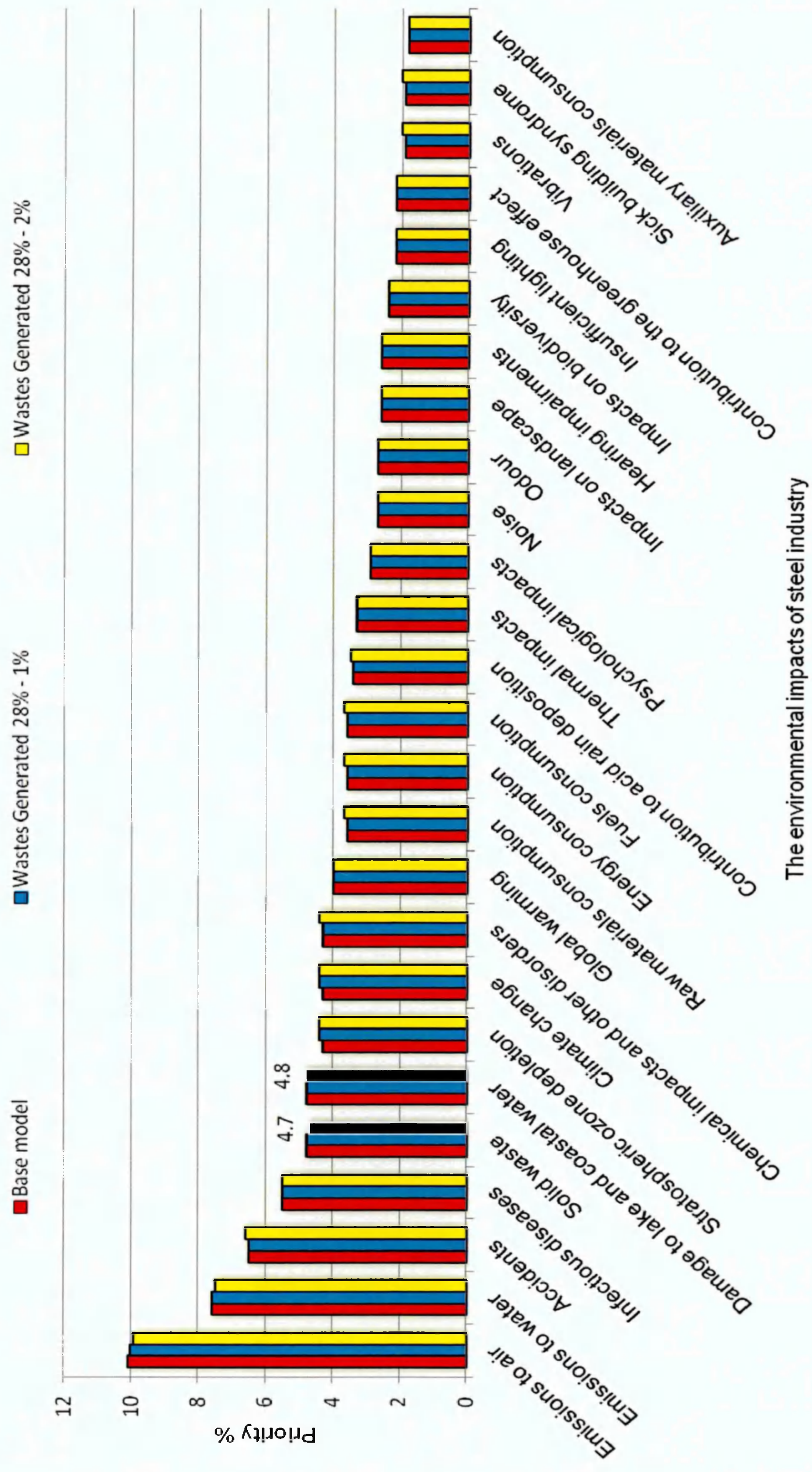

Figure 5.11 Sensitivity analysis when the weight of wastes generated was reduced.

■ Changes in the priority are highlighted

5.6.5 Sensitivity analysis when the weight of impacts on the working environment was raised

The sensitivity analysis was applied to see how the priority list was affected when the weight allocated to impacts on working environment was raised. Table 5.12 illustrates the priorities of the criteria with respect to the goal and the sensitivity analysis when the weight of impacts on working environment was raised by 1%. Table 5.13 illustrates the priorities of the criteria with respect to the goal and the sensitivity analysis when the weight of impacts on working environment was raised by 2%.

The sensitivity analysis indicated that when the weight of impacts on the working environment was raised by 1% the ranking of the alternatives remained stable, while the ranking of some alternatives (stratospheric ozone depletion, climate change, chemical impacts and other disorders, impacts on landscape and hearing impairments) was a little sensitive to changes in the importance of opportunities when the weight of impacts on the working environment was raised by 2% (figure 5.12).

Table 5.12 The priorities of different criteria after the weight of impacts on the working environment was raised by 1%.

<table>
<tr><th></th><th>Rank</th><th>Environmental impacts of steel industry</th><th>Weight %</th></tr>
<tr><td rowspan="26">Resource Consumption 12.7%

Waste Generated 27.9%

Impacts on the working environment 31.6%

Impacts on natural environment 27.9%</td><td>1</td><td>Emissions to air</td><td>10.1</td></tr>
<tr><td>2</td><td>Emissions to water</td><td>7.6</td></tr>
<tr><td>3</td><td>Accidents</td><td>6.6</td></tr>
<tr><td>4</td><td>Infectious diseases</td><td>5.6</td></tr>
<tr><td>5</td><td>Solid waste</td><td>4.8</td></tr>
<tr><td>6</td><td>Damage to lake and coastal water</td><td>4.7</td></tr>
<tr><td>7</td><td>Stratospheric ozone depletion</td><td>4.3</td></tr>
<tr><td>8</td><td>Climate change</td><td>4.3</td></tr>
<tr><td>9</td><td>Chemical impacts and other disorders</td><td>4.4</td></tr>
<tr><td>10</td><td>Global warming</td><td>4.0</td></tr>
<tr><td>11</td><td>Raw materials consumption</td><td>3.6</td></tr>
<tr><td>12</td><td>Energy consumption</td><td>3.6</td></tr>
<tr><td>13</td><td>Fuels consumption</td><td>3.6</td></tr>
<tr><td>14</td><td>Contribution to acid rain deposition</td><td>3.4</td></tr>
<tr><td>15</td><td>Thermal impacts</td><td>3.4</td></tr>
<tr><td>16</td><td>Psychological impacts</td><td>2.9</td></tr>
<tr><td>17</td><td>Noise</td><td>2.7</td></tr>
<tr><td>18</td><td>Odour</td><td>2.7</td></tr>
<tr><td>19</td><td>Impacts on landscape</td><td>2.6</td></tr>
<tr><td>20</td><td>Hearing impairments</td><td>2.6</td></tr>
<tr><td>21</td><td>Impacts on biodiversity</td><td>2.4</td></tr>
<tr><td>22</td><td>Insufficient lighting</td><td>2.2</td></tr>
<tr><td>23</td><td>Contribution to the greenhouse effect</td><td>2.2</td></tr>
<tr><td>24</td><td>Vibrations</td><td>2.0</td></tr>
<tr><td>25</td><td>Sick building syndrome</td><td>2.0</td></tr>
<tr><td>26</td><td>Auxiliary materials consumption</td><td>1.8</td></tr>
</table>

Changes in the weight and in the priority are highlighted.

Table 5.13 The priorities of different criteria after the weight of impacts on the working environment was raised by 2%.

	Rank	Environmental impacts of steel industry	Weight %
Resource Consumption 12.6% Waste Generated 27.8% Impacts on the working environment 31.9% Impacts on natural environment 27.8%	1	Emissions to air	10.0
	2	Emissions to water	7.6
	3	Accidents	6.6
	4	Infectious diseases	5.6
	5	Solid waste	4.8
	6	Damage to lake and coastal water	4.7
	7	Stratospheric ozone depletion	4.3
	8	Climate change	4.3
	9	Chemical impacts and other disorders	4.4
	10	Global warming	4.0
	11	Raw materials consumption	3.6
	12	Energy consumption	3.6
	13	Fuels consumption	3.6
	14	Contribution to acid rain deposition	3.4
	15	Thermal impacts	3.4
	16	Psychological impacts	3.0
	17	Noise	2.7
	18	Odour	2.7
	19	Impacts on landscape	2.6
	20	Hearing impairments	2.7
	21	Impacts on biodiversity	2.4
	22	Insufficient lighting	2.2
	23	Contribution to the greenhouse effect	2.1
	24	Vibrations	2.0
	25	Sick building syndrome	2.0
	26	Auxiliary materials consumption	1.8

Changes in the weight and in the priority are highlighted.

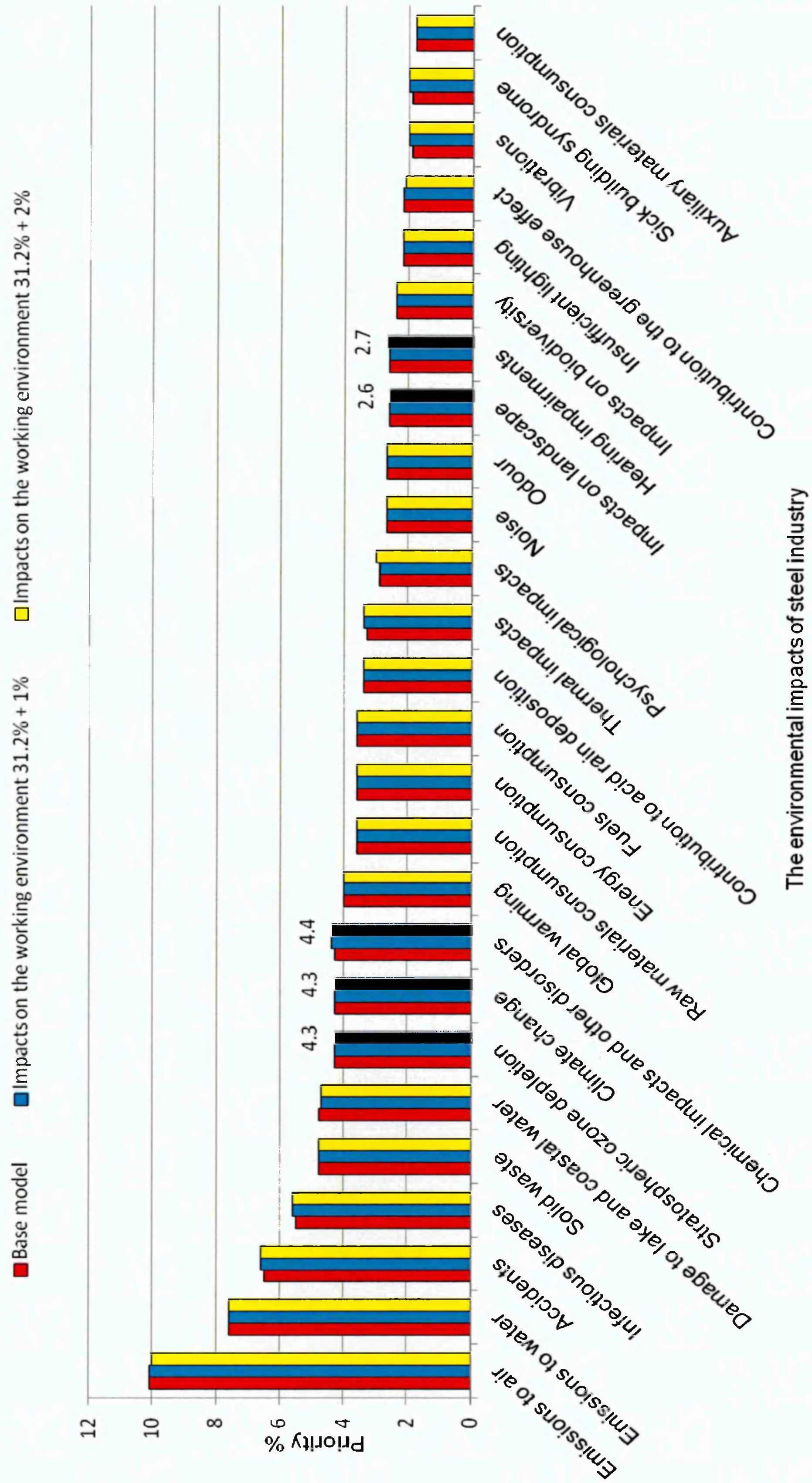

Figure 5.12 Sensitivity analysis when the weight of impacts on the working environment was raised.

■ Changes in the priority are highlighted

5.6.6 Sensitivity analysis when the weight of impacts on the working environment was reduced

Table 5.14 illustrates the priorities of the criteria with respect to the goal and the sensitivity analysis when the weight of impacts on the working environment was reduced by 1%. Table 5.15 illustrates the priorities of the criteria with respect to the goal and the sensitivity analysis when the weight of impacts on the working environment was reduced by 5%.

As shown in figure 5.13, when the weight of impacts on the working environment was reduced, the ranking of some alternatives was a little sensitive to changes in the importance of opportunities in all cases. The ranking of contribution to the greenhouse effect switches with the ranking of insufficient lighting when the weight of impacts on the working environment was reduced by 1, 2, 3 and 4%. In addition, the ranking of auxiliary materials consumption switches with the ranking of vibrations when the weight of impacts on the working environment was reduced by 5%.

Table 5.14 The priorities of different criteria after the weight of impacts on the working environment was reduced by 1%.

<table>
<tr><th></th><th>Rank</th><th>Environmental impacts of steel industry</th><th>Weight %</th></tr>
<tr><td rowspan="26">Resource Consumption 12.8%

Waste Generated 28.2%

Impacts on the working environment 30.8%

Impacts on natural environment 28.2%</td><td>1</td><td>Emissions to air</td><td>10.2</td></tr>
<tr><td>2</td><td>Emissions to water</td><td>7.7</td></tr>
<tr><td>3</td><td>Accidents</td><td>6.4</td></tr>
<tr><td>4</td><td>Infectious diseases</td><td>5.4</td></tr>
<tr><td>5</td><td>Solid waste</td><td>4.9</td></tr>
<tr><td>6</td><td>Damage to lake and coastal water</td><td>4.8</td></tr>
<tr><td>7</td><td>Stratospheric ozone depletion</td><td>4.4</td></tr>
<tr><td>8</td><td>Climate change</td><td>4.4</td></tr>
<tr><td>9</td><td>Chemical impacts and other disorders</td><td>4.3</td></tr>
<tr><td>10</td><td>Global warming</td><td>4.0</td></tr>
<tr><td>11</td><td>Raw materials consumption</td><td>3.7</td></tr>
<tr><td>12</td><td>Energy consumption</td><td>3.7</td></tr>
<tr><td>13</td><td>Fuels consumption</td><td>3.7</td></tr>
<tr><td>14</td><td>Contribution to acid rain deposition</td><td>3.4</td></tr>
<tr><td>15</td><td>Thermal impacts</td><td>3.3</td></tr>
<tr><td>16</td><td>Psychological impacts</td><td>2.9</td></tr>
<tr><td>17</td><td>Noise</td><td>2.7</td></tr>
<tr><td>18</td><td>Odour</td><td>2.7</td></tr>
<tr><td>19</td><td>Impacts on landscape</td><td>2.6</td></tr>
<tr><td>20</td><td>Hearing impairments</td><td>2.6</td></tr>
<tr><td>21</td><td>Impacts on biodiversity</td><td>2.4</td></tr>
<tr><td>22</td><td>Insufficient lighting</td><td>2.1</td></tr>
<tr><td>23</td><td>Contribution to the greenhouse effect</td><td>2.2</td></tr>
<tr><td>24</td><td>Vibrations</td><td>1.9</td></tr>
<tr><td>25</td><td>Sick building syndrome</td><td>1.9</td></tr>
<tr><td>26</td><td>Auxiliary materials consumption</td><td>1.8</td></tr>
</table>

Changes in the weight and in the priority are highlighted.

Table 5.15 The priorities of different criteria after the weight of impacts on the working environment was reduced by 5%.

	Rank	Environmental impacts of steel industry	Weight %
Resource Consumption 13% Waste Generated 28.7% Impacts on the working environment 29.6% Impacts on natural environment 28.7%	1	Emissions to air	10.4
	2	Emissions to water	7.8
	3	Accidents	6.2
	4	Infectious diseases	5.2
	5	Solid waste	5.0
	6	Damage to lake and coastal water	4.9
	7	Stratospheric ozone depletion	4.4
	8	Climate change	4.4
	9	Chemical impacts and other disorders	4.1
	10	Global warming	4.1
	11	Raw materials consumption	3.7
	12	Energy consumption	3.7
	13	Fuels consumption	3.7
	14	Contribution to acid rain deposition	3.5
	15	Thermal impacts	3.1
	16	Psychological impacts	2.8
	17	Noise	2.8
	18	Odour	2.8
	19	Impacts on landscape	2.7
	20	Hearing impairments	2.5
	21	Impacts on biodiversity	2.4
	22	Insufficient lighting	2.1
	23	Contribution to the greenhouse effect	2.2
	24	Vibrations	1.8
	25	Sick building syndrome	1.8
	26	Auxiliary materials consumption	1.9

Changes in the weight and in the priority are highlighted.

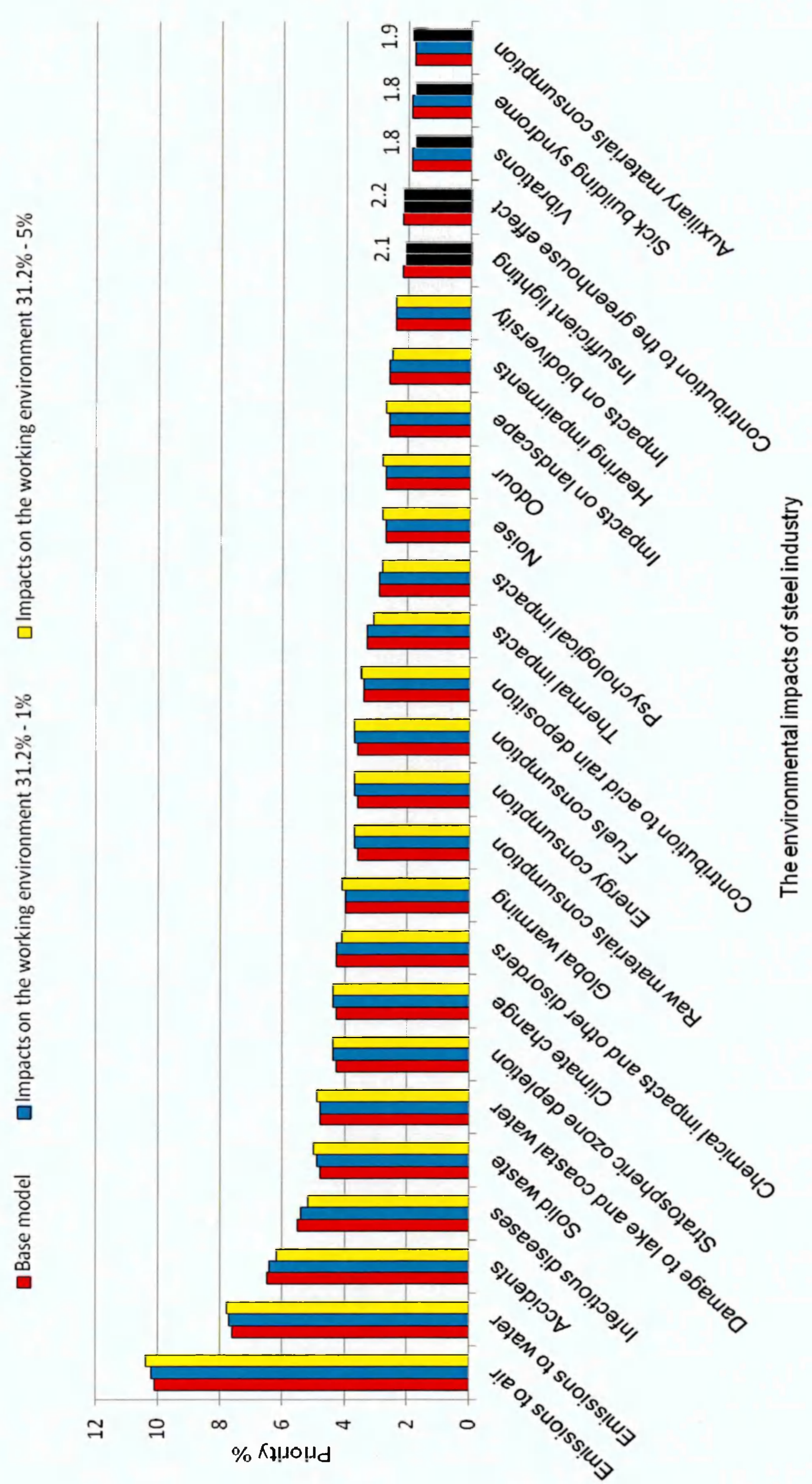

Figure 5.13 Sensitivity analysis when the weight of impacts on the working environment was raised.

