Quantification of energy consumption and production drivers in steel manufacturing plants

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Dissertation submitted in fulfilment of the requirements for the degree *Magister* in Mechanical Engineering at the Potchefstroom Campus of the North-West University

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May 2016

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ABSTRACT

Title: Quantification of energy consumption and production drivers in steel manufacturing plants

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Keywords: Energy consumption, Production, Quantification process, Steel plants

The South African government has introduced regulations with the aim to monitor and reduce carbon emissions. Energy efficiency tax incentives and future compulsory Department of Energy reporting are reviewed in this study. These regulations require accurate and verifiable data of energy consumption and production drivers to determine energy savings.

Steel production plants are large, integrated and complex energy consumers; errors in quantification can therefore be considerable. Research has shown that current quantification techniques use inaccurate data due to disorganised, decentralised and unverifiable data sources and collecting procedures. The need therefore exists to improve the quality of the steel plants' energy reporting and quantification of energy consumption.

In this study, background is provided on a steel plant's production process and main components. The different energy carriers consumed are identified and their measurement process described. The study conducts a literature review of current energy quantification techniques in steel manufacturing companies. The requirements for Measurement and Verification specified in global and local standards are reviewed.

A methodology is also developed to quantify energy consumption and production drivers on a steel plant. The methodology is presented as a set of steps that can be followed. The steps consists of identifying, quantifying and normalising the energy carriers and production drivers on a plant. The methodology also includes verification and validation steps from literature.

The methodology compiled in the study is validated on steel production organisations with facilities based in South Africa. The results are compared with previous quantification results published. Differences in the estimation of energy carriers is observed as 9%, 10%, 1% and 2% for the four case studies respectively. The main reason for the differences is that previous quantification methods use untraceable assumptions.

ACKNOWLEDGEMENTS

I would like to thank God, for showing me His way during the years that led up to the commencement of this study. Without His love and guidance, I would not have succeeded.

To my parents, brother and close family. Thank you for the life lessons you have taught me through the years and your unconditional love, support and encouragement during my studies.

To Dr Jan Vosloo, thank you for your valuable inputs and guidance during the writing of this dissertation.

To all my friends and colleagues, thank you for the valuable inputs, guidance and support.

Prof E.H. Mathews and Prof M. Kleingeld, thank you for giving me the opportunity to do my Magister degree at CRCED Pretoria.

Thank you to TEMM International (Pty) Ltd and Enermanage (Pty) Ltd for the opportunity, financial assistance and support to complete this study.

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LIST OF ABBREVIATIONS

AD	Air Dried
AR	As Received
BF	Blast Furnace
BFG	Blast Furnace Gas
BOF	Basic Oxygen Furnace
COG	Coke Oven Gas
CIS	Commonwealth of Independent States
CMVPSA	Council of Measurement and Verification Professionals of South Africa
DB	Dry Basis
DoE	Department of Energy
DR	Direct Reduction
EAF	Electric Arc Furnace
EIA	U.S. Energy Information Administration
GHG	Greenhouse Gas
GRI	Global Reporting Initiative
IEA	International Energy Agency
IPMVP	International Performance Measurement and Verification Protocol
ISO	International Organisation for Standardisation
LPG	Liquefied Petroleum Gas
M&V	Measurement and Verification
MVCSA	Measurement and Verification Council of South Africa
PCI	Pulverised Coal Injection
SABS	South African Bureau of Standards
SANAS	South African National Accreditation System
SANEDI	South African National Energy Development Institute
SANS	South African National Standard
SI	International System of Units
SL/RN	Stelco-Lurgi/Republic Steel-National Lead