■ Changes in the priority are highlighted

5.6.7 Sensitivity analysis when the weight of impacts on natural environment was raised

Table 5.16 illustrates the priorities of the criteria with respect to the goal and the sensitivity analysis when the weight of impacts on natural environment was raised by 2%. Table 5.17 illustrates the priorities of the criteria with respect to the goal and the sensitivity analysis when the weight of impacts on natural environment was raised by 3%.

The sensitivity analysis indicated that when the weight of impacts on natural environment was raised by 2% the ranking of the alternatives remained stable, while the ranking of some alternatives was a little sensitive to changes in the importance of opportunities when the weight of natural environment was raised by 3%. As shown in figure 5.14, the ranking of damage to lake and coastal water switches with the ranking of solid waste. Also, the ranking of contribution to the greenhouse effect switches with the ranking of insufficient lighting.

Table 5.16 The priorities of different criteria after the weight of impacts on natural environment was raised by 2%.

	Rank	Environmental impacts of steel industry	Weight %
Resource Consumption 12.6%	1	Emissions to air	10.1
	2	Emissions to water	7.6
	3	Accidents	6.5
Waste Generated 27.8%	4	Infectious diseases	5.5
	5	Solid waste	4.8
	6	Damage to lake and coastal water	4.8
Impacts on the working environment 31%	7	Stratospheric ozone depletion	4.4
	8	Climate change	4.4
	9	Chemical impacts and other disorders	4.3
Impacts on natural environment 28.5%	10	Global warming	4.1
	11	Raw materials consumption	3.6
	12	Energy consumption	3.6
	13	Fuels consumption	3.6
	14	Contribution to acid rain deposition	3.5
	15	Thermal impacts	3.3
	16	Psychological impacts	2.9
	17	Noise	2.7
	18	Odour	2.7
	19	Impacts on landscape	2.7
	20	Hearing impairments	2.6
	21	Impacts on biodiversity	2.4
	22	Insufficient lighting	2.2
	23	Contribution to the greenhouse effect	2.2
	24	Vibrations	1.9
	25	Sick building syndrome	1.9
	26	Auxiliary materials consumption	1.8

Changes in the weight and in the priority are highlighted.

Table 5.17 The priorities of different criteria after the weight of impacts on natural environment was raised by 3%.

	Rank	Environmental impacts of steel industry	Weight %
Resource Consumption 12.6%	1	Emissions to air	10.0
	2	Emissions to water	7.5
	3	Accidents	6.4
	4	Infectious diseases	5.4
	5	Solid waste	4.8
	6	Damage to lake and coastal water	4.9
	7	Stratospheric ozone depletion	4.5
	8	Climate change	4.5
	9	Chemical impacts and other disorders	4.3
Waste Generated 27.7%	10	Global warming	4.1
	11	Raw materials consumption	3.6
	12	Energy consumption	3.6
	13	Fuels consumption	3.6
Impacts on the working environment 30.9%	14	Contribution to acid rain deposition	3.5
	15	Thermal impacts	3.3
	16	Psychological impacts	2.9
	17	Noise	2.7
	18	Odour	2.7
Impacts on natural environment 28.8%	19	Impacts on landscape	2.7
	20	Hearing impairments	2.6
	21	Impacts on biodiversity	2.4
	22	Insufficient lighting	2.1
	23	Contribution to the greenhouse effect	2.2
	24	Vibrations	1.9
	25	Sick building syndrome	1.9
	26	Auxiliary materials consumption	1.8

Changes in the weight and in the priority are highlighted.

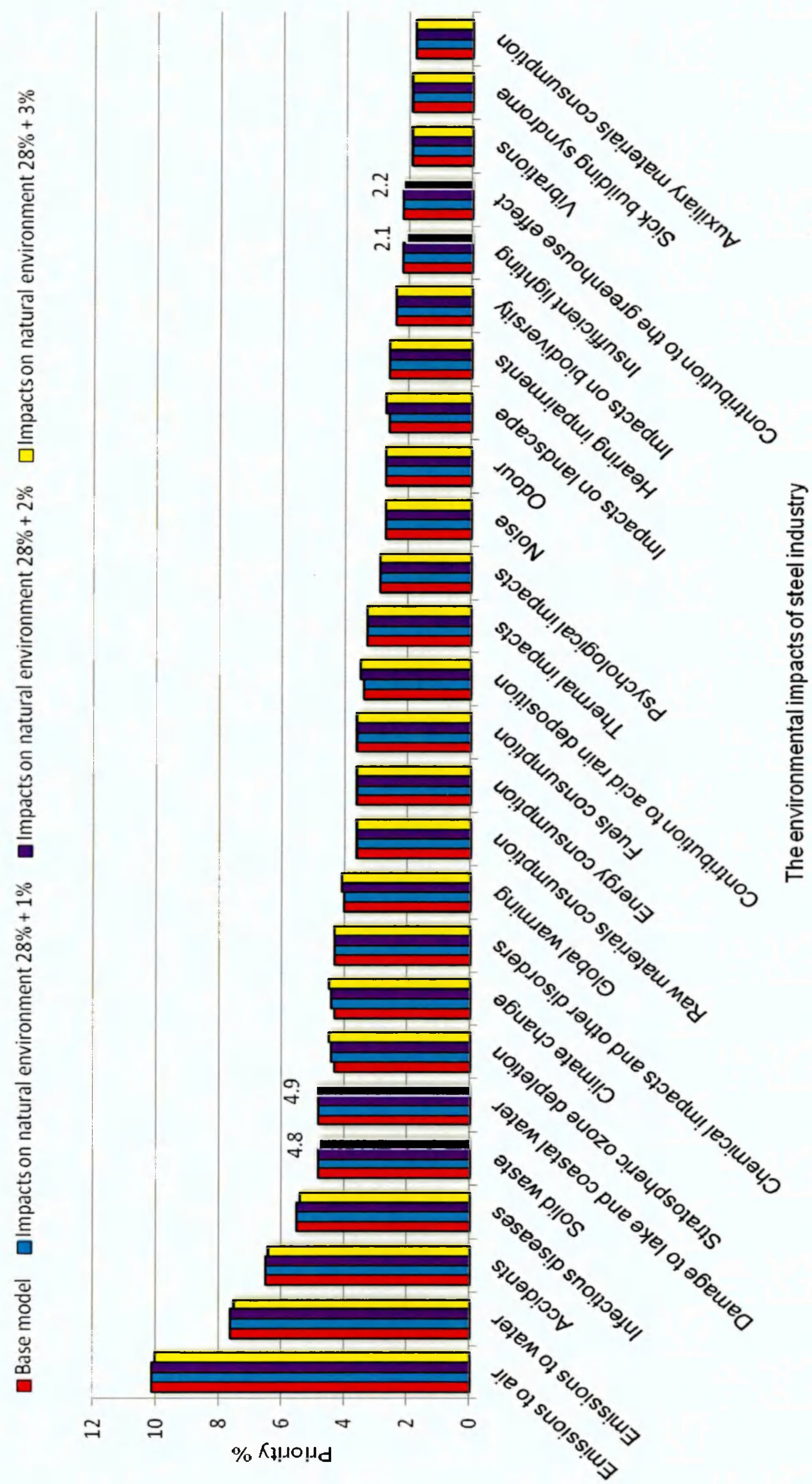

Figure 5.14 Sensitivity analysis when the weight of impacts on natural environment was raised .

▮ Changes in the the priority are highlighted

5.6.8 Sensitivity analysis when the weight of impacts on natural environment was reduced

Table 5.18 illustrates the priorities of the criteria with respect to the goal and the sensitivity analysis when the weight of impacts on natural environment was reduced by 1%. Table 5.19 illustrates the priorities of the criteria with respect to the goal and the sensitivity analysis when the weight of impacts on natural environment was reduced by 2%.

As shown in figure 5.15, the sensitivity analysis indicated that when the weight of impacts on natural environment was reduced by1%, the ranking of the alternatives remained stable, while the ranking of some alternatives was a little sensitive to changes in the importance of opportunities when the weight of natural environment was reduced by 2%. It is clear that the ranking of chemical impacts and other disorders switches with the ranking of stratospheric ozone depletion.

Table 5.18 The priorities of different criteria after the weight of impacts on natural environment was reduced by 1%.

	Rank	Environmental impacts of steel industry	Weight %
Resource Consumption 12.8% Waste Generated 28.1% Impacts on the working environment 31.3% Impacts on natural environment 27.8%	1	Emissions to air	10.2
	2	Emissions to water	7.7
	3	Accidents	6.5
	4	Infectious diseases	5.5
	5	Solid waste	4.9
	6	Damage to lake and coastal water	4.7
	7	Stratospheric ozone depletion	4.3
	8	Climate change	4.3
	9	Chemical impacts and other disorders	4.3
	10	Global warming	4.0
	11	Raw materials consumption	3.6
	12	Energy consumption	3.6
	13	Fuels consumption	3.6
	14	Contribution to acid rain deposition	3.4
	15	Thermal impacts	3.3
	16	Psychological impacts	2.9
	17	Noise	2.7
	18	Odour	2.7
	19	Impacts on landscape	2.6
	20	Hearing impairments	2.6
	21	Impacts on biodiversity	2.4
	22	Insufficient lighting	2.2
	23	Contribution to the greenhouse effect	2.1
	24	Vibrations	1.9
	25	Sick building syndrome	1.9
	26	Auxiliary materials consumption	1.8

Changes in the weight and in the priority are highlighted.

Table 5.19 The priorities of different criteria after the weight of impacts on natural environment was reduced by 2%.

	Rank	Environmental impacts of steel industry	Weight %
	1	Emissions to air	10.2
	2	Emissions to water	7.7
	3	Accidents	6.6
	4	Infectious diseases	5.5
	5	Solid waste	4.9
	6	Damage to lake and coastal water	4.7
Resource Consumption 12.8%	7	Stratospheric ozone depletion	4.2
	8	Climate change	4.2
	9	Chemical impacts and other disorders	4.4
	10	Global warming	3.9
Waste Generated 28.3%	11	Raw materials consumption	3.7
	12	Energy consumption	3.7
	13	Fuels consumption	3.7
	14	Contribution to acid rain deposition	3.4
Impacts on the working environment 31.5%	15	Thermal impacts	3.3
	16	Psychological impacts	2.9
	17	Noise	2.7
	18	Odour	2.7
	19	Impacts on landscape	2.6
Impacts on natural environment 27.5%	20	Hearing impairments	2.6
	21	Impacts on biodiversity	2.3
	22	Insufficient lighting	2.2
	23	Contribution to the greenhouse effect	2.1
	24	Vibrations	2.0
	25	Sick building syndrome	2.0
	26	Auxiliary materials consumption	1.8

Changes in the weight and in the priority are highlighted.

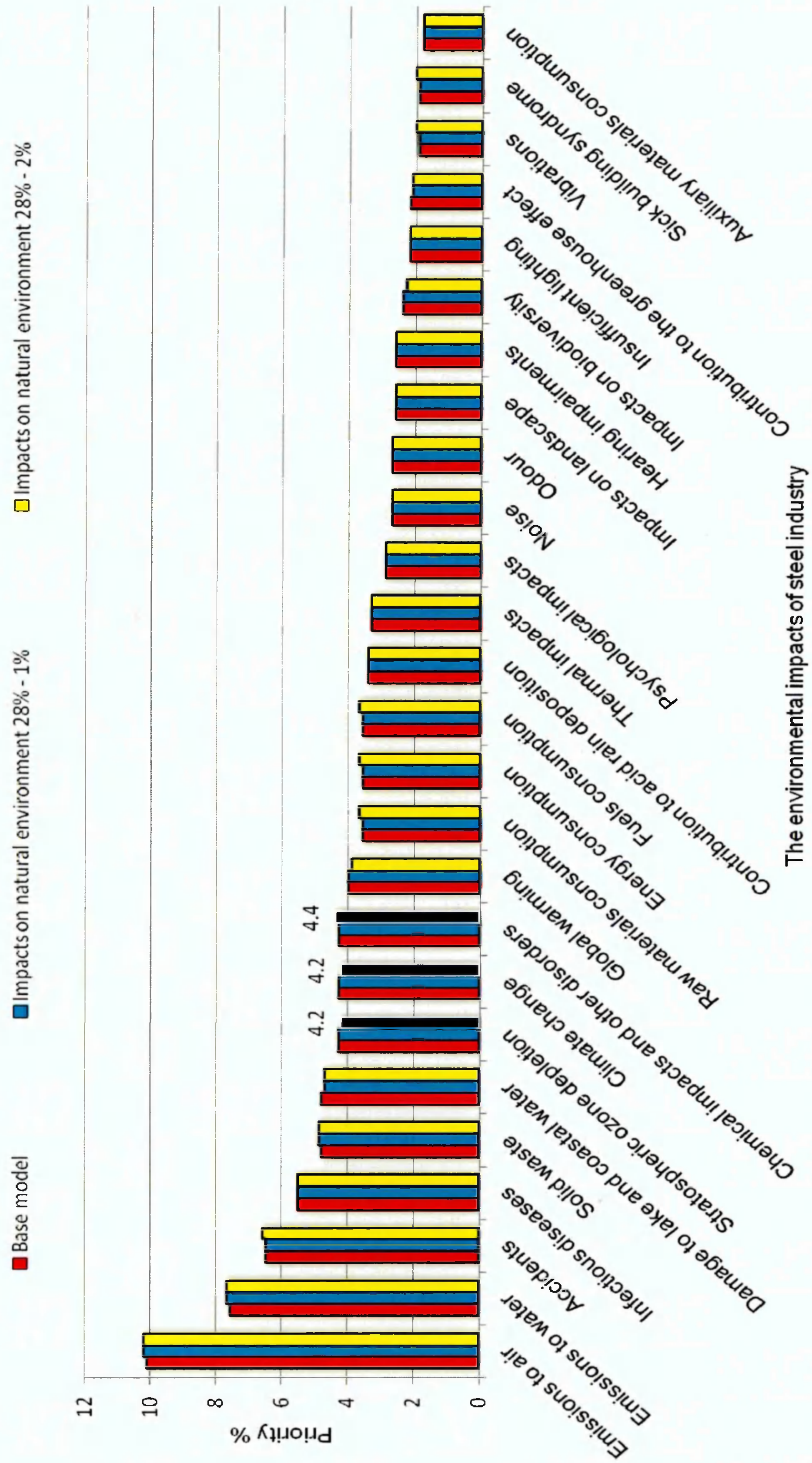

Figure 5.15 Sensitivity analysis when the weight of impacts natural environment was reduced.

■ Changes in the the priority are highlighted

From the above sensitivity analysis, it can be seen that when the importance of the main criteria was changed up and down by seven percent in all possible combinations, the ranking of the alternatives remained stable in most cases and the ranking of some alternatives was a little sensitive to changes in some cases.

In addition to the above, several sensitivity analyses were carried out to examine the sensitivity of the alternatives to changes in the priorities when the importance of the main criteria was changed up and down by 10, 15, and 20% in all possible combinations. The following sections expound these sensitivity analyses.

5.6.9 Sensitivity analysis when the weight of resource consumption was changed up and down by 10, 15 and 20%

The first sensitivity analysis shows that when the weight of resource consumption was changed up and down by 10, 15 and 20% the ranking of the alternatives was a little sensitive to changes in the importance of opportunities (table 5.20 and table 5.21). Moreover, as shown in figure 5.16, this sensitivity analysis indicated that the ranking of emissions to air, emissions to water, accident, infectious diseases, solid waste and damage to lake and coastal water remained the highest significant weights.

Table 5.20 The priorities of different criteria after the weight of resource consumption was raised by 20%.

<table>
<tr><td rowspan="27">Resource Consumption 15.2%

Waste Generated 27.2%

Impacts on the working environment 30.3%

Impacts on natural environment 27.2%</td><th>Rank</th><th>Environmental impacts of steel industry</th><th>Weight %</th></tr>
<tr><td>1</td><td>Emissions to air</td><td>9.8</td></tr>
<tr><td>2</td><td>Emissions to water</td><td>7.4</td></tr>
<tr><td>3</td><td>Accidents</td><td>6.3</td></tr>
<tr><td>4</td><td>Infectious diseases</td><td>5.3</td></tr>
<tr><td>5</td><td>Solid waste</td><td>4.7</td></tr>
<tr><td>6</td><td>Damage to lake and coastal water</td><td>4.6</td></tr>
<tr><td>7</td><td>Stratospheric ozone depletion</td><td>4.2</td></tr>
<tr><td>8</td><td>Climate change</td><td>4.2</td></tr>
<tr><td>9</td><td>Chemical impacts and other disorders</td><td>4.2</td></tr>
<tr><td>10</td><td>Global warming</td><td>3.9</td></tr>
<tr><td>11</td><td>Raw materials consumption</td><td>4.4</td></tr>
<tr><td>12</td><td>Energy consumption</td><td>4.4</td></tr>
<tr><td>13</td><td>Fuels consumption</td><td>4.4</td></tr>
<tr><td>14</td><td>Contribution to acid rain deposition</td><td>3.3</td></tr>
<tr><td>15</td><td>Thermal impacts</td><td>3.2</td></tr>
<tr><td>16</td><td>Psychological impacts</td><td>2.8</td></tr>
<tr><td>17</td><td>Noise</td><td>2.6</td></tr>
<tr><td>18</td><td>Odour</td><td>2.6</td></tr>
<tr><td>19</td><td>Impacts on landscape</td><td>2.6</td></tr>
<tr><td>20</td><td>Hearing impairments</td><td>2.5</td></tr>
<tr><td>21</td><td>Impacts on biodiversity</td><td>2.3</td></tr>
<tr><td>22</td><td>Insufficient lighting</td><td>2.1</td></tr>
<tr><td>23</td><td>Contribution to the greenhouse effect</td><td>2.1</td></tr>
<tr><td>24</td><td>Vibrations</td><td>1.9</td></tr>
<tr><td>25</td><td>Sick building syndrome</td><td>1.9</td></tr>
<tr><td>26</td><td>Auxiliary materials consumption</td><td>2.2</td></tr>
</table>

Changes in the weight and in the priority are highlighted.

Table 5.21 The priorities of different criteria after the weight of resource consumption was reduced by 20%.

	Rank	Environmental impacts of steel industry	Weight %
Resource Consumption 10.2% Waste Generated 28.9% Impacts on the working environment 32.1% Impacts on natural environment 28.9%	1	Emissions to air	10.4
	2	Emissions to water	7.8
	3	Accidents	6.7
	4	Infectious diseases	5.7
	5	Solid waste	5.0
	6	Damage to lake and coastal water	4.9
	7	Stratospheric ozone depletion	4.5
	8	Climate change	4.5
	9	Chemical impacts and other disorders	4.5
	10	Global warming	4.1
	11	Raw materials consumption	2.9
	12	Energy consumption	2.9
	13	Fuels consumption	2.9
	14	Contribution to acid rain deposition	3.5
	15	Thermal impacts	3.4
	16	Psychological impacts	3.0
	17	Noise	2.8
	18	Odour	2.8
	19	Impacts on landscape	2.7
	20	Hearing impairments	2.7
	21	Impacts on biodiversity	2.4
	22	Insufficient lighting	2.2
	23	Contribution to the greenhouse effect	2.2
	24	Vibrations	2.0
	25	Sick building syndrome	2.0
	26	Auxiliary materials consumption	1.5

Changes in the weight and in the priority are highlighted.

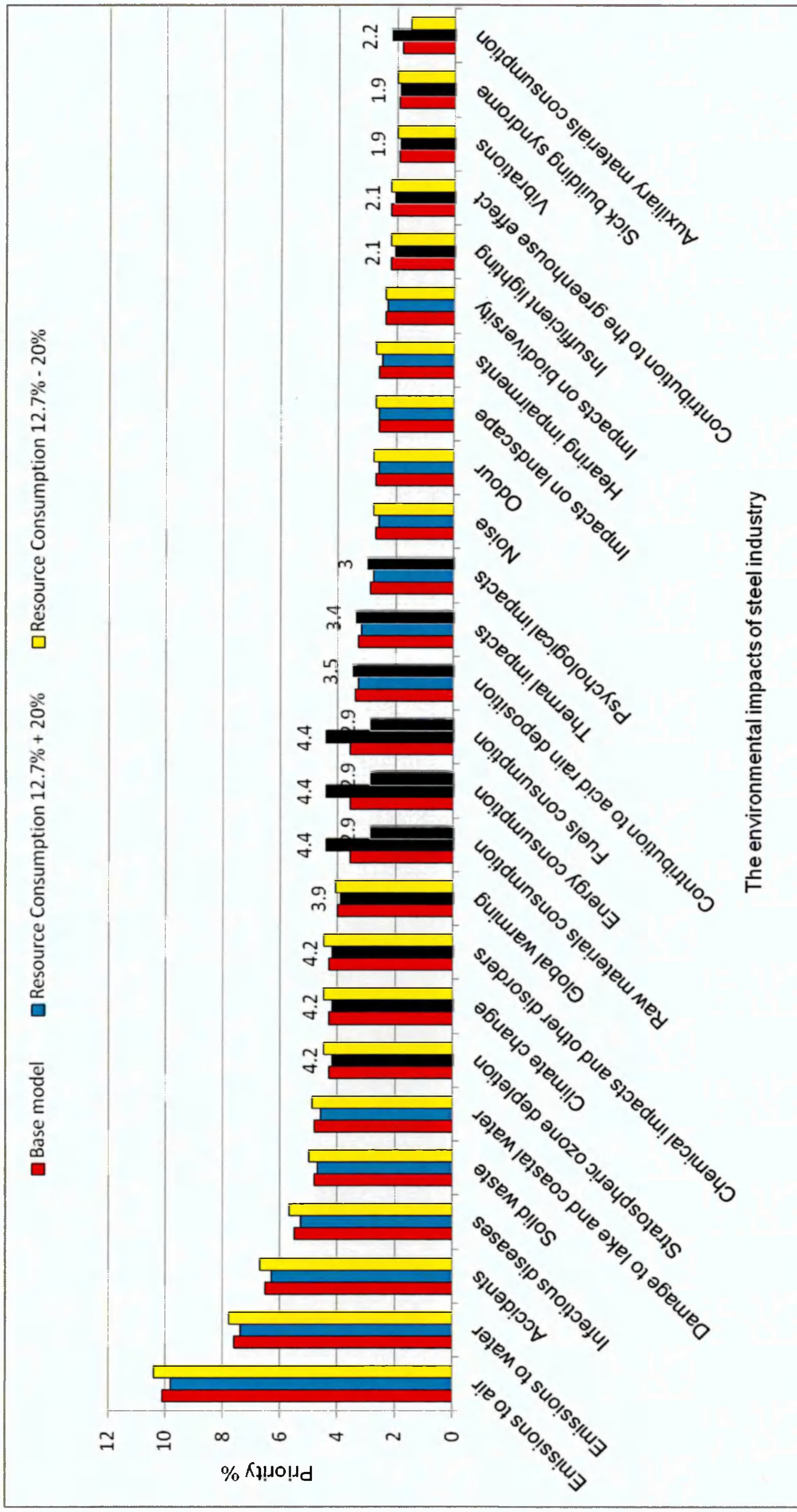

Figure 5.16 Sensitivity analysis when the weight of resource consumption was changing up and down by 20%

■ Changes in the the priority are highlighted

5.6.10 Sensitivity analysis when the weight of waste generated was changed up and down by 10, 15 and 20%

The second sensitivity analysis indicated that when the weight of waste generated was changed up and down by 10, 15 and 20% the ranking of the alternatives was a little sensitive to changes in some cases and sensitive to changes in other cases (table 5.22 and table 5.23). Furthermore, the emissions to air remained the highest significant weight (figure 5.17).

Table 5.22 The priorities of different criteria after the weight of waste generated was raised by 20%.

	Rank	Environmental impacts of steel industry	Weight %
Resource Consumption 11.7% Waste Generated 33.6% Impacts on the working environment 28.8% Impacts on natural environment 25.9%	1	Emissions to air	12.1
	2	Emissions to water	9.1
	3	Accidents	6.0
	4	Infectious diseases	5.1
	5	Solid waste	5.8
	6	Damage to lake and coastal water	4.4
	7	Stratospheric ozone depletion	4.0
	8	Climate change	4.0
	9	Chemical impacts and other disorders	4.0
	10	Global warming	3.7
	11	Raw materials consumption	3.4
	12	Energy consumption	3.4
	13	Fuels consumption	3.4
	14	Contribution to acid rain deposition	3.2
	15	Thermal impacts	3.1
	16	Psychological impacts	2.7
	17	Noise	3.3
	18	Odour	3.3
	19	Impacts on landscape	2.4
	20	Hearing impairments	2.4
	21	Impacts on biodiversity	2.2
	22	Insufficient lighting	2.0
	23	Contribution to the greenhouse effect	2.0
	24	Vibrations	1.8
	25	Sick building syndrome	1.8
	26	Auxiliary materials consumption	1.7

Changes in the weight and in the priority are highlighted.

Table 5.23 The priorities of different criteria after the weight of waste generated was reduced by 20%.

	Rank	Environmental impacts of steel industry	Weight %
Resource Consumption 13.7% Waste Generated 22.4% Impacts on the working environment 33.6% Impacts on natural environment 30.2%	1	Emissions to air	8.1
	2	Emissions to water	6.1
	3	Accidents	7.0
	4	Infectious diseases	5.9
	5	Solid waste	3.9
	6	Damage to lake and coastal water	5.1
	7	Stratospheric ozone depletion	4.7
	8	Climate change	4.7
	9	Chemical impacts and other disorders	4.7
	10	Global warming	4.3
	11	Raw materials consumption	3.9
	12	Energy consumption	3.9
	13	Fuels consumption	3.9
	14	Contribution to acid rain deposition	3.7
	15	Thermal impacts	3.6
	16	Psychological impacts	3.1
	17	Noise	2.2
	18	Odour	2.2
	19	Impacts on landscape	2.8
	20	Hearing impairments	2.8
	21	Impacts on biodiversity	2.6
	22	Insufficient lighting	2.3
	23	Contribution to the greenhouse effect	2.3
	24	Vibrations	2.1
	25	Sick building syndrome	2.1
	26	Auxiliary materials consumption	2.0

Changes in the weight and in the priority are highlighted.

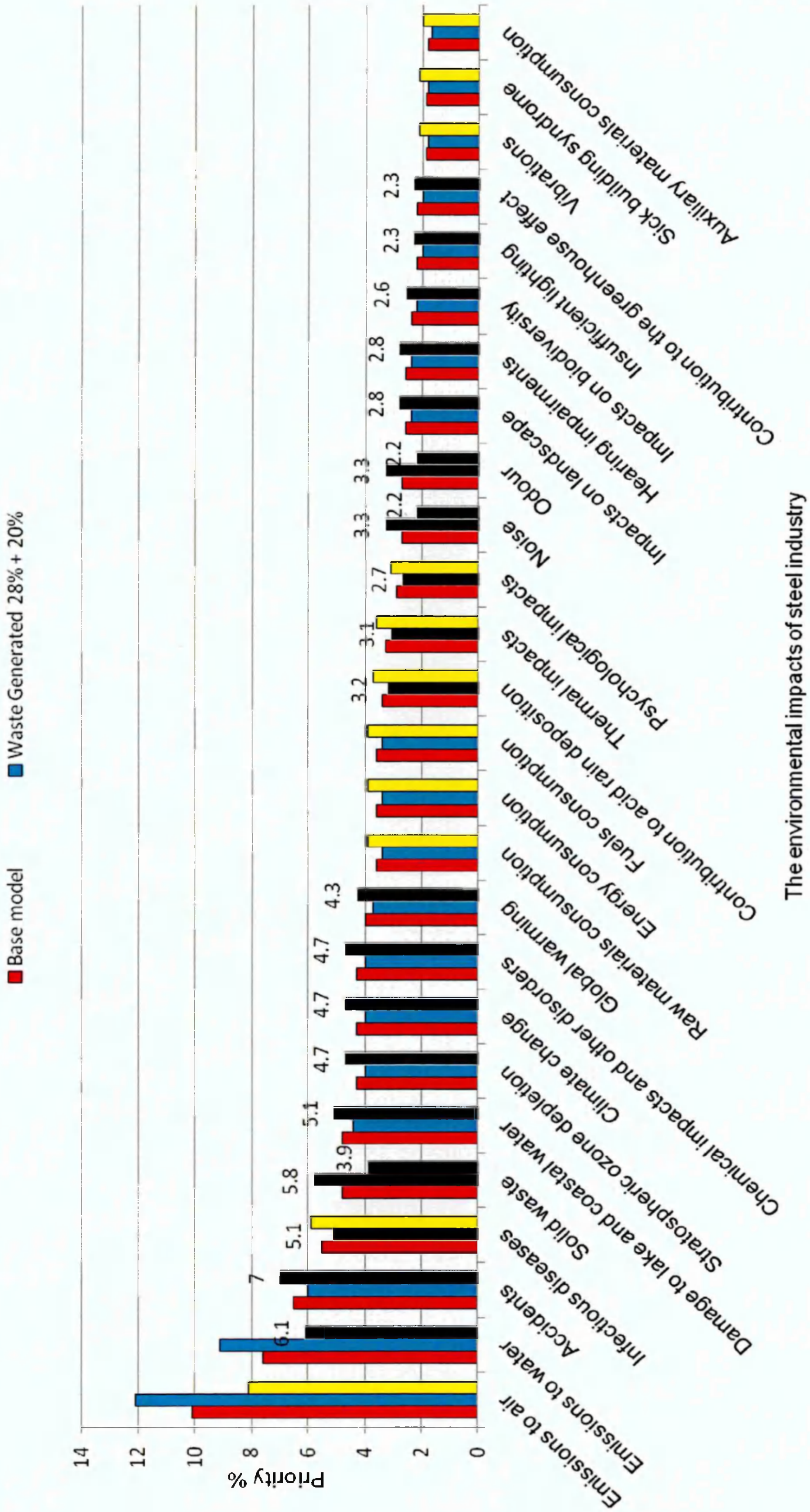

Figure 5.17 Sensitivity analysis when the weight of waste generated was changing up and down by 20%.

■ Changes in the the priority are highlighted

5.6.11 Sensitivity analysis when the weight of impacts on the working environment was changed up and down by 10, 15 and 20%

The third sensitivity analysis indicated that when the weight of impacts on the working environment was changed up and down by 10, 15 and 20% the ranking of the alternatives are sensitive to changes in the importance of opportunities (table 5.24 and table 5.25). In addition, the emissions to air remained the highest significant weight (figure 5.18).

Table 5.24 The priorities of different criteria after the weight of impacts on the working environment was raised by 20%.

	Rank	Environmental impacts of steel industry	Weight %
Resource Consumption 11.6%	1	Emissions to air	9.2
Waste Generated 25.5%	2	Emissions to water	6.9
Impacts on the working environment 37.4%	3	Accidents	7.8
Impacts on natural environment 25.5%	4	Infectious diseases	6.6
	5	Solid waste	4.4
	6	Damage to lake and coastal water	4.3
	7	Stratospheric ozone depletion	3.9
	8	Climate change	3.9
	9	Chemical impacts and other disorders	5.2
	10	Global warming	3.7
	11	Raw materials consumption	3.3
	12	Energy consumption	3.3
	13	Fuels consumption	3.3
	14	Contribution to acid rain deposition	3.1
	15	Thermal impacts	4.0
	16	Psychological impacts	3.5
	17	Noise	2.5
	18	Odour	2.5
	19	Impacts on landscape	2.4
	20	Hearing impairments	3.1
	21	Impacts on biodiversity	2.2
	22	Insufficient lighting	2.6
	23	Contribution to the greenhouse effect	2.0
	24	Vibrations	2.3
	25	Sick building syndrome	2.3
	26	Auxiliary materials consumption	1.7

Changes in the weight and in the priority are highlighted.

Table 5.25 The priorities of different criteria after the weight of impacts on the working environment was reduced by 20%.

	Rank	Environmental impacts of steel industry	Weight %
	1	Emissions to air	11.0
	2	Emissions to water	8.3
	3	Accidents	5.2
	4	Infectious diseases	4.4
	5	Solid waste	5.3
Resource	6	Damage to lake and coastal water	5.2
Consumption	7	Stratospheric ozone depletion	4.7
13.9%	8	Climate change	4.7
	9	Chemical impacts and other disorders	3.5
Waste	10	Global warming	4.4
Generated	11	Raw materials consumption	4.0
30.6%	12	Energy consumption	4.0
	13	Fuels consumption	4.0
Impacts on	14	Contribution to acid rain deposition	3.7
the working	15	Thermal impacts	2.7
environment	16	Psychological impacts	2.3
25%	17	Noise	3.0
	18	Odour	3.0
Impacts on	19	Impacts on landscape	2.9
natural	20	Hearing impairments	2.1
environment	21	Impacts on biodiversity	2.6
30.6%	22	Insufficient lighting	1.7
	23	Contribution to the greenhouse effect	2.4
	24	Vibrations	1.6
	25	Sick building syndrome	1.6
	26	Auxiliary materials consumption	2.0

Changes in the weight and in the priority are highlighted.

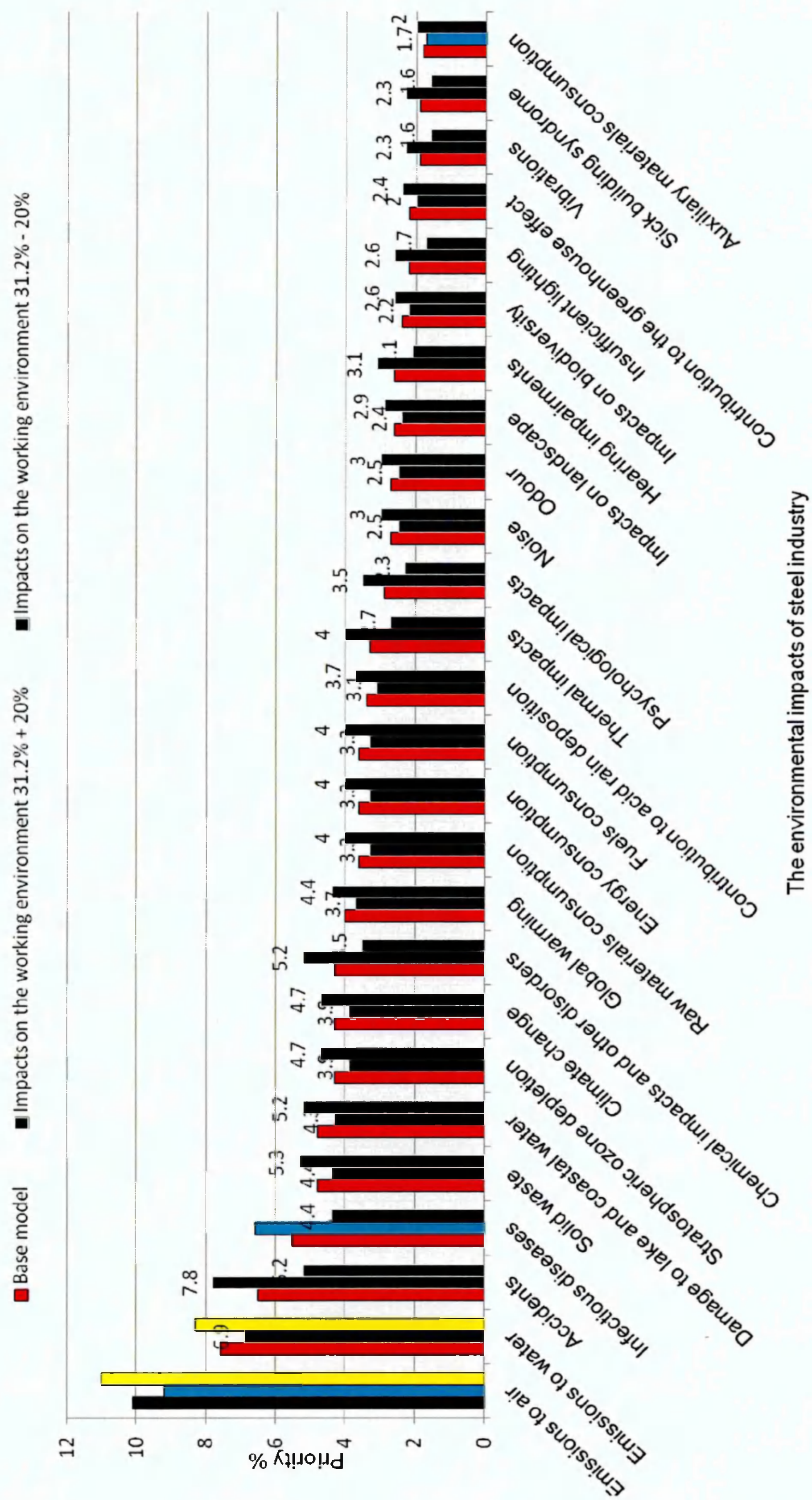

Figure 5.18 Sensitivity analysis when the weight of impacts on the working environment was changing up and down by 20%.

Changes in the the priority are highlighted

5.6.12 Sensitivity analysis when the weight of impacts on natural environment was changed up and down by 10, 15 and 20%

The fourth sensitivity analysis indicated that when the weight of impacts on natural environment was changed up and down by 10, 15 and 20%, the ranking of the alternatives was sensitive to changes in the importance of opportunities (table 5.26 and table 5.27). In addition, it is clear that ranking of emissions to air, emissions to water, and accident remained the highest significant weights (figure 5.19).

Table 5.26 The priorities of different criteria after the weight of impacts on natural environment was raised by 20%.

	Rank	Environmental impacts of steel industry	Weight %
Resource Consumption 11.7% Waste Generated 25.9% Impacts on the working environment 28.8% Impacts on natural environment 33.6%	1	Emissions to air	9.4
	2	Emissions to water	7.0
	3	Accidents	6.0
	4	Infectious diseases	5.1
	5	Solid waste	4.5
	6	Damage to lake and coastal water	5.7
	7	Stratospheric ozone depletion	5.2
	8	Climate change	5.2
	9	Chemical impacts and other disorders	4.0
	10	Global warming	4.8
	11	Raw materials consumption	3.4
	12	Energy consumption	3.4
	13	Fuels consumption	3.4
	14	Contribution to acid rain deposition	4.1
	15	Thermal impacts	3.1
	16	Psychological impacts	2.7
	17	Noise	2.5
	18	Odour	2.5
	19	Impacts on landscape	3.1
	20	Hearing impairments	2.4
	21	Impacts on biodiversity	2.8
	22	Insufficient lighting	2.0
	23	Contribution to the greenhouse effect	2.6
	24	Vibrations	1.8
	25	Sick building syndrome	1.8
	26	Auxiliary materials consumption	1.7

Changes in the weight and in the priority are highlighted.