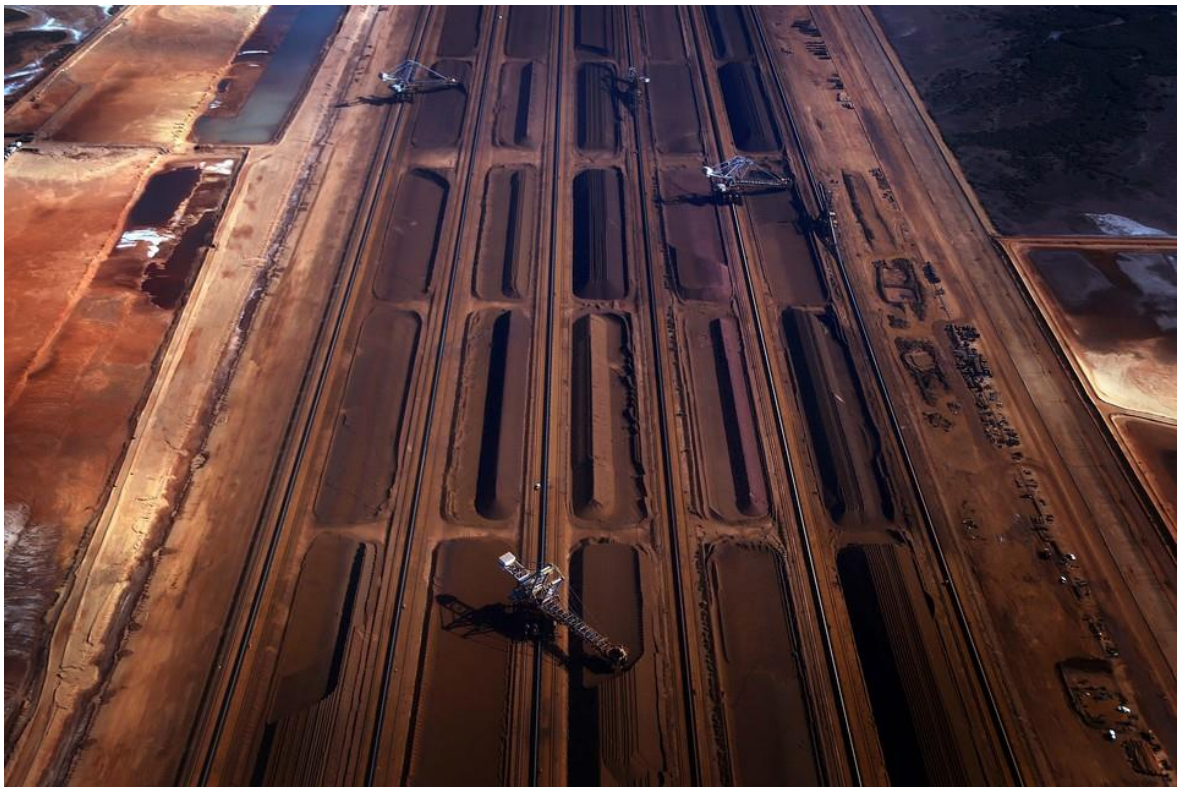
LIST OF SYMBOLS

A	Ash
CV	Calorific Value
D	Production Driver
E	Energy
e	Error
IM	Inherent Moisture
HHV	Higher Heating Value
m	Mass
MM	Molar Mass
M	Moisture
VM	Volatile Matter
TM	Total Moisture
P	Power
SE	Specific Energy
e_v	Specific Energy by Volume
e_m	Specific Energy by Mass
V	Volume

LIST OF UNITS

GJ	Gigajoule
GWh	Gigawatt-hour
g/mole	Gram per mole
kWh	Kilowatt-hour
kg	Kilogram
m^3	Cubic metre
MJ	Megajoule
MJ/kg	Megajoule per kilogram
MJ/m^3	Megajoule per cubic metre
MWh/t	Megawatt-hour per tonne
TJ	Terajoule
t	Tonne

1 INTRODUCTION



Bucket-wheel reclaimers are used to move iron ore at a loading terminal [1]

1.1 Background on energy

1.1.1 GLOBAL ENERGY

Global energy consumption is the total energy consumed by all of civilisation. It includes the consumption of all energy sources employed towards civilisation's activities by all sectors, by all countries. Global energy consumption is usually quantified per year. As it is the measure of civilisation, global energy consumption has profound implications for civilisation's economic, social and political sectors.

Because of the importance of energy consumption, organisations such as the International Energy Agency (IEA), the European Environment Agency and the U.S. Energy Information Administration (EIA) document and distribute energy figures intermittently. Superior data and comprehension of global energy consumption may expose universal tendencies and patterns, which could assist in isolating present energy issues and inspire a drive towards valuable cooperative solutions.