Table 5.27 The priorities of different criteria after the weight of impacts on natural environment was reduced by 20%.

	Rank	Environmental impacts of steel industry	Weight %
	1	Emissions to air	10.9
	2	Emissions to water	8.2
	3	Accidents	7.0
	4	Infectious diseases	5.9
	5	Solid waste	5.2
Resource Consumption 13.7%	6	Damage to lake and coastal water	3.8
	7	Stratospheric ozone depletion	3.5
	8	Climate change	3.5
	9	Chemical impacts and other disorders	4.7
Waste Generated 30.2%	10	Global warming	3.2
	11	Raw materials consumption	3.9
	12	Energy consumption	3.9
	13	Fuels consumption	3.9
Impacts on the working environment 33.6%	14	Contribution to acid rain deposition	2.7
	15	Thermal impacts	3.6
	16	Psychological impacts	3.1
	17	Noise	2.9
	18	Odour	2.9
Impacts on natural environment 22.4%	19	Impacts on landscape	2.1
	20	Hearing impairments	2.8
	21	Impacts on biodiversity	1.9
	22	Insufficient lighting	2.3
	23	Contribution to the greenhouse effect	1.7
	24	Vibrations	2.1
	25	Sick building syndrome	2.1
	26	Auxiliary materials consumption	2.0

Changes in the weight and in the priority are highlighted.

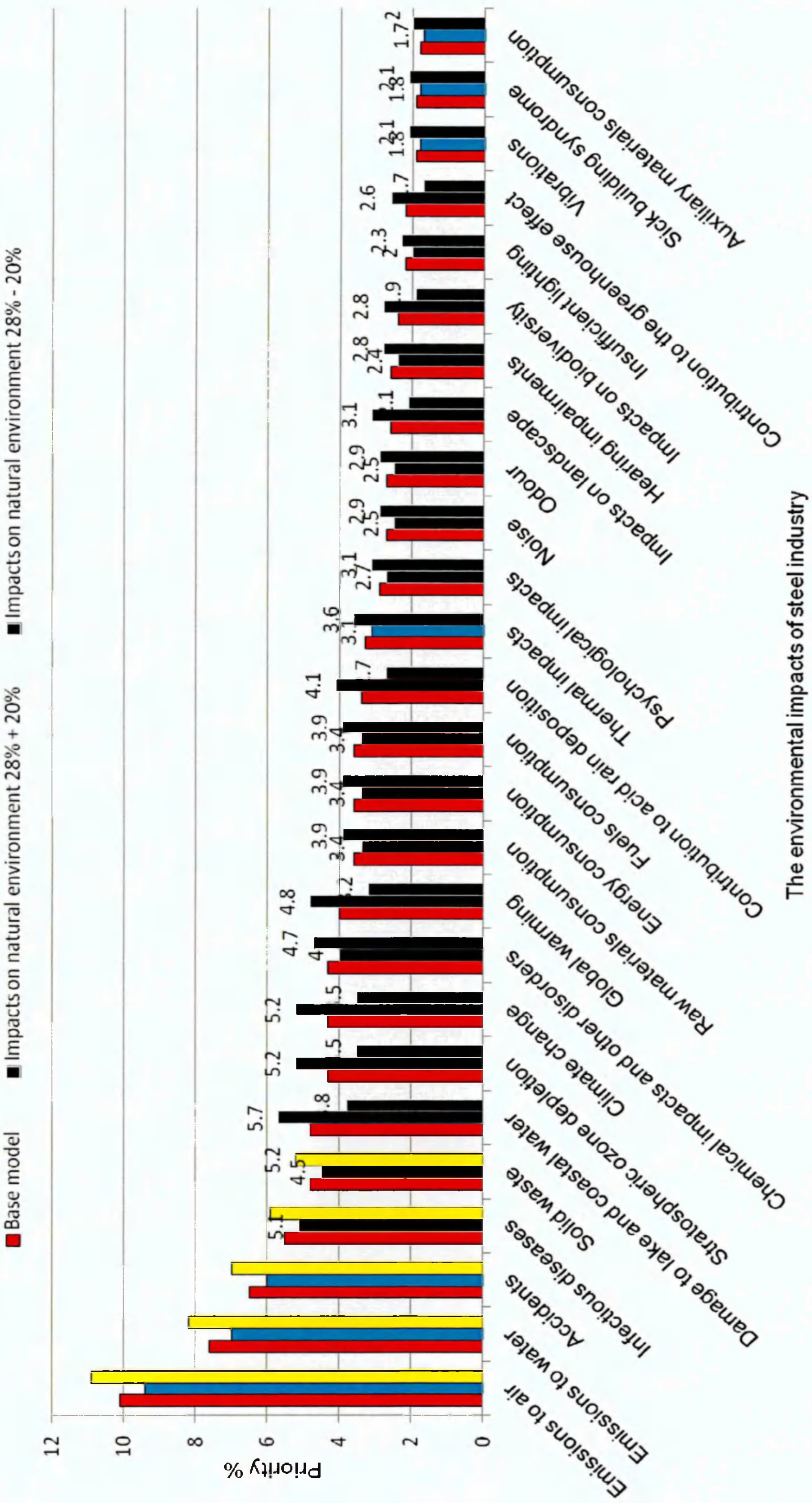

Figure 5.19 Sensitivity analysis when the weight of impacts on natural environment was changing up and down by 20%.

■ Changes in the the priority are highlighted

5.7 Conclusion on results and sensitivity analysis

In this chapter a model for environmental impacts of the steel industry has been developed to investigate the most important environmental parameters and their importance in order to help managing the environmental impacts of steel industry.

It can be concluded that the impacts of the steel industry on the working environment have a value of 0.312, the highest significant weight. The waste generated and impacts on the natural environment both have a value of 0.280, the second-highest. The resource consumption has the lowest weight with a value of 0.127. In addition, findings from the use of AHP highlighted the importance of emissions to air, emissions to water, accident, infectious diseases, solid waste and damage to lake and coastal water respectively, with weights of 0.101, 0.076, 0.065, 0.055, 0.048 and 0.048 respectively. Other environmental impacts mentioned in this study are less important.

A series of sensitivity analyses were conducted to investigate the impact of changing the priority of the criteria on the alternatives' ranking.

After developing the model for environmental impacts in steel industry and indicating the most important criteria and sub-criteria using AHP software, the derived model needs to be validated. The next chapter deals with this problem.

6. CHAPTER SIX

The Validation of Environmental Impacts Model in the Steel Industry

6.1 Introduction

After developing the environmental impacts model in the steel industry and indicating the most important criteria and sub-criteria using AHP software, the derived model needs to be validated. There are two ways to validate the proposed model to prove its validity, namely to validate the criteria and sub-criteria of the proposed model and validate the results of the AHP model.

6.2 Validation of the criteria and sub-criteria of the proposed model

In this validation process, the validity of the criteria and sub-criteria of the proposed model are assessed, to see this model from the perspectives of the professionals in the steel industry. The third part of the questionnaire was designed to assist in the evaluation of the criteria and sub-criteria of the proposed model and contained two questions:

Q1 Are there any more criteria and sub-criteria that should have been considered and need to be included? Please provide details.

Q2 Are there any criteria or sub-criteria have no added value and need to be deleted? Please provide details.

The response was very encouraging. Bearing in mind the overall response rate of 60% (n=30, comprising experienced managers and engineers in different plants in the Libyan iron and steel industry), 28 respondents were satisfied with the contents of the proposed model and had no additional comments. Two respondents suggested that "Noise as a sub-criterion should be changed from the list of waste generated to the list of the impact on the working environment" and that "Odour is not considered to be one of the sub-criteria".

Regarding the concern that "Noise as a sub-criterion should be changed from the list of waste generated to the list of the impact on the working environment", albeit noise does have an impact on the working environment, it also has an impact on the natural environment (Barton 1999, Pandya and Dharmadhikari 2002). In addition, regarding the concern that "Odour is not considered to be one of the sub-criteria", based on the literature review, Barton (1999) stated that odour results from many process stages of the steel industry, such as coke production, blast furnace and coating.

6.3 Validation of the results of the AHP model

After developing the model for environmental impacts in the steel industry and indicating the most important criteria and sub-criteria using AHP software, the derived results of the model need to be validated. The following sections deal with this problem using mathematics.

6.3.1 Synthesizing the pairwise comparison matrix for the main criteria

As mentioned previously, after the completed questionnaires were returned, the geometric mean technique was used to calculate the average of respondents frequency. Then, the criteria must be evaluated in pairs so as to determine the relative importance between them and their relative weight to the global goal. The evaluation begins by determining the relative weight of the initial criteria groups (Figure 6.1). Table 6.1 shows the relative weigh data between the criteria.

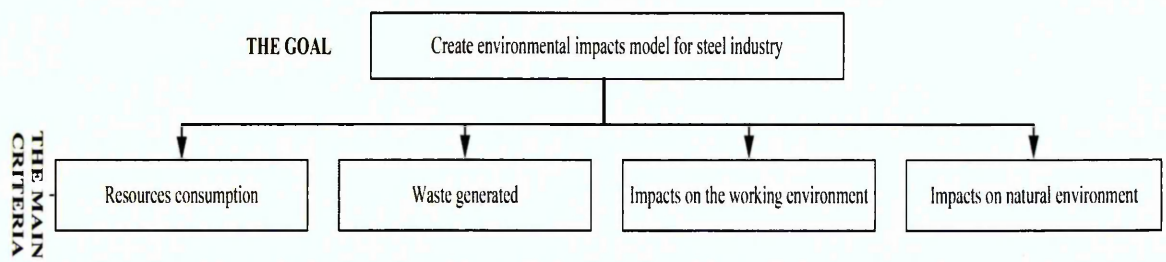

Figure 6.1 The main criteria

Table 6.1 Pairwise comparison matrix for the criteria with respect to overall goal

	Resources consumption	Waste generated	Impacts on the working environment	Impacts on natural environment
Resources consumption	1	$\frac{1}{2}$	$\frac{1}{3}$	$\frac{1}{2}$
Waste generated	2	1	1	1
Impacts on the working environment	3	1	1	1
Impacts on natural environment	2	1	1	1
$\sum$	8	3.5	3.3333333	3.5

6.3.2 Calculating the priority vector for the main criteria

In order to interpret and give relative weights to each criterion, it is necessary to normalise the previous comparison matrix. The normalisation is made by dividing each table value by the total column value. Then, the contribution of each criterion to the goal is determined by calculation made using the priority vector (or Eigenvector). The priority vector in table 6.2 can be obtained by finding the row averages.

Table 6.2 Weights on Criteria

	Resources consumption	Waste generated	Impacts on the working environment	Impacts on natural environment	Priority Vector
Resources consumption	0.125	0.142	0.0999999	0.142	0.1276785
Waste generated	0.25	0.285	0.3	0.285	0.2803571
Impacts on the working environment	0.375	0.285	0.3	0.285	0.3116071
Impacts on natural environment	0.25	0.2857142	0.3	0.2857142	0.2803571
					$\sum = 1$

6.3.3 Calculating the consistency rate for the main criteria group

The next step is to look for any data inconsistencies. The objective is to capture enough information to determine whether the decision makers have been consistent in their choices (Teknomo 2006). For example, if the decision makers affirm that the resources consumption is more important than waste generated, and that waste generated is more important than impacts on the working environment, it would be inconsistent to affirm that the impacts on the working environment are more important than resources consumption (i.e. if A>B and B>C, it would be inconsistent to say that A<C). The inconsistency index is based on Maximum Eigenvector. Table 6.3 demonstrates the calculation of Maximum Eigenvector(λ_{Max}).

Table 6.3 Calculation of Maximum Eigenvector

Eigenvector	0.127	0.280	0.312	0.280
Total (Sum)	8	3.5	3.3333333	3.5
Maximum Eigenvector (λ_{Max})	[(0.1276785×8)+(0.2803571×3.5)+(0.3116071×3.3333333)+ (0.2803571×3.5)]= 4.0226179			

$$CI = \frac{\lambda_{Max} - n}{n - 1}$$

Where CI is the Consistency Index and (n) is the number of evaluated criteria. For this study, the consistency index (CI) is:

$$CI = \frac{4.0226179 - 4}{4 - 1} = 0.0075393$$

In order to verity whether the consistency index (CI) is adequate, Saaty (2005) suggests what has been called consistency rate (CR), which is determined by the ratio between the consistency index and random consistency index (CI). The matrix will be considered consistent if the resulting ratio is less than 10%. The calculation of the consistency rate is given by following formula (Saaty 2005):

$$CR = \frac{CI}{RI} < 0.1$$

The RI value is fixed and is based on the number of evaluated criteria, as shown in table 6.4.

Table 6.4 Table of random consistency indices (RI) (Saaty 2005)

N	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

For this study, the consistency rate for initial criteria group is:

$$CR = \frac{0.0075393}{0.9} = 0.008$$

As the value of CR is less than 0.1, the judgments are acceptable. The priority criteria results for the first level can be seen in figure 6.2.

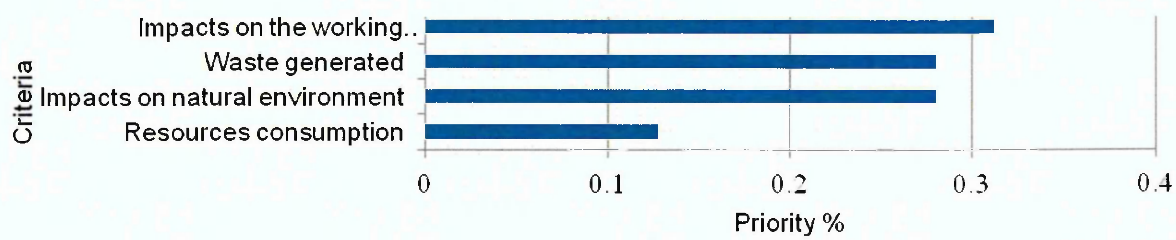

Figure 6.2 The priorities of the main criteria with respect to the goal

6.3.4 Evaluating the criteria's relative weights for the second level of the hierarchy

As with the main criteria group, it is necessary to evaluate the criteria's relative weights for the second level of the hierarchy (Figure 6.3). This process is executed just like the step to evaluate the first level of hierarchy (criteria group) as outlined above. The pairwise comparison matrices and priority vectors for the remaining criteria can be found as shown in tables 6.5-6.12.

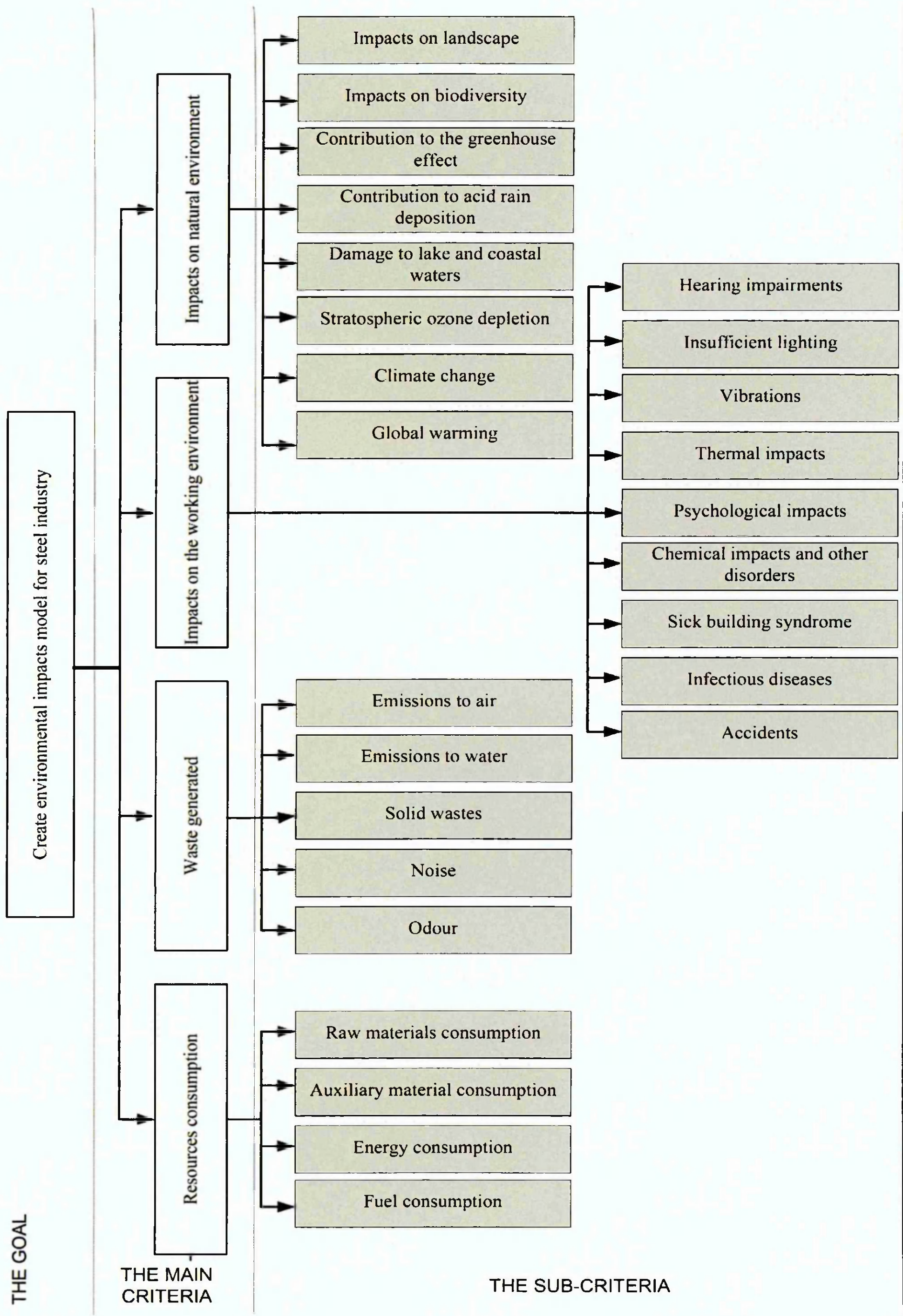

Figure 6.3 The structure of environmental impacts model for steel industry

Table 6.5 Pairwise comparison matrix for resources consumption

	Raw materials consumption	Auxiliary material consumption	Energy consumption	Fuel consumption
Raw materials consumption.	1	2	1	1
Auxiliary material consumption.	$\frac{1}{2}$	1	$\frac{1}{2}$	$\frac{1}{2}$
Energy consumption	1	2	1	1
Fuel consumption	1	2	1	1
$\sum$	3.5	7	3.5	3.5

Table 6.6 Weights on sub-criteria of resources consumption

	Raw materials consumption	Auxiliary material consumption	Energy consumption	Fuel consumption	Priority Vector
Raw materials consumption	0.2857142	0.2857142	0.2857142	0.2857142	0.2857142
Auxiliary material consumption	0.1428571	0.1428571	0.1428571	0.1428571	0.1428571
Energy consumption	0.2857142	0.2857142	0.2857142	0.2857142	0.2857142
Fuel consumption	0.2857142	0.2857142	0.2857142	0.2857142	0.2857142
					$\sum = 1$
λ_{Max} = 4.0, CI = 0, RI = 0.9, CR = 0 < 0.1 OK.					

Table 6.7 Pairwise comparison matrix of waste generated

	Emissions to air	Emissions to water	Solid wastes	Noise	Odour
Emissions to air	1	2	2	3	3
Emissions to water	$\frac{1}{2}$	1	2	3	3
Solid wastes	$\frac{1}{2}$	$\frac{1}{2}$	1	2	2
Noise	$\frac{1}{3}$	$\frac{1}{3}$	$\frac{1}{2}$	1	1
Odour	$\frac{1}{3}$	$\frac{1}{3}$	$\frac{1}{2}$	1	1
$\sum$	2.6666666	4.1666666	6	10	10

Table 6.8 Weights on sub-criteria of waste generated

	Emissions to air	Emissions to water	Solid wastes	Noise	Odour	Priority Vector
Emissions to air	0.375	0.48	0.3333333	0.3	0.3	0.3576666
Emissions to water	0.1875	0.24	0.3333333	0.3	0.3	0.2721666
Solid wastes	0.1875	0.12	0.1666666	0.2	0.2	0.1748333
Noise	0.1249999	0.0799999	0.0833333	0.1	0.1	0.0976666
Odour	0.1249999	0.0799999	0.0833333	0.1	0.1	0.0976666
						$\sum = 1$
λ_{Max} = 5.0901367, CI = 0.0225341, RI = 1.12, CR = 0.02 < 0.1 OK.						