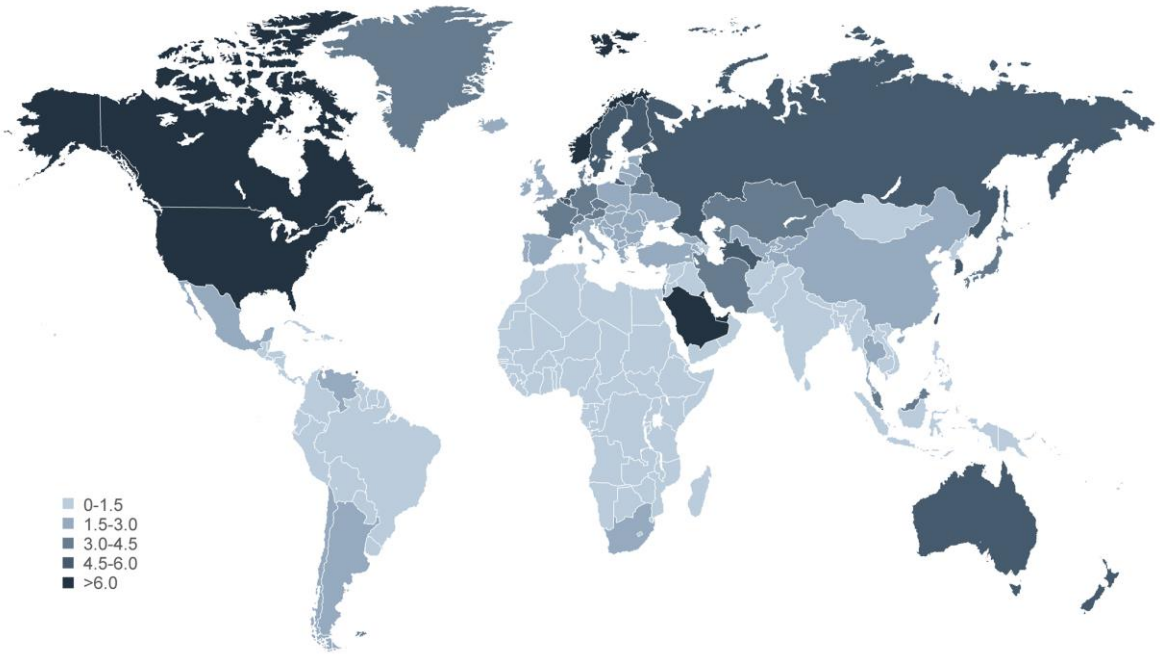


Figure 1-1: World primary energy consumption per capita, adapted from BP [2]

Fossil fuel energy consumption growth peaked in the years 2000 to 2008. In October 2012, coal accounted for half the rise in energy consumption of the previous decade, increasing faster than all renewable energy sources [2], [3].

Figure 1-1 shows the world primary energy consumption per capita. The unit of the primary energy consumption is million tonnes oil equivalent. Asia consumes 41% of the total global energy supply, while North America and Europe consume close to 21%, respectively [2].

1.1.2 ENERGY IN SOUTH AFRICA

South Africa's energy sector is vital to its economy, as the country depends on its large scale coal mining industry to fuel a large fleet of coal fired power stations. South Africa has minimal reserves of oil and natural gas and expends its large coal deposits to fulfil most of its energy demands, predominantly in the electricity generation industry. Most of the oil expended in the country, used primarily in the transportation sector, is imported from Middle Eastern and West African manufacturers and is refined locally. South Africa also has a sophisticated synthetic fuels industrial sector, manufacturing gasoline and diesel fuels. The synthetic fuels industry produces almost all of the country's locally manufactured petroleum due to minimal crude oil production [4].