Table 6.9 Pair-wise comparison matrix for impacts on the working environment

	Hearing impairments	Insufficient lighting	Vibrations	Thermal impacts	Psychological impacts	Chemical impacts and other disorders	Sick building syndrome	Infectious diseases	Accidents
Hearing impairments	1	2	1	1	1	$\frac{1}{2}$	1	$\frac{1}{2}$	$\frac{1}{3}$
Insufficient lighting	$\frac{1}{2}$	1	1	$\frac{1}{2}$	1	$\frac{1}{2}$	1	$\frac{1}{2}$	$\frac{1}{2}$
Vibrations	1	1	1	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	1	$\frac{1}{3}$	$\frac{1}{3}$
Thermal impacts	1	2	2	1	1	$\frac{1}{2}$	2	1	$\frac{1}{3}$
Psychological impacts	1	1	2	1	1	$\frac{1}{2}$	2	$\frac{1}{2}$	$\frac{1}{2}$
Chemical impacts and other disorders	2	2	2	2	2	1	2	$\frac{1}{2}$	$\frac{1}{2}$
Sick building syndrome	1	1	1	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	1	$\frac{1}{3}$	$\frac{1}{3}$
Infectious diseases	2	2	3	1	2	2	3	1	1
Accidents	3	2	3	3	2	2	3	1	1
Σ	12.5	14	16	10.5	11	8	16	5.6666666	4.8333332

Table 6.10 Weights on sub-criteria of impacts on the working environment

	Hearing impairments	Insufficient lighting	Vibrations	Thermal impacts	Psychological impacts	Chemical impacts and other disorders	Sick building syndrome	Infectious diseases	Accidents	Priority Vector
Hearing impairments	0.08	0.143	0.063	0.095	0.091	0.063	0.063	0.088	0.069	0.084
Insufficient lighting	0.04	0.071	0.063	0.048	0.091	0.063	0.063	0.088	0.103	0.07
Vibrations	0.08	0.071	0.063	0.048	0.045	0.063	0.063	0.059	0.069	0.062
Thermal impacts	0.08	0.143	0.125	0.095	0.091	0.063	0.125	0.176	0.069	0.107
Psychological impacts	0.08	0.071	0.125	0.095	0.091	0.063	0.125	0.088	0.103	0.093
Chemical impacts and other disorders	0.16	0.143	0.125	0.190	0.182	0.125	0.125	0.088	0.103	0.138
Sick building syndrome	0.08	0.071	0.063	0.048	0.045	0.063	0.063	0.059	0.069	0.062
Infectious diseases	0.16	0.143	0.188	0.095	0.182	0.25	0.188	0.176	0.207	0.177
Accidents	0.24	0.143	0.188	0.286	0.182	0.25	0.188	0.176	0.207	0.207
										$\sum = 1$

λ_{Max} = 9.2679998, CI = 0.0334999, RI = 1.45, CR = 0.02 < 0.1 OK.

Table 6.11 Pair-wise comparison matrix for impacts on natural environment

	Impacts on landscape	Impacts on biodiversity	Contribution to the greenhouse effect	Contribution to acid rain deposition	Damage to lake and coastal waters	Stratospheric ozone depletion	Climate change	Global warming
Impacts on landscape	1	1	1	1	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	1
Impacts on biodiversity	1	1	1	1	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$
Contribution to the greenhouse effect	1	1	1	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$
Contribution to acid rain deposition	1	1	2	1	$\frac{1}{2}$	1	1	1
Damage to lake and coastal waters	2	2	2	2	1	1	1	1
Stratospheric ozone depletion	2	2	2	1	1	1	1	1
Climate change	2	2	2	1	1	1	1	1
Global warming	1	2	2	1	1	1	1	1
Σ	11	12	13	8.5	6	6.5	6.5	7

Table 6.12 Weights on sub-criteria of impact on natural environment

	Impacts on landscape	Impacts on biodiversity	Contribution to the greenhouse effect	Contribution to acid rain deposition	Damage to lake and coastal waters	Stratospheric ozone depletion	Climate change	Global warming	Priority Vector
Impacts on landscape	0.091	0.083	0.077	0.118	0.083	0.077	0.077	0.143	0.094
Impacts on biodiversity	0.091	0.083	0.077	0.118	0.083	0.077	0.077	0.071	0.085
Contribution to the greenhouse effect	0.091	0.083	0.077	0.059	0.083	0.077	0.077	0.071	0.077
Contribution to acid rain deposition	0.091	0.083	0.154	0.118	0.083	0.154	0.154	0.143	0.123
Damage to lake and coastal waters	0.182	0.167	0.154	0.235	0.167	0.154	0.154	0.143	0.170
Stratospheric ozone depletion	0.182	0.167	0.154	0.118	0.167	0.154	0.154	0.143	0.155
Climate change	0.182	0.167	0.154	0.118	0.167	0.154	0.154	0.143	0.155
Global warming	0.091	0.167	0.154	0.118	0.167	0.154	0.154	0.143	0.144
									$\sum = 1$
λ_{Max} =8.1435, CI = 0.0205, RI = 1.41, CR = 0.014539 < 0.1 OK.									

6.3.5 Develop overall priority ranking

Once the comparisons are carried out and the consistency calculation for all levels is completed, the overall priority vector can be obtained by multiplying the priority vector for the sub-criteria by the vector of priority of the criteria. Table 6.13 and figure 6.4 show the importance rankings of the environmental impacts of steel industry.

Figure 6.13 The importance rankings of the environmental impacts of steel industry

Criteria	Sub-criterion	Overall priority vector
Resource consumption **(0.127)**	Raw materials consumption **(0.286)**	0.0363
	Auxiliary materials consumption **(0.143)**	0.0182
	Energy consumption **(0.286)**	0.0363
	Fuels consumption **(0.286)**	0.0363
Wastes generated **(0.280)**	Emissions to air **(0.360)**	0.1008
	Emissions to water **(0.272)**	0.0762
	Solid wastes **(0.174)**	0.0488
	Noise **(0.097)**	0.0272
	Odour **(0.097)**	0.0272
Impacts on the working environment **(0.312)**	Hearing impairments **(0.084)**	0.0262
	Insufficient lighting **(0.070)**	0.0218
	Vibrations **(0.062)**	0.0193
	Thermal impacts **(0.107)**	0.0334
	Psychological impacts **(0.094)**	0.0293
	Chemical impacts and other disorders **(0.138)**	0.0430
	Sick building syndrome **(0.062)**	0.0193
	Infectious diseases **(0.176)**	0.0549
	Accidents **(0.207)**	0.0646
Impacts on natural environment **(0.280)**	Impacts on landscape **(0.094)**	0.0263
	Impacts on biodiversity **(0.085)**	0.0238
	Contribution to the greenhouse effect **(0.077)**	0.0216
	Contribution to acid rain deposition **(0.123)**	0.0344
	Damage to lake and coastal waters **(0.170)**	0.0476
	Stratospheric ozone depletion **(0.155)**	0.0434
	Climate change **(0.155)**	0.0434
	Global warming **(0.144)**	0.0403

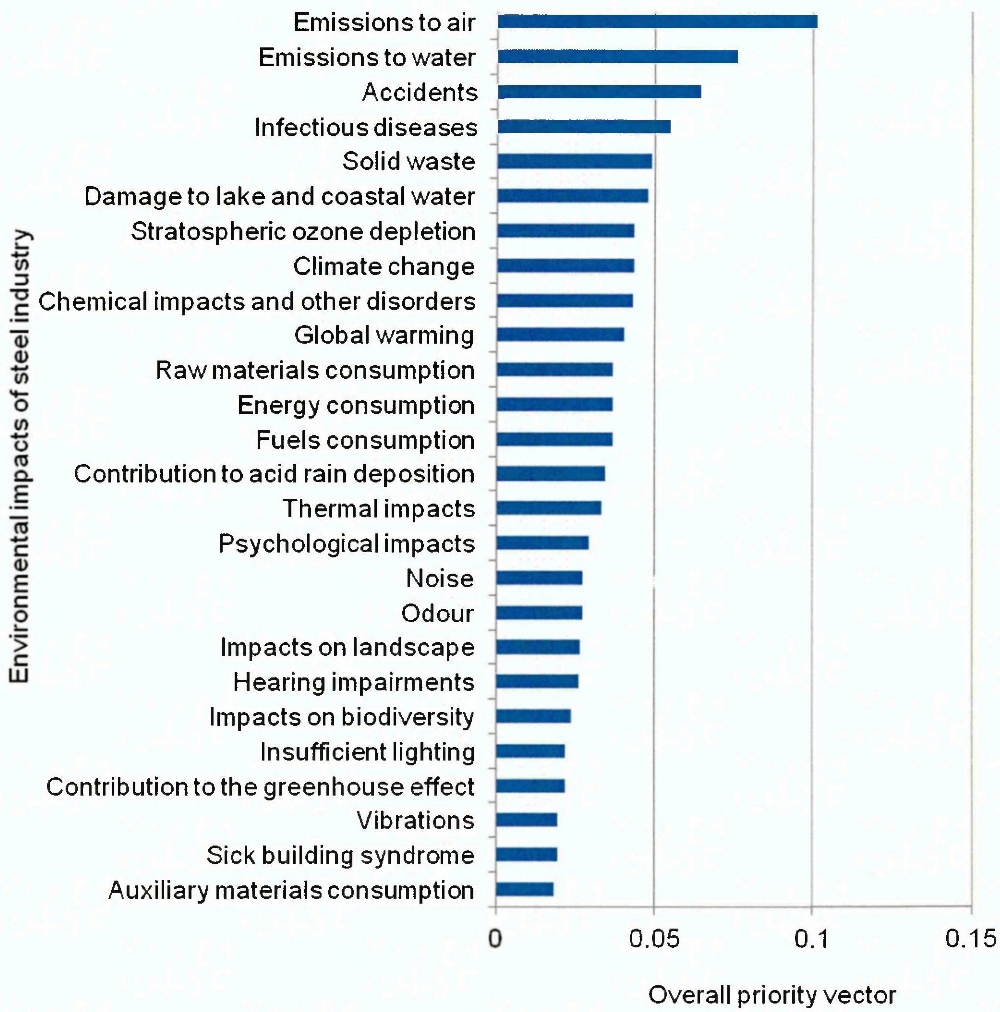

Figure 6.4 The importance rankings of the environmental

6.4 Conclusion

After developing the environmental impacts model in the steel industry using AHP software and indicating the most important criteria and sub-criteria, the checking of the validation of the proposed model has been presented. The validation was conducted in two ways. Firstly, the contents of the proposed model were validated using questionnaire. In this validation process, the validity of the contents of the proposed model was assessed, and the model was considered from the perspectives of the professionals in the steel industry. Secondly, the results of the AHP model about the priorities of the criteria and sub-criteria were validated using Mathematics. There is a significant agreement between the results of the AHP and the results using mathematics.

From the discussion above, it can be concluded that the proposed model is successful and validated for environmental impacts in the steel industry.

7. CHAPTER SEVEN

Conclusion, contribution to knowledge, limitations, applications and future research work

7.1 Discussion of research

Iron and steel are essential to everyday life, making up numerous products we all use. Steel manufacturing is expanding in most major steel producing countries (World Steel Association 2010). The processing of iron and steel is associated with a number of sustainable development challenges, including various economic, environmental and social issues. For example, the steel industry is an important source of employment and wealth creation. On the other hand, the impact on the environment of the steel industry is relatively large. The steel industry is one of the most important sources of pollutants. Different types of pollutants result from the different steps in steel production. These pollutants cause a variety of environmental impacts.

In this respect the steel industry must be able to measure and assess its environmental impacts and to demonstrate continuous improvements over the long term. Achieving this objective requires environmental management strategy to manage and minimise the impacts on the environment. This study focused on developing environmental impacts model in the steel industry to investigate the most important environmental parameters and their importance in order to manage the environmental impacts of the steel industry.

Based on the literature review and the elements considered as waste which were derived from the waste survey of the Libyan iron and steel industry, the potential environmental impacts of the steel industry were identified as criteria and sub-criteria. Then, the model was built using the AHP software based on the identified criteria and sub-criteria determining the goal. The model consists of the overall goal which is creating an environmental impacts model for the steel industry to identify, quantify and rank the criteria and sub-criteria to illustrate the situation and make the analysis clear and understandable. Pairwise comparisons were used to derive accurate ratio scale priorities.

The results were computed and presented as a prioritised list of environmental impacts. It can be concluded that the impacts of the steel industry on the working environment have a value of 0.312, the highest significant weight. The wastes generated and impacts on natural environment both have a value of 0.280, the second-highest. Resource consumption has the lowest weight, with a value of 0.127. In addition, findings from the use of AHP highlighted the importance of emissions to air, emissions to water, accident, infectious diseases, solid wastes and damage to lake and coastal waters respectively, with weights of 0.101, 0.076, 0.065, 0.055, 0.048 and 0.048 respectively. Other environmental impacts mentioned in this study are less important. A series of sensitivity analyses were conducted to investigate the impact of changing the priority of the criteria on the alternatives' ranking. Results are presented by tables and graphs, and discussed.

The validation of the proposed model was carried out to assess its validity and to see this model from the perspectives of the professionals in the steel industry.

7.2 Contribution to knowledge

Literature review has revealed that the steel industry still needs more attention to conduct environmental impacts assessment, improve hazardous waste management practices, and make environmental investments at regular intervals. Hence, the main contribution to knowledge presented by this research is a valid and robust model to measure environmental impacts of steel industry. The aim of the model is to investigate the most important environmental criteria and their importance in order to manage the environmental impacts of the steel industry. In addition, this research has delivered further contributions to the area of research, as listed below:

- This research presents new insight on waste elements in the Libyan iron and steel industry. Through literature and waste survey a list of waste elements were identified. They were then classified according to an information model.
- Based on this information and previous literature, a total list of 4 main criteria and 26 sub-criteria were compiled. These criteria are unique as they are based on the Libyan iron and steel industry.
- Furthermore, a contribution was made by analysing the relationship between each criterion. The outcome was a hierarchical order of each

criterion, with the most important criteria being at the top. Managers in steel industry will find it highly efficacious to know the relative importance of each environmental impact criteria. They will be able to focus their attention on the criteria which are more important to the industry.

- Another contribution was made by conducting sensitivity analysis in order to examine how changes in the weights of the criteria could affect the ranking results. This verified that the model is valid.

7.3 Limitations, applications and future research work

The model in this research work was developed and validated using information from the Libyan iron and steel industry. If the model is to be used in a different organisation, it is necessary to establish the relative importance of the criteria for the new setting. As technological development take place in the steel industry, it may be necessary to revise the list of criteria and sub-criteria used the model. This work has identified relative important of criterion that impact on the environment. However, it is necessary to measure impact on environment more accurately to validate the relative importance of criterion. A major piece of research is required to achieve this. Further improvements can be achieved by fine-Turing the relative importance of the criterion. This is best achieved by using the model in industry and making necessary adjustment as new evidence emerge on the impact on environment.

REFERENCES

- AL-HARBI, K. M. (2001). Application of the AHP in project management, *International journal of project management*, 19 (1), 19-27.

- BANSAL, P. and Roth, K. (2000). Why companies go green: a model of ecological responsiveness. *Academy of management journal* 43, 717–76.

- BARNES, W. and DHANDA, K. (2007). Reverse logistics and clean technology adoption: The case of the steel industry. *International business & economics research journal.* 6 (9), 7-20.

- BARTON, J. (1999). Sectoral restructuring and environmental management in the EU iron and steel sector. *European environment.* 9**,** 142–153.

- BRANCA, T. A., COLLA, V. and VALENTINI, R. (2009). A way to reduce environmental impact of ladle furnace slag. *Ironmaking and steelmaking,* 36 (8), 597-602.

- CLEMENS, B. (2001). Changing environmental strategies overtime: An empirical study of the steel industry in the United States. *Journal of environmental management.* 62, 221–231.

- CLEMENS, B. and PAPADAKIS, M. (2008). Environmental management and strategy in the Face of regulatory intensity: Radioactive contamination in the US steel industry. *Business strategy and the environment*, 17, 480-492.

- COLLIS, J. and HUSSEY, R. (2003). Business research: a practical guide for undergraduate and postgraduate students, Second edition. Basingstoke: Palgrave macmillan.

- DAHLSTROM, K. and EKINS, P. (2006). Combining economic and environmental dimensions: Value chain analysis of UK iron and steel flows. *Ecological economics,* 58 (3), 507-519.

- DAWSON, C. (2009) Introduction to research methods: A practical guide for anyone undertaking a research project, Fourth edition. How to books Ltd. Oxford, United Kingdom.

- DEMAILLY, D. and QUIRION, P. (2008). European emission trading scheme and competitiveness: A case study on the iron and steel industry. *Energy economics,* 30 (4), 2009-2027.

- EMI, T. and MIN, D. (2005). Strategies and achievements for moving towards minimum wastes and emissions in Asian steel industry. *Ironmaking and steelmaking*. 32,242-250.

- EXPERT CHOICE (2000). Quick start guide and tutorials.
- FORMAN, E. and GASS, S. (2001). The analytic hierarchy process-An exposition. *Operations research,* 49, (4), 469-486.
- GIELEN, D. and MORIGUCHI, Y. (2002). CO_2 in the iron and steel industry: An analysis of Japanese emission reduction potentials. *Energy policy,* 30 (10), 849-863.
- GIELEN, D. (2003). CO_2 removal in the iron and steel industry. *Energy conversion and management,* 44 (7), 1027-1037.
- GOLDEN, B. and WASIL, E. (1989). The analytic hierarchy process: Applications and studies. Heidelberg, Springer-Verlag.
- GRIMBLE, R. and CHAN, M.K. (1995). Stakeholder analysis for natural resource management in developing countries. Natural resources forum 19, 113-124.
- GRIMBLE, R. and WELLARD, K. (1997). Stakeholder methodologies in natural resource management: a review of principles, contexts experiences and opportunities. Agricultural systems 55, 173-193.
- HANROT, F., SERT, D., DELINCHANT, J., PIETRUCK, R., BURGLER, T., BABICH, A., FERNANDEZ M., ALVAREZ, R. and DIEZ, M. (2009). CO_2

mitigation for steelmaking using charcoal and plastics waste as reducing agents and secondary raw materials. 1st Spanish national conference on advances in materials recycling and eco – energy Madrid, 12-13 November 2009 S05-4.

- HARCEAG, V., WINCKELBAUER, G. and HRI, M. (1999) Pollution prevention: An opportunity for the Romanian iron and steel industry - Life cycle assessment, the first step to pollution prevention - Life cycle assessment, a case study in the iron and steel industry. Tools and methods for pollution prevention, 62, 39-49.

- HIDALGO, I., SZABO, L., CISCAR, JC. and SORIA, A. (2005). Technological prospects and CO_2 emission trading analyses in the iron and steel industry: A global model. *Energy*, 30, 583–610.

- HILLMAN, A. and HITT, M. (1999). Corporate political strategy formulation: a model of approach, participation, and strategy decisions. *Academy of management review* 24 (4), 825-842.

- HILSON, G. and MURCK, B. (2000). Sustainable development in the mining industry: clarifying the corporate perspective. *Resources policy* 26, 227–238.

- HO, W., DEY, P.K. and HIGSON, H.E. (2006). Multiple criteria decision making techniques in higher education, *International journal of educational management,* 20, (5), 319-337.

- HO, W. (2008) Integrated analytic hierarchy process and its applications - A literature review, *European journal of operation research,* 186, (1), 211-228.

- ISHIZAKA, A and LABIB, A (2009), Analytic hierarchy process and expert choice: Benefits and limitations, OR Insight, 22, (4), 201-20.

- KANEKO, S., YONAMINEB, A. and YONG J. (2006). Technology choice and CDM projects in China: case study of a small steel company in Shandong province. *Energy policy,* 34, 1139-1151.

- KAWAL, J. (2000). Development of environmentally friendly steel products (Eco-products) at Nippon steel. Nippon steel technical report No. 81.

- KIM, Y. and WORRELL, E. (2002). International comparison of CO_2 emission trends in the iron and steel industry. *Energy policy,* 30 (10), 827-838.

- KLASSEN, R. and WHYBARK, D. (1999). Environmental management in operations: the selection of environmental technologies. *Decision sciences* 30 (3), 601-631.

- KLASSEN, RD. and WHYARK, DC. (1999). The impact of environmental technologies on manufacturing performance. *Academy of Management* 42, 599-615.

- KUMAR, R. (2005). Research methodology. A step-by-step guide for beginners. First edition. Sage publications Ltd.

- KUMAR, S. and VAIDYA, O. (2006). Analytic hierarchy process: An overview of applications. *European journal of operational research* 169, 1, 1-29.

- KUMAR, R. (2011). Research methodology. A step-by-step guide for beginners. Third edition. Sage publications Ltd.

- LIANEXAY, B., SINTHA, G., SOUTTHANOME, K., MIRUZA, M., COOWANITWONG, N., DIEN, V. and UMA, W. (2007). Environmental impact assessment of Thai iron and steel factory. *International conference on sustainable architectural design and urban planning* Hanoi architectural university, May 15-16, 2007, Hanoi, Vietnam.

- LIBERATORE, M. and R. NYDICK (2008). The analytic hierarchy process in medical and health care decision making: A literature review. European *journal of operational research*, 189, (1), 194-207.

- LIBYAN IRON AND STEEL COMPANY, Annual reports (2007-2010).

- LIBYAN IRON AND STEEL COMPANY [on line] last accessed at 23 September 2010. http://libyansteel.com/lisco/index.php?lang=ar

- LIN, C.T. and WU, C.S. (2008) Selecting marketing strategy for private hotels in Taiwan using the analytic hierarchy process, *Service industries journal*, 28,(8), 1077-1091.

- LOGSDON, J. (1983). Organizational responses to environmental issues. In r*esearch in corporate social performance and policy* (Preston, L., ed.), 25–46. Greenwich, CT: JAI Press.

- MATEI, E., PREDESCU, C., SOHACIU, M. and BERBECARU, A. (2007). Method for assessment of potentially pollution of slag from iron and steel industry. Proc. of the 3rd IASME/WSEAS Int. Conf. on energy, environment, Ecosystems and sustainable development, Agios Nikolaos, Greece, July 24-26, pp. 23-25, 2007.

- MATHIESEN, L. and MCESTAD, O. (2004). Climate policy and the steel industry: Achieving global emission reductions by an incomplete climate agreement. *The energy journal*, Vol. 25, No. 4.

- MELINTE, I., BALANESCU, M., SURUGIU, G., TANTAU, A., MELINTE, O. and MITROI, D. (2008). Integrated system for the assessment and control of the CO_2 emissions released in iron and steel industry. The 9th WSEAS international conference on mathematics & computers in biology & chemistry. Bucharest, Romania. 48-53.

- MINETT, S. (2009). Swedish steel pant goes green and avoids clogging with continuous and filters. Pumps Magazine, 61, 34-36.

- MOTZ, H. and GEISELER, J. (2001). Products of steel slags an opportunity to save natural resources. *Waste management,* 21 (3), 285-293.

- NACHMIAS, C. and NACHMIAS, D. (2004) Research methods in the social sciences. Fifth edition. Arnold.

- ODA, J., AKIMOTO, K., SANO, F. and TOMODA, T. (2007). Diffusion of energy efficient technologies and CO_2 emission reductions in iron and steel sector. *Energy economics,* 29 (4), 868-888.

- OLIVER, C. (1991). Strategic responses to institutional processes. *Academy of management review* 16 (1), 145-179.

- OMKARPRASAD, V. and SUSHIL, K. (2006). Analytic hierarchy process: an overview of applications. *European journal of operational research,* 169, **(**1), 1-29.

- OZAWA, L., SHEINBAUM, C., MARTIN, N., WORRELL, E. and PRICE, L. (2002). Energy use and CO_2 emissions in mexico's iron and steel industry. *Energy,* 27 (3), 225-239.

- PANDYA, GH. and DHARMADHIKARI, DM. (2002). A comprehensive investigation of noise exposure in and around an integrated iron and steel works. AIHAJ, 63 (2), 172-177.

- PANIGRAHI, B. (2001). Processing of low carbon steel plate and hot strip-an overview. Bull. Mater. Sci., 24 (4), 361–371.

- PATTERSN, J. and CHENG, M. (1975) Steel industry wastes. J*ournal water pollution control federation*, 47, 1473-1476.

- PEASLEE, K. (2008). Opportunities and challenges in steel manufacturing: engineering a brighter future. *Iron & steel technology*, 91-102.

- PENIWATI, K. (1996). The analytic hierarchy process: The possibility theorem for group decision making. In proceedings of the fourth international symposium on the analytic hierarchy process, pp. 202-214. Simon Fraser university, Burnaby, British Columbia, Canada.

- PRAKESH, A. (1999). A new institutionalist perspective on ISO 14000 and responsible care. *Business strategy and the environment* 8, 322-335.

- PROCTOR, D.M., FEHLING, K. A. and SHAY, E. C., (2000). Physical and chemical characteristics of blast furnaces, basic oxygen furnaces and electrical arc furnaces steel industry. *Environmental science*. 34 (8), 1576-1582.

- RAMANATHAN, R. and GANESH, L. S. (1994). Group preference aggregation methods employed in the AHP: an evaluation and an intrinsic process for deriving members' weightages. European journal of operational research 79, 249-265.

- RAMANATHAN, R. (2001). A note on the use of the analytical hierarchy process for environmental impact assessment. *Journal of environmental management* 63, 27-35.

- REAP, J., ROMAN, F., DUNCAN, S. and BRAS, B. (2008). A survey of unresolved problems in life cycle assessment - Part 2: Impact assessment and interpretation. *Int J. Life cycle assess* 13, 374-88.

- REDDY, A., PRADHAN, R. and CHANDRA, S. (2006). Utilization of basic oxygen furnace (BOF) slag in the production of a hydraulic cement binder. *International journal miner. Process,* 79, 98-105.

- RENNINGS, K. and WIGGERING, H. (1997). Steps towards indicators of sustainable development: Linking economic and ecological concepts. *Ecological economics*, 20, 25-36.

- SAATY, T.L. (1980). The analytic hierarchy process, McGraw-Hill, New York, NY, U.S.A.

- SAATY, T. and FORMAN, E. (1992). The hierarchon: A Dictionary of hierarchies. Pittsburgh, PA: RWS publications.

- SAATY, T.L. (1994). Fundamentals of decision making and priority theory with the AHP, RWS publications, Pittsburgh, PA, U.S.A.

- SAATY, T.L. and VARGAS, L. (2000). Models, methods, concepts and applications of the analytic hierarchy process, Kluwer academic publishers, Boston, MA, U.S.A.

- SAATY, T. L. (2000). Fundamentals of decision making and priority theory with the Analytic Hierarchy Process. Pittsburg: RWS Publications.

- SAATY, T.L. (2001). Decision making with dependence and feedback the analytic network process, 2nd ed., RWS publications, Pittsburgh, PA.

- SAATY, T. L. (2005). Theory and application of the analytic network process: Decision making with benefits, opportunities, cost, and risks. Pittsburgh: RWS publications.

- SCAIFE, P., NUNN, J., COTTRELL, A. and WIBBERLEY, L. (2002). Towards sustainable steelmaking - an LCA perspective. *ISIJ international*, 42, S5-S9.

- SHEN, H. and FORSSBERG, E. (2003). An overview of recovery of metals from slags. *Waste manage.* 23, 933-949.

- SHIM, J. P. (1989). Bibliographical research on the analytic hierarchy process (AHP). Socio-economic planning sciences, 23, 161-167.

- SINGH, R., MURTY, H., GUPTA, S. and DIKSHIT, A. (2007). Development of composite sustainability performance index for steel industry. *Ecological indicators,* 7 (3), 565-588.

- SINGH, R., MURTY, H., GUPTA, S. and DIKSHIT, A. (2008a). Development and implementation of environmental strategies for steel industry. *Int. J. environmental technology and management*, 8,69-86.

- SINGH, R., MURTY, H., GUPTA, S. and DIKSHIT, A. (2008b) Integrated environment management in steel industries. *International journal of management and decision making,* 9 (2), 103-128.

- SLOANE, E.B., LIBERATORE, M.J., NYDICK, R.L., LUO, W. and CHUNG,Q.B. (2003), Using the analytic hierarchy process as a clinical engineering tool to facilitate an iterative, multidisciplinary, microeconomic health technology assessment, *Computers & operations research*, 30, 1447-1465.

- SPENGLER, T., GELDERMANN, J., HTIHRE, S., SIEVERDINGBECK, A. and RENTZ, O. (1998). Development of a multiple criteria based decision support system for environmental assessment of recycling measures in the iron and steel making industry. *Journal of cleaner production*, 6, 37-52.

- SZEKELY, J. (1996). Steelmaking and industrial ecology is steel a green material? *ISIJ international,* 36 (1), 121-132.

- TEKNOMO, K. (2006). Analytic hierarch process (AHP) tutorial. Available at http://people.revoledu.com/kardi/tutorial/ahp.

- TRIDECH, S. and CHENG, K. (2008). Low carbon manufacturing: Characterization, theoretical models and implementation. T*he 6th international conference on manufacturing research (ICMR08),* 9-11th September 2008. Brunel University, UK, 403-412.

- UDO, G. (2000). Using analytic hierarchy process to analyze the information technology outsourcing decision. *Industrial management and data system*, 100, (9), 421-429.

- VAIDYA, O. S. and KUMAR, S. (2006) Invited review analytic hierarchy process: An overview of applications, *European journal of operational research*, 169, 1-29.

- VAIDYA, O.S. and S. KUMAR, (2006). Analytic hierarchy process: An overview of applications, *European journal of operational research*, Vol. 169, 1-29.

- WANG, K., WANG, C., LU, X. and CHEN, J. (2007). Scenario analysis on CO_2 emissions reduction potential in China's iron and steel industry. *Energy policy* 35, 2320-2335.

- VARGAS, L. (1990). An overview of the analytic hierarchy process and its applications. *European journal of operational research* 48, (1), 2-8.

- WILLIAM, B. and DHANDA, K. (2007). Reverse logistics and clean technology adoption: The case of the steel industry. *International business & economics research journal.* 6, 7-20.

- WORLD STEEL ASSOCIATION. (2010). April 2010 crude steel production [on line]' last accessed at 25. May. 2010. http://www.worldsteel.org/?action=newsdetail&id=300

- WORLD STEEL ASSOCIATION. (2010). June 2010 crude steel production [on line]' last accessed at 30. Sep. 2010. http://www.worldsteel.org/?action=newsdetail&id=303

- ZAHEDI, F. (1986). The analytic hierarchy process: a survey of the method and its applications, Interface 16, (4), 96-108.

- ZENG, S., LAN, Y. and HUANG, J. (2009). Mitigation paths for Chinese iron and steel industry to tackle global climate change. *International journal of greenhouse gas control.* 3, 675-682.

- ZHOU, H., LI, G., NIE, Z. and ZUO, T. (2002). Discussion of environmental problem and study of environmental impact on steel industry in China. *Journal of iron and steel research international,* 9 (2), 24-27.

Appendix A

Crude steel production in the 65 countries

Crude steel production in the 65 countries, in thousands of metric tons (Source: World steel Association 2010)

No.	Region	June		% Ch.	6 months		% Ch.
		2010	2009		2010	2009	
1	Austria	636	525	21.1	3547	2464	43.9
2	Belgium	790 e	382	106.6	4156	2405	72.8
3	Bulgaria	58	61	-5.1	399	335	19.2
4	Czech Republic	464	386	20.2	2721	2045	33.0
5	Finland	340	262	29.6	1949	1249	56.1
6	France	1457	1109	31.4	8220	5859	40.3
7	Germany	3856	2514	53.4	22744	13834	64.4
8	Greece	210 e	211	-0.5	1040	1071	-2.9
9	Hungary	130	110	17.9	824	605	36.3
10	Italy	2264	1705	32.8	13530	9879	37.0
11	Luxembourg	175	138	26.8	1359	993	36.9
12	Netherlands	559	328	70.2	3140	1920	63.5
13	Poland	800 e	677	18.1	4238	3173	33.6
14	Romania	340 e	169	100.8	1859	1130	64.5
15	Slovakia	394	321	22.7	2432	1728	40.7
16	Slovenia	50 e	32	58.5	298	182	63.9
17	Spain	1380	1182	16.7	8851	6772	30.7
18	Sweden	447	219	104.3	2540	1356	87.3
19	United Kingdom	794	813	-2.3	5147	4406	16.8
20	Other E.U (e)	167 e	139	20.1	1013	835	21.2
European Union		**15311**	**11283**	**35.7**	**90004**	**62240**	**44.6**
21	Bosnia-Herzegovina	48	42	14.7	312	229	35.9

Appendix A (Continued)

No.	Region	June			6 months		
		2010	2009	% Ch.	2010	2009	% Ch.
22	Croatia	5 e	3	83.7	30	17	79.8
23	Macedonia	30 e	18	70.5	141	142	-0.9
24	Norway	45 e	53	-15.1	259	294	-12.1
25	Serbia	155	45	246.4	654	249	163.0
26	Switzerland	120	77	55.0	661	456	44.9
27	Turkey	2495	2191	13.8	13496	11938	13.1
Other Europe		**2898**	**2428**	**19.3**	**15552**	**13325**	**16.7**
28	Byelorussia	236	205	15.1	1342	1347	-0.4
29	Kazakhstan	405	350	15.7	2075	1883	10.2
30	Moldova	0 e	12	-100.0	190	122	55.7
31	Russia	5430	5122	6.0	32685	26784	22.0
32	Ukraine	2470	2304	7.2	16358	13615	20.1
33	Uzbekistan	60 e	64	-6.3	354	374	-5.3
The Commonwealth of Independent States (CIS)		**8601**	**8057**	**6.8**	**53004**	**44125**	**20.1**
34	Canada	1125 e	697	61.3	6539	4174	56.7
35	Cuba	25 e	13	90.8	143	110	29.5
36	El Salvador	7 e	6	9.4	40	17	129.9
37	Guatemala	25 e	24	3.3	144	84	72.0
38	Mexico	1435 e	1220	17.6	8455	6546	29.2
39	Trinidad and Tobago	50 e	33	51.4	306	170	80.5
40	United States	7199	4364	65.0	41007	24268	69.0
North America		**9866**	**6358**	**55.2**	**56635**	**35370**	**60.1**
41	Argentina	421	311	35.1	2448	1659	47.6

Appendix A (Continued)

No.	Region	June		% Ch.	6 months		% Ch.
		2010	2009		2010	2009	
42	Brazil	2850	1942	46.8	16380	10565	55.0
43	Chile	40 e	80	-50.0	204	493	-58.6
44	Colombia	90 e	69	31.4	496	525	-5.5
45	Ecuador	20 e	24	-15.6	112	127	-12.0
46	Paraguay	7 e	4	84.2	39	23	67.4
47	Peru	75 e	41	85.2	443	304	46.0
48	Uruguay	7 e	6	9.4	40	19	107.3
49	Venezuela	195 e	281	-30.7	1134	2273	-50.1
South America		**3705**	**2757**	**34.4**	**21297**	**15988**	**33.2**
50	Algeria	40 e	30	33.3	235	263	-10.5
51	Egypt	513	449	14.3	3043	2680	13.6
52	Libya	67	102	-35.0	396	572	-30.8
53	Morocco	14	54	-73.6	264	242	8.8
54	South Africa	690	599	15.3	4155	3363	23.6
55	Zimbabwe	0 e	0	0.0	0	0	0.0
Africa		**1324**	**1234**	**7.3**	**8093**	**7119**	**13.7**
56	Iran	1000	933	7.2	5942	5785	2.7
57	Qatar	165 e	125	32.3	988	556	77.9
58	Saudi Arabia	410	442	-7.4	2652	2219	19.5
Middle East		**1575**	**1500**	**5.0**	**9582**	**8560**	**12.0**
59	China	53766	49309	9.0	323172	266887	21.1
60	India	5350 e	5251	1.9	32529	30366	7.1
61	Japan	9352	6883	35.9	54573	36690	48.7
62	South Korea	4801	3939	21.9	28339	21943	29.2
63	Taiwan	1520 e	1234	23.2	9069	6935	30.8

Appendix A (Continued)

No.	Region	June		% Ch.	6 months		% Ch.
		2010	2009		2010	2009	
Asia		**74789**	**66616**	**12.3**	**447683**	**362820**	**23.4**
64	Australia	616	361	70.9	3543	1919	84.7
65	New Zealand	72	67	7.6	430	385	11.7
Oceania		**688**	**427**	**61.1**	**3974**	**2304**	**72.5**
Total 65 countries		***118756***	***100661***	***18.0***	***705823***	***551851***	***27.9***

The 65 country included in this table accounted for more than 98% of total world crude steel production in 2009.

C.I.S - Commonwealth of Independent States

e- estimated.

Appendix B

Questionnaire for Development of an Environmental Impact Model for Steel Industry

Sheffield Hallam University
SHARPENS YOUR THINKING

MATERIALS AND ENGINEERING RESEARCH INSTITUTE

Questionnaire for Development of an Environmental Impact Model for Steel Industry

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This paper consists of 14 pages including the cover page

Questionnaire for Development of an Environmental Impact Model for Steel Industry

We are aiming to develop an environmental impact model for steel industry as shown on page 4 of this document. Also we identified a list of pair wise comparison between the criteria and sub-criteria mentioned in the model in relation to the steel industry. As an experienced manager/engineer in this sector, we are seeking your assistance to make this exercise successful. Your participation means a great deal to us and we would like to thank you in advance for your time and consideration and your answers will be kept confidential.

❖ Part 1

Please complete the following information and return it together with the complete questionnaire;

Name: (optional)

……………………………………………………………………………………..

Designation:

……………………………………………………………………………………..

Years of Experience: (   )

Tel No: …………………………………

E-mail: …………………………………

❖ Part 2 Pair wise comparison

In this section a pair wise comparison between each two criteria or each two sub-criteria will be carried out. The following example shows a pair wise comparison between two criteria namely: (Resource consumption) and (Waste generated), the possible outcomes from this comparison should be ONLY one of the following three scenarios:

First Scenario, If you think the Resources consumption is equally important with the wastes generated, circle figure 1.

Second Scenario, If you think that the "Resources consumption" is for example, 8 times more important than the "Waste generated", then circle the figure 8 on the **LEFT** hand side.

Third Scenario, If you think it is the opposite i.e. the "Waste generated" is 8 times more important than the "Resources consumption", then circle figure 8 on the **RIGHT** hand side.

First Scenario:

Resources consumption		**Waste generated**
(Raw materials, Auxiliary materials, Energy, Fuels)		(Emissions at air, Emissions at water, Solid waste, Noise, Odour)
9 8 7 6 5 4 3 2	(1)	2 3 4 5 6 7 8 9

1=equal, 3=moderate, 5=strong, 7=very strong, 9=extreme

Second Scenario:

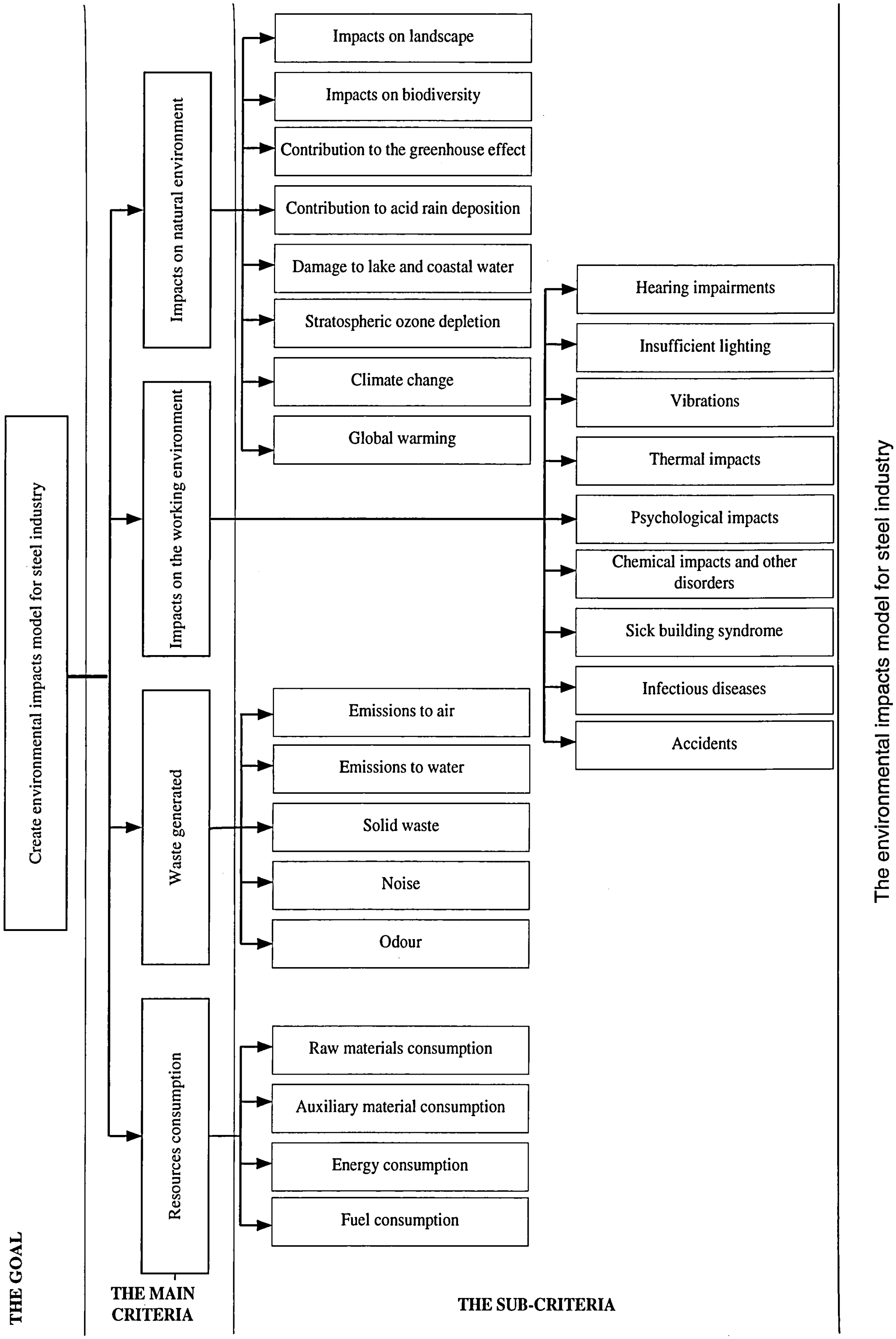
Resources consumption		**Waste generated**
(Raw materials, Auxiliary materials, Energy, Fuels)		(Emissions at air, Emissions at water, Solid waste, Noise, Odour)
9 (8) 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9

1=equal, 3=moderate, 5=strong, 7=very strong, 9=extreme

Third Scenario:

Resources consumption		**Waste generated**
(Raw materials, Auxiliary materials, Energy, Fuels)		(Emissions at air, Emissions at water, Solid waste, Noise, Odour)
9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 (8) 9

1=equal, 3=moderate, 5=strong, 7=very strong, 9=extreme


THE GOAL
Create environmental impacts model for steel industry
THE MAIN CRITERIA
Impacts on natural environment
Impacts on the working environment
Waste generated
Resources consumption
THE SUB-CRITERIA
Impacts on landscape
Impacts on biodiversity
Contribution to the greenhouse effect
Contribution to acid rain deposition
Damage to lake and coastal water
Stratospheric ozone depletion
Climate change
Global warming
Hearing impairments
Insufficient lighting
Vibrations
Thermal impacts
Psychological impacts
Chemical impacts and other disorders
Sick building syndrome
Infectious diseases
Accidents
Emissions to air
Emissions to water
Solid waste
Noise
Odour
Raw materials consumption
Auxiliary material consumption
Energy consumption
Fuel consumption
The environmental impacts model for steel industry

Section A: Please circle an appropriate number in the scale to indicate the relative importance of the two factors shown in each question.

Q1

Resource Consumption		**Waste generated**
(Raw materials, Auxiliary materials, Energy, Fuels)		(Emissions at air, Emissions at water, Solid waste, Noise, Odour)
9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9

Q2

Resource Consumption		**Impact on the working environment**
(Raw materials, Auxiliary materials, Energy, Fuels)		(Hearing impairments, Insufficient lighting, Vibration, Thermal impacts, Psychological impacts, Chemical impacts and other disorders, Sick building syndrome, Infectious disease, Accidents)
9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9

Q3

Resource Consumption		**Impacts on natural environment**
(Raw materials, Auxiliary materials, Energy, Fuels)		(Impacts on landscape, Impacts on biodiversity, Contribution to the greenhouse effect, Contribution to acid rain deposition, Damage to lake and coastal water, Stratospheric ozone depletion, Climate change, Global warming)
9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9

Q4

Waste generated		**Impact on the working environment**
(Emissions at air, Emissions at water, Solid waste, Noise, Odour)		(Hearing impairments, Insufficient lighting, Vibration, Thermal impacts, Psychological impacts, Chemical impacts and other disorders, Sick building syndrome, Infectious disease, Accidents)
9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9

Q5

Waste generated		**Impacts on natural environment**
(Emissions at air, Emissions at water, Solid waste, Noise, Odour)		(Impacts on landscape, Impacts on biodiversity, Contribution to the greenhouse effect, Contribution to acid rain deposition, Damage to lake and coastal water, Stratospheric ozone depletion, Climate change, Global warming)
9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9

Q6

Impact on the working environment		**Impacts on natural environment**
(Hearing impairments, Insufficient lighting, Vibration, Thermal impacts, Psychological impacts, Chemical impacts and other disorders, Sick building syndrome, Infectious disease, Accidents)		(Impacts on landscape, Impacts on biodiversity, Contribution to the greenhouse effect, Contribution to acid rain deposition, Damage to lake and coastal water, Stratospheric ozone depletion, Climate change, Global warming)
9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9

Section B: Please use the same way as above to compare the importance of the following sub-criteria.

Q7

Raw Materials Consumption		**Auxiliary Materials Consumption**
9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9

Q8

Raw Materials Consumption		**Energy Consumption**
9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9

Q9

Raw Materials Consumption		**Fuels Consumption**
9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9

Q10

Auxiliary Materials Consumption		**Energy Consumption**
9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9

Q11

Auxiliary Materials Consumption		**Fuels Consumption**
9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9

Q12

Energy Consumption		**Fuels Consumption**
9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9

Q13

Emissions at air		**Emission at water**
9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9

Q14

Emissions at air		**Solid waste**
9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9

Q15

Emissions at air		**Noise**
9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9

Q16

Emissions at air		Odour
9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9

Q17

Emission at water		Solid waste
9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9

Q18

Emission at water		Noise
9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9

Q19

Emission at water		Odour
9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9

Q20

Solid waste		Noise
9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9

Q21

Solid waste		Odour
9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9

Q22

Noise		Odour
9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9

Q23

Hearing impairments		Insufficient lighting
9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9

Q24

Hearing impairments		Vibrations
9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9

Q25

Hearing impairments		Thermal impacts
9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9

Q26

Hearing impairments		Psychological impacts
9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9

Q27

Hearing impairments		Chemical impacts and other disorders
9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9

Q28

Hearing impairments		Sick building syndrome
9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9

Q29

Hearing impairments		Infection diseases
9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9

Q30

Hearing impairments		Accidents
9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9

Q31

Insufficient lighting		Vibrations
9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9

Q32

Insufficient lighting		Thermal impacts
9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9

Q33

Insufficient lighting		Psychological impacts
9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9

Q34

Insufficient lighting		Chemical impacts and other disorders
9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9

Q35

Insufficient lighting		Sick building syndrome
9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9

Q36

Insufficient lighting		Infection diseases
9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9

Q37

Insufficient lighting		Accidents
9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9

Q38

Vibrations		Thermal impacts
9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9

Q39

Vibrations		Psychological impacts
9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9

Q40

Vibrations		Chemical impacts and other disorders
9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9

Q41

Vibrations		Sick building syndrome
9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9

Q42

Vibrations		Infection diseases
9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9

Q43

Vibrations		Accidents
9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9

Q44

Thermal impacts		Psychological impacts
9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9

Q45

Thermal impacts		Chemical impacts and other disorders
9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9

Q46

Thermal impacts		Sick building syndrome
9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9

Q47

Thermal impacts		Infection diseases
9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9

Q48

Thermal impacts		Accidents
9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9

Q49

Psychological impacts		Chemical impacts and other disorders
9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9

Q50

Psychological impacts		Sick building syndrome
9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9

Q51

Psychological impacts		Infection diseases
9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9

Q52

Psychological impacts		Accidents
9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9

Q53

Chemical impacts and other disorders		Sick building syndrome
9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9

Q54

Chemical impacts and other disorders		Infection diseases
9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9

Q55

Chemical impacts and other disorders		Accidents
9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9

Q56

Sick building syndrome		Infection diseases
9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9

Q57

Sick building syndrome		Accidents
9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9

Q58

Infection diseases		Accidents
9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9

Q59

Impacts on landscape		Impacts on biodiversity
9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9

Q60

Impacts on landscape		Contribution to the greenhouse effect
9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9

Q61

Impacts on landscape		Contribution to acid rain deposition
9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9

Q62

Impacts on landscape		Damage to lake and coastal water
9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9

Q63

Impacts on landscape		Stratospheric ozone depletion
9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9

Q64

Impacts on landscape		Climate change
9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9

Q65

Impacts on landscape		Global warming
9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9

Q66

Impacts on biodiversity									Contribution to the greenhouse effect							
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9

Q67

Impacts on biodiversity									Contribution to acid rain deposition							
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9

Q68

Impacts on biodiversity									Damage to lake and coastal water							
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9

Q69

Impacts on biodiversity									Stratospheric ozone depletion							
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9

Q70

Impacts on biodiversity									Climate change							
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9

Q71

Impacts on biodiversity									Global warming							
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9

Q72

Contribution to the greenhouse effect									Contribution to acid rain deposition							
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9

Q73

Contribution to the greenhouse effect									Damage to lake and coastal water							
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9

Q74

Contribution to the greenhouse effect									Stratospheric ozone depletion							
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9

Q75

Contribution to the greenhouse effect									Climate change							
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9

Q76

Contribution to the greenhouse effect		Global warming
9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9

Q77

Contribution to acid rain deposition		Damage to lake and coastal water
9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9

Q78

Contribution to acid rain deposition		Stratospheric ozone depletion
9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9

Q79

Contribution to acid rain deposition		Climate change
9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9

Q80

Contribution to acid rain deposition		Global warming
9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9

Q81

Damage to lake and coastal water		Stratospheric ozone depletion
9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9

Q82

Damage to lake and coastal water		Climate change
9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9

Q83

Damage to lake and coastal water		Global warming
9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9

Q84

Stratospheric ozone depletion		Climate change
9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9

Q85

Stratospheric ozone depletion		Global warming
9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9

Q86

Climate change			Global warming
9 8 7 6 5 4 3 2		1	2 3 4 5 6 7 8 9

Section C:

Are there any more criteria and sub-criteria should have been considered and need to be included, please provide details?

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Are there any criteria or sub-criteria have no added value and need to be deleted, please provide details?

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Thank you very much

Waste Data

Waste name: liquids associated with natural gas			
Description of waste	**Source**	**Chemical properties**	**Physical properties**
Colourless liquid with a pungent smell produced from natural gas condensate as a result of pressure difference.	Natural gas pipelines in the natural gas station.	Not obtained.	- Colourless liquid. - A pungent odour like smell of natural gas.
Annual quantity	**Current disposal or treatment methods**	**Notes**	
Unstable and vary depends on operating conditions.	Collected in plastic drums and transferred to the company's yard waste.		

Waste Data

Waste name: Belts residues			
Description of waste	**Source**	**Chemical properties**	**Physical properties**
	- Direct reduction plant. - Calcining plant. - Steel melt shops (1&2).	Not obtained.	Rubber belts with brown and black colour.
Annual quantity	**Current disposal or treatment methods**	**Notes**	
Approximately 1300 metres per year.	Collected and transferred to the company's yard waste.	- Can be used in units that do not need to great lengths in cold rolling mill. - Can be sold.	

Waste Data

Waste name: Plastic drums			
Description of waste	**Source**	**Chemical properties**	**Physical properties**
Plastic drums with different sizes.	- Water and gas unit services. - Power and desalination plant.	Not obtained.	Cylindrical plastic drums with different sizes.
Annual quantity	**Current disposal or treatment methods**	**Notes**	
Approximately 2700 drums per year.	Sold by auction.	Can be used to save some liquids such as consumed oils.	

Waste Data

Waste name: Acetone			
Description of waste	**Source**	**Chemical properties**	**Physical properties**
Liquid chemical used for the purpose of cleaning.	Water and gas unit services.	The same chemical properties of acetone.	Colourless liquid, highly volatile.
Annual quantity	**Current disposal or treatment methods**	**Notes**	
Approximately 4000 litres per year.	Collected in drums and sold by auction.	Consider the possibility of re-use in cleaning operations during maintenance.	

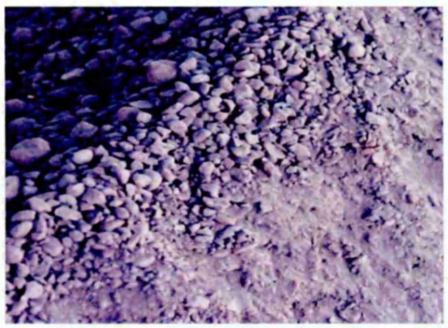
Waste Data

Waste name: Photocopying toners			
Description of waste	**Source**	**Chemical properties**	**Physical properties**
Remnants of the ink photocopiers resulting from the maintenance of these machines.	All departments of the company.	Carbon in polymer "Styrene Acrylate copolymer polyester resin".	Fine powder with a black colour.
Annual quantity	**Current disposal or treatment methods**	**Notes**	
Approximately 6 cans of each department.	Collected and transferred to the company's yard waste.		

Waste Data

Waste name: Printing inks			
Description of waste	**Source**	**Chemical properties**	**Physical properties**
Used printer cartridges with different sizes and types.	All departments of the company.	Not obtained.	Liquid and fine powder with different colours.
Annual quantity	**Current disposal or treatment methods**	**Notes**	
Not obtained.	Disposal by the Department of Computers.		

Waste Data

Waste name: Iron oxide powder			
Description of waste	**Source**	**Chemical properties**	**Physical properties**
	Direct reduction plant.	Iron oxide (Fe_2O_3) 88.6% Aluminium oxide (Al_2O_3) 4.1% Silicon dioxide (SiO_2) 3.0% Calcium oxide CaO 0.73% Magnesium oxide (MgO) 0.5% Sulphur (S) 0.006%	- Small balls of iron oxide ore range in size from 3 mm or less.
Annual quantity	**Current disposal or treatment methods**	**Notes**	
Approximately 70000 tons/year.	Collected and transferred to the company's yard waste.	- Can be re-used with the carbon as raw materials for electric arc furnaces. - Can be sold to cement company.	

Waste Data

Waste name: Sludge			
Description of waste	**Source**	**Chemical properties**	**Physical properties**
	Direct reduction plant.	Ferrous oxide (FeO) 62.0% Silicon dioxide (SiO_2) 1.7-2.6% Magnesium oxide (MgO) 0.7-2.2% Aluminium oxide (Al_2O_3) 0.5-2.0% Calcium oxide CaO 1.4% Phosphor (P) 0.09%	Iron powder with dark colour.
Annual quantity	**Current disposal or treatment methods**	**Notes**	
Approximately 17197 tons/year.	Collected and transferred to the company's yard waste.	- Can be re-used for electric arc furnaces. - Can be used in the paint and cement industry.	

Waste Data

Waste name: Iron powder after reduction			
Description of waste	**Source**	**Chemical properties**	**Physical properties**
	Direct reduction plant.	Iron (Fe) 89.6% Aluminium (Al) 3.19% Manganese (Mg) 2.2% Silicon (Si) 2.2% Calcium (Ca) 1.9% Carbon (C) 1.8%	Metal pieces and small balls with diameter less than 3 mm.
Annual quantity	**Current disposal or treatment methods**	**Notes**	
Approximately 14600 tons/year.	Collected and transferred to the company's yard waste.	Can be re-used for electric arc furnaces.	

Waste Data

Waste name: Powder lime and dolomite			
Description of waste	**Source**	**Chemical properties**	**Physical properties**
	Calcining plant	Not obtained.	White powder produced from the burning of lime.
Annual quantity	**Current disposal or treatment methods**	**Notes**	
Approximately 1100 tons/year.	Collected and transferred to the company's yard waste.		

Waste Data

Waste name: Refractory bricks			
Description of waste	**Source**	**Chemical properties**	**Physical properties**
	- Direct reduction plant. - Steel melt shops (1&2). - Bar and rod mill. - Light and medium sections mill. - Hot strip mill. - Cold rolling mill.	Aluminium oxide (Al_2O_3) 50-75% Silicon dioxide (SiO_2) 20-45% Iron oxide (Fe_2O_3) 0.2-2.0% Titanium dioxide TiO_2 3.0%	- Specific Density = 2.7 g/cm^3 - Porosity = 17%. - Water absorption = 6%.
Annual quantity	**Current disposal or treatment methods**	**Notes**	
Approximately 2500 tons/year.	Collected and transferred to the company's yard waste.	Can be crushed and mixed with thermal cement and used as a thermal material.	

Waste Data

Waste name: Furnace slag			
Description of waste	**Source**	**Chemical properties**	**Physical properties**
	Steel melt shops (1&2).	Calcium oxide CaO 30-45% Silicon dioxide (SiO_2) 23-27% Iron oxide (Fe_2O_3) 14-27% Aluminium oxide (Al_2O_3) 6-8% Magnesium oxide (MgO) 4-7% Manganese oxide (MnO) 0.5-2%	- High hardness and strength. - Density: 1.6-2.1 g/cm^3
Annual quantity	**Current disposal or treatment methods**	**Notes**	
- Depends on the amount of production. - The average amount accumulated per year about 104,068 tons/year.	Throw in the slag yard.	After milling can be used in some industries, such as building materials, concrete, and road construction.	

Waste Data

Waste name: Belts dust			
Description of waste	**Source**	**Chemical properties**	**Physical properties**
	- Direct reduction plant. - Steel melt shops (1&2).	Iron oxide (Fe_2O_3) 54% Calcium oxide CaO 29% Magnesium oxide (MgO) 14% Silicon oxide SiO 1.4% Aluminium oxide (Al_2O_3) 1.2%	Powder resulting from reduced iron.
Annual quantity	**Current disposal or treatment methods**	**Notes**	
Approximately 12850 tons/year.	Collected and transferred to the company's yard waste.	This waste is highly toxic.	

Waste Data

Waste name: Furnace dust			
Description of waste	**Source**	**Chemical properties**	**Physical properties**
Dust pellets collected by dust suction system.	- Direct reduction plant. - Steel melt shops (1&2).	Iron oxide (Fe_2O_3) 30% Calcium oxide CaO 13% Magnesium oxide (MgO) 5% Manganese oxide (MnO) 4% Carbon (C) 2%	Oxide powder.
Annual quantity	**Current disposal or treatment methods**	**Notes**	
Approximately 12,850 tons/year.	Collected and transferred to the company's yard waste.	- This waste is highly toxic.	

Waste Data

Waste name: Carbon electrodes			
Description of waste	**Source**	**Chemical properties**	**Physical properties**
	Steel melt shops (1&2).	Not obtained.	Not obtained.
Annual quantity	**Current disposal or treatment methods**	**Notes**	
Not obtained.	- Some of them can be repaired and re-used. - Carbon electrodes that cannot be repaired break and are added to the furnaces as a source of carbon.	Consider the possibility of grinding and recycling.	

Waste Data

Waste name: Waste spreaders			
Description of waste	**Source**	**Chemical properties**	**Physical properties**
	Casting machines in steel melt shops (1&2).	Depends on the specifications of steel product.	Blocks of iron resulting from the freeze molten metal in spreaders.
Annual quantity	**Current disposal or treatment methods**	**Notes**	
Approximately 5700 tons/year.	Re-used as raw material for electric arc furnaces.	Consider the possibility of grinding and recycling.	

Waste Data

Waste name: Scrap rollers			
Description of waste	**Source**	**Chemical properties**	**Physical properties**
	- Steel melt shops (1&2). - Bar and rod mill. - Light and medium sections mill. - Hot strip mill. - Cold rolling mill.	Not obtained.	Hollow cylindrical shape and flat.
Annual quantity	**Current disposal or treatment methods**	**Notes**	
Approximately 470 tons/year.	Sold by auction.	Consider the possibility of utilising them as raw materials for the manufacture of some spare parts produced by the company.	

Waste Data

Waste name: Scales			
Description of waste	**Source**	**Chemical properties**	**Physical properties**
	- Steel melt shops (1&2). - Bar and rod mill. - Light and medium sections mill. - Hot strip mill. - Cold rolling mill.	Iron oxide (Fe_2O_3) 97.1-98.1% Silicon dioxide (SiO_2) 0.41-0.88% Aluminium oxide (Al_2O_3) 0.06-0.46% Calcium oxide CaO 0.06-0.18% Carbon (C) 0.07-1.0% Phosphor (p) 0.01-0.03%	Scales and powders of small sizes ranging from 0.4 mm to 1.5 mm.
Annual quantity	**Current disposal or treatment methods**	**Notes**	
Approximately 5670 tons/year.	Collected and transferred to the company's yard waste.	- Consider the possibility of adding to the raw materials in electric arc furnaces as a source of oxygen. - Can be used in the cement industry.	

Waste Data

Waste name: Scrap bar and rod			
Description of waste	**Source**	**Chemical properties**	**Physical properties**
	Bar and rod mill.	Depends on the specifications of products.	Twisted iron rods with different diameters.
Annual quantity	**Current disposal or treatment methods**	**Notes**	
Depends on the amount of production (approximately 2% of the weight of production).	Re-used as raw material (scrap) for electric arc furnaces.		

Waste Data

Waste name: Scrap slabs			
Description of waste	**Source**	**Chemical properties**	**Physical properties**
	Hot strip mill.	According to the chemical composition of specifications (American Iron and Steel Institute AISI 1008 to AISI1023).	Metal slabs with different thickness.
Annual quantity	**Current disposal or treatment methods**	**Notes**	
Approximately 7215 tons/year.	Re-used as scrap for electric arc furnaces.		

Waste Data

Waste name: Remnants of the slabs			
Description of waste	**Source**	**Chemical properties**	**Physical properties**
	- Steel melt shop 2. - Hot strip mill.	According to the chemical composition of specifications (American Iron and Steel Institute AISI 1008 to AISI1023).	Iron pieces
Annual quantity	**Current disposal or treatment methods**	**Notes**	
Approximately 22,000 tons/year.	Re-used as scrap for electric arc furnaces.		

Waste Data

Waste name: Thermal wool			
Description of waste	**Source**	**Chemical properties**	**Physical properties**
Fibres and a solid insulating material used to insulate steam lines and heavy fuel, as well as thermal insulation in reheating furnaces.	- Direct reduction plant. - Steel melt shop (1&2). - Bar and rod mill. - Light and medium sections mill. - Hot strip mill. - Power and desalination plant. -Water and gas services unit	Not obtained.	Solid material (wool and fibres).
Annual quantity	**Current disposal or treatment methods**	**Notes**	
Non-specific and varies depending on the maintenance program.	Collected and stored in a dedicated yard.	This waste is highly toxic.	

Waste Data

Waste name: Insulating substance			
Description of waste	**Source**	**Chemical properties**	**Physical properties**
- Organic substance used in the gas services unit. - Solid fibres used to isolate the steam lines and heavy fuel.	Gas services unit.	The same properties of these materials before used.	Light materials with white colour; can be spread by the wind.
Annual quantity	**Current disposal or treatment methods**	**Notes**	
Approximately 2 m^3 organic substance and 25kg solid fibre.	Collected and transferred to the company's yard waste.		

Waste Data

Waste name: Residues of the aluminium samples			
Description of waste	**Source**	**Chemical properties**	**Physical properties**
	Quality control laboratories.	Aluminium (Al) ≥ 96.2% Silicon (Si) ≤ 0.5% Magnesium (Mg) ≤ 0.8% Zinc (Zn) ≤ 0.5% Copper (Cu) ≤ 0.5% Ti anium (Ti) ≤ 0.03%	Aluminium alloys.
Annual quantity	**Current disposal or treatment methods**	**Notes**	
Approximately 2 tons/year.	Re-used as raw material for electric arc furnaces in steel melt shop 2.	Can be sold by auction.	

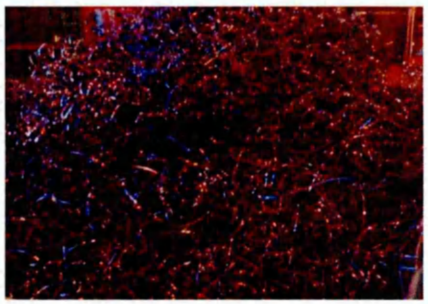
Waste Data

Waste name: Zinc slag			
Description of waste	**Source**	**Chemical properties**	**Physical properties**
Templates zinc slag.	A galvanizing line in cold rolling mill.	Zinc (Z_n) 96% Aluminium (Al) 1.5% Iron (Fe) 1.1% Lead (Pb) 0.026%	Solid templates, square shaped and silver colour.
Annual quantity	**Current disposal or treatment methods**	**Notes**	
Approximately 225 kg/year.	Collected and stored in dedicated yard to sell by auction.	Consider the possibility of extracting zinc and reusing.	

Waste Data

Waste name: Oxides treatment			
Description of waste	**Source**	**Chemical properties**	**Physical properties**
	Chemical processing line in cold rolling mill.	Ferrous oxide (FeO) 0.76% Iron oxide (Fe_2O_3) 97.8% Aluminium oxide (Al_2O_3) 0.2% Silicon dioxide (SiO_2) 0.16% Calcium oxide CaO 0.15% Phosphor (p) 0.009%	Fine powder with a brown colour.
Annual quantity	**Current disposal or treatment methods**	**Notes**	
Approximately 2720 tons/year.	Collected in bags and transferred to the company's yard waste.	Consider the possibility of injecting this waste into electric arc furnaces using carbon injection system.	

Waste Data

Waste name: Grinding and Turning waste			
Description of waste	**Source**	**Chemical properties**	**Physical properties**
	- Mechanical maintenance workshop. - Planning and manufacturing spare parts Unit - Steel melt shops (1&2). - Training centre.	Depends on the type of metal.	Different metals pieces.
Annual quantity	**Current disposal or treatment methods**	**Notes**	
Approximately 205 tons/year.	Re-used as scrap for electric arc furnaces.		

Waste Data

Waste name: Emulsion cooling			
Description of waste	**Source**	**Chemical properties**	**Physical properties**
A mixture of water and oil.	- Mechanical maintenance workshop. - Steel melt shops (1&2). - Bar and rod mill. - Light and medium sections mill. - Hot strip mill. - Cold rolling mill. - Quality control laboratories. - Planning and manufacturing spare parts unit. - Training centre.	Contains a proportion 1.5-5% of oil.	White viscous liquid
Annual quantity	**Current disposal or treatment methods**	**Notes**	
Approximately 350 m^3/year.	Oil-water separation, collection of oil in metal drums; transferred to yard to sell by auction.	Consider the possibility of re-refined oil for reuse.	

Waste Data

Waste name: Consumed oils			
Description of waste	**Source**	**Chemical properties**	**Physical properties**
	- Direct reduction plant. - Calcining plant. - Steel melt shops (1&2). - Bar and rod mill. - Light and medium sections mill. - Hot strip mill. - Cold rolling mill. - Power and desalination plant. - Electrical networks unit. - Water and gas services unit -Planning and manufacturing spare parts unit. - Mechanical maintenance workshop. - Transportation unit.	Depends on the nature of the use of oil.	- Viscous liquids with dark colour (Between brown and black). - Other properties depend on the nature of the use of oil.
Annual quantity	**Current disposal or treatment methods**	**Notes**	
-Depends on the operating and maintenance programmes. - Approximately 220 tons/year.	Collected in metal drums and transferred to the yard to sell by auction.	Consider the possibility of re-refined oil for reused.	

Waste Data

Waste name: Metal drums			
Description of waste	**Source**	**Chemical properties**	**Physical properties**
	- Direct reduction plant. - Calcining plant. - Steel melt shops (1&2). - Bar and rod mill. - Light and medium sections mill. - Hot strip mill. - Cold rolling mill. - Power and desalination plant. - Electrical networks unit - Water and gas services unit -Planning and manufacturing spare parts unit. - Mechanical maintenance workshop. - Transportation unit.	Not obtained.	Cylindrical metal drums with different capacities.
Annual quantity	**Current disposal or treatment methods**	**Notes**	
Approximately 5000 drums/year.	Collected and transferred to the yard waste to sell by auction.	Can be reused to store consumed oils.	

Waste Data

Waste name: Consumed greases			
Description of waste	**Source**	**Chemical properties**	**Physical properties**
Remnants of the grease due to the leakage in machines.	- Direct reduction plant. - Calcining plant. - Steel melt shops (1&2). - Bar and rod mill. - Light and medium sections mill. - Hot strip mill. - Cold rolling mill. - Power and desalination plant. - Electrical networks unit - Water and gas services unit -Planning and manufacturing spare parts unit. - Mechanical maintenance workshop. - Transportation unit.	Depends on the nature of use.	- Consumed greases with dark colours. - Other properties depend on the nature of the use of oil.
Annual quantity	**Current disposal or treatment methods**	**Notes**	
Depends on the operating and maintenance programmes.	Collected in metal drums and transferred to the company's yard waste.	Consider the possibility of treatment for re-used.	

Waste Data

Waste name: Wood			
Description of waste	**Source**	**Chemical properties**	**Physical properties**
	- Steel melt shops (1&2). - Power and desalination plant.	Not obtained.	Pieces of wood (different sizes and shapes).
Annual quantity	**Current disposal or treatment methods**	**Notes**	
Approximately 750 tons/year.	Collected and transferred to the yard to sell by auction.	Consider the possibility of re-use by civil maintenance unit.	

Waste Data

Waste name: Cardboard boxes and plastic			
Description of waste	**Source**	**Chemical properties**	**Physical properties**
Cardboard boxes and plastic bags used to store operating requirements and spare parts.	- Steel melt shops (1&2). - Power and desalination plant. - Quality control laboratories.	Not obtained.	Waste paper and plastic in different sizes.
Annual quantity	**Current disposal or treatment methods**	**Notes**	
Approximately 50 tons/year.	Collected and transferred to the yard to sell by auction.	Consider the possibility of separating each type separately and selling to recycling plants.	

Waste Data

Waste name: Consumed spare parts			
Description of waste	**Source**	**Chemical properties**	**Physical properties**
Consumed spare parts due to either the end of their life or due to routine maintenance and annual maintenance.	- All the company's factories. - Power and desalination plant. - Mechanical maintenance workshop. - Water and gas services unit - Transportation unit.	Materials metal (mostly iron).	Solids in different sizes and types.
Annual quantity	**Current disposal or treatment methods**	**Notes**	
Not obtained and depends on the operating and maintenance programmes.	Collected and transferred to the yard to sell by auction.	Consider the possibility of use of the components of these pieces to restore some of the other pieces.	

Waste Data

Waste name: Consumed electronic parts			
Description of waste	**Source**	**Chemical properties**	**Physical properties**
Consumed electronic parts due to maintenance of electronic devices such as transistors, resistors, capacitors, and some integrated circuits.	- Direct reduction plant. - Calcining plant. - Steel melt shops (1&2). - Bar and rod mill. - Light and medium sections mill. - Hot strip mill. - Cold rolling mill - Power and desalination plant. - Electrical networks unit. - Water and gas services unit. - Computer, systems and communications unit. - Electrical and electronic maintenance workshop. - Mechanical maintenance workshop. - Transportation unit. - Training centre.	Not obtained.	Electronic parts in different sizes and types.
Annual quantity	**Current disposal or treatment methods**	**Notes**	
Not obtained and depends on the maintenance programmes	Collected it in boxes and transferred to the company's yard waste.	Consider the possibility of sale by auction.	

Waste Data

Waste name: Consumed electronic devices			
Description of waste	**Source**	**Chemical properties**	**Physical properties**
- Computers. - Printers. - Photocopiers. - Communication devices.	- Computer, systems and communications unit. - Electrical and electronic maintenance workshop.	Not obtained.	Electronic devices in different types.
Annual quantity	**Current disposal or treatment methods**	**Notes**	
Approximately 90 computers, 10 printers, 5 photocopiers and 30 communication devices.	Sold by auction.		

Waste Data

Waste name: Consumed batteries			
Description of waste	**Source**	**Chemical properties**	**Physical properties**
	- Steel melt shops (1&2). - Bar and rod mill. - Light and medium sections mill. - Transportation unit.	Not obtained.	Batteries in different size and types.
Annual quantity	**Current disposal or treatment methods**	**Notes**	
Approximately 0.5-1.0 ton/year.	Collected and transferred to the yard to sell by auction.		

Waste Data

Waste name: Tyres - shredded			
Description of waste	**Source**	**Chemical properties**	**Physical properties**
	- Steel melt shops (1&2). - Transportation unit.	Carbon 70-75% Hydrogen 6-7% Sulphur 1.3-1.7% Iron 13-15% Zinc oxide 1.2-2.0%	Black rubber tyres of different sizes.
Annual quantity	**Current disposal or treatment methods**	**Notes**	
Approximately 1000 pieces/year.	Sold by auction.	Consider the possibility of use as a source of carbon in steel melt shops.	

Waste Data

Waste name: Construction and demolition wastes			
Description of waste	**Source**	**Chemical properties**	**Physical properties**
- Sand. - Marble. - Brick. - Flagstones. - Empty paint cans. - Plastic tubes. - Electrical materials. - Iron pipe. - Glass. - Water heaters. - Other materials.	Civil maintenance unit.	Inorganic substances.	Solids (different sizes and colours).
Annual quantity	**Current disposal or treatment methods**	**Notes**	
Approximately: $10m^3$ (sand, marble, brick and flagstones). 500 pieces (empty paint cans). 1.0 ton (plastic tubes). 500 pieces (electrical materials). 1.0 ton (iron pipe). $2\ m^3$ (glass). 100 pieces (water heaters). 200 pieces (other materials).	Collected and transferred to the company's yard waste.	Consider the possibility of recycling of some materials such as metal cans and plastic bottles.	

Waste Data

Waste name: Filters			
Description of waste	**Source**	**Chemical properties**	**Physical properties**
Dust filters.	- Calcining plant. - Steel melt shops (1&2).	Not obtained.	Textile bags.
Annual quantity	**Current disposal or treatment methods**	**Notes**	
Approximately 500 filters/year.	Collected and transferred to the company's yard waste.		

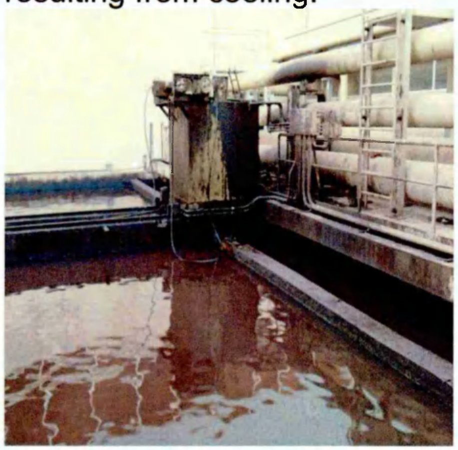
Waste Data

Waste name: Granules carbon			
Description of waste	**Source**	**Chemical properties**	**Physical properties**
Small granules of carbon.	Power and desalination plant.	Carbon is a key element in the composition of this material.	Black granules.
Annual quantity	**Current disposal or treatment methods**	**Notes**	
Approximately 0.5 ton/year.	Collected in drums and transferred to the company's yard waste.		

Waste Data

Waste name: Wastewater			
Description of waste	**Source**	**Chemical properties**	**Physical properties**
Water and some human waste resulting from the use of health facilities company.	Health facilities in the company.	BOD_5 360 ppm S.S 424 ppm pH 6-8 COD 640 ppm TSD 100 ppm Ammonia 26 ppm Heavy metals none Toxic materials none Max hardness 5 ppm	Smelly liquid.
Annual quantity	**Current disposal or treatment methods**	**Notes**	
Approximately 120000 m^3/year.	Transferred to the water treatment plant for treatment and disposal at sea.	Consider the possibility of use in cooling.	

Waste Data

<table>
<tr><td colspan="4">Waste name: Industrial wastewater</td></tr>
<tr><th>Description of waste</th><th>Source</th><th>Chemical properties</th><th>Physical properties</th></tr>
<tr>
<td>Water contains some impurities resulting from cooling.
</td>
<td>- Direct reduction plant.
- Steel melt shops (1&2).
- Bar and rod mill.
- Light and medium sections mill.
- Hot strip mill.
- Cold rolling mill
- Power and desalination plant.
- Water and gas services unit.</td>
<td>
<table>
<tr><th>Item</th><th>DR plant</th><th>Steel plant</th></tr>
<tr><td>Max Temperature C°</td><td>60°</td><td>52°</td></tr>
<tr><td>S.S (pmm)</td><td>50</td><td>150</td></tr>
<tr><td>TDS (pmm)</td><td>400</td><td>700</td></tr>
<tr><td>$CaCO_3$</td><td colspan="2">40</td></tr>
<tr><td>Chloride as Cl (pmm)</td><td>50</td><td>200</td></tr>
<tr><td>pH</td><td colspan="2">7.5-8.5</td></tr>
</table>
</td>
<td>Semi-dark liquid.</td>
</tr>
<tr><th>Annual quantity</th><th>Current disposal or treatment methods</th><th>Notes</th><th></th></tr>
<tr><td>Not obtained.</td><td>Transferred to the water treatment plant for treatment. Part re-used in direct and indirect cooling; remainder disposed of at sea.</td><td></td><td></td></tr>
</table>

Waste Data

Waste name: Waste paper (consumed paper)			
Description of waste	**Source**	**Chemical properties**	**Physical properties**
Consumed paper resulting from daily use.	All company departments.	Properties of paper.	Properties of paper.
Annual quantity	**Current disposal or treatment methods**	**Notes**	
Not obtained.	Marketing to recycling plants.		

Waste Data

Waste name: Trash			
Description of waste	**Source**	**Chemical properties (%)**	**Physical properties**
Non-industrial waste such as paper, wood, empty cans and food waste.	All company departments.	Organic substance such as food wastes and inorganic substances such as paper, wood and cans.	Mixed substances (different sizes and colours).
Annual quantity	**Current disposal or treatment methods**	**Notes**	
Not obtained.	Throw the waste into landfill outside the company.	Consider the possibility of sorting the trash from the source for recycling such as paper, metal cans and plastic (particularly the remnants of offices).	