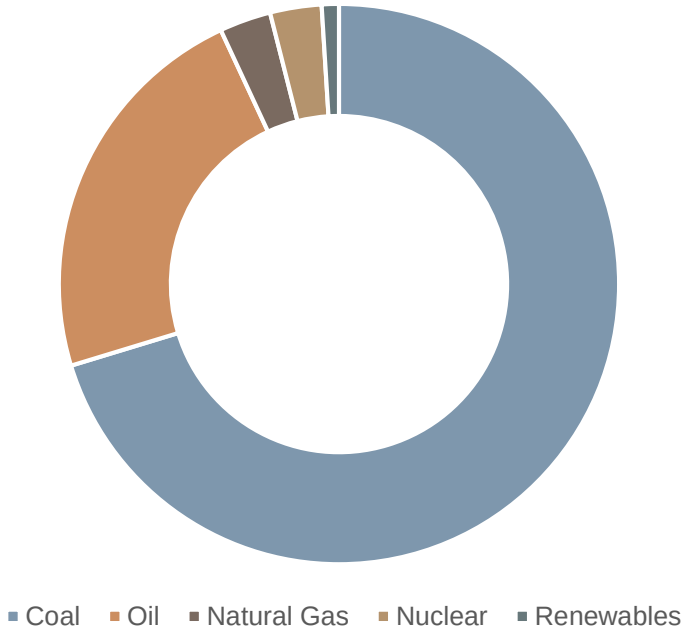


Figure 1-2: Total primary energy consumption in South Africa 2014 [4]

South Africa's total primary energy consumption is indicated in Figure 1-2. Primary energy consisted of 71% from coal, trailed by 23% from oil, 3% from natural gas, 3% from nuclear and 1% from renewables (primarily from hydropower) [2]. South Africa's dependency on coal has steered the country to grow to be the foremost carbon dioxide emitter in Africa and the 14th largest emitter per capita globally [4].

South Africa’s economy is highly energy intensive which leads to high carbon emissions. South Africa’s energy sector is responsible for a significant portion of its Greenhouse Gas (GHG) emissions. To address the challenges of climate change South Africa has taken steps to reduce its business-as-usual GHG emissions by 34% by 2020 and 42% by 2025 [5]. The steps taken to achieve this are presented by the government as new regulations.

1.2 Overview of regulations

1.2.1 SOUTH AFRICAN DEPARTMENT OF ENERGY

New regulations concerning the mandatory provision of energy data have been published in Section 19 of the National Energy Act. The regulations require consumers to report on industry specific energy consumption values if their yearly energy consumption is above 180 TJ (Terajoule) or equivalent 50 GWh (Gigawatt-hour) [6].

The South African Department of Energy (DoE) requires mandatory reports in a set form and period. The regulation aims to support the DoE to gather, arrange and distribute energy data in an effective way. This will enable the DoE to distribute accurate energy information. Additionally, the information will be used to guarantee a well-versed energy planning procedure for the country [7].

It is consequently important that these energy consumers keep accurate, up-to-date and well documented data. To ensure that this is possible, consumers must − constantly and accurately − monitor consumed energy sources. A process with the goal of quantifying consumption data conforming to global and local standards will help to address this need [8].

1.2.2 SECTION 12L, 12I TAX INCENTIVES

In 2009, the Minister of Finance revealed that there would be tax incentives for organisations that can validate energy efficiency savings, employing the Income Tax Act of 1962 for this purpose.

Similar tax incentives have been available since 2009, in the form of Section 12I, the Industrial Policy Project Investment incentive for production-related projects with a requirement to reduce 10% of the energy consumption. Soon after that, the suggested Section 12L regulations on the grant for energy efficiency savings were published for public comment by 15 November 2011. The DoE published the opening date of 1 November 2013 for the Section 12L regulation. The Section 12L regulation stipulates that an income deduction must be allowed for energy efficiency savings achieved by the entity in respect of a year of assessment [9].

The Section 12L regulation specifies the process to follow for determining the quantity of energy efficiency savings and requirements for receiving the proposed tax grant. The energy efficiency savings are calculated using energy consumption and a production driver. It requires that energy savings reports have to be compiled by Measurement and Verification (M&V) professionals. The M&V body has to be accredited by the South African

National Accreditation System (SANAS). The reported savings must be certified by the South African National Energy Development Institute (SANEDI) through the issuing of a certificate [10].

To meet the requirements of 12L, government has provided a structure to implement 12L with technical support. This is given in the form of the South African National Standard (SANS) 50 010 guarantee through the accreditation of energy efficiency M&V bodies by SANAS and approval through SANEDI.

This requires verifiable data of energy consumption and production drivers in order to calculate the energy efficiency savings. The verified data on the kWh energy efficiency savings (that SANEDI will be the authority on) will be used to calculate the total deductions against taxable income. This verified data will form the basis to calculate the estimated tax revenue forgone, currently at 45c per kWh, set to increase to 95c per kWh in 2015 [11], [12].

1.3 Background on the steel industry

1.3.1 SECTORIAL ENERGY IN SOUTH AFRICA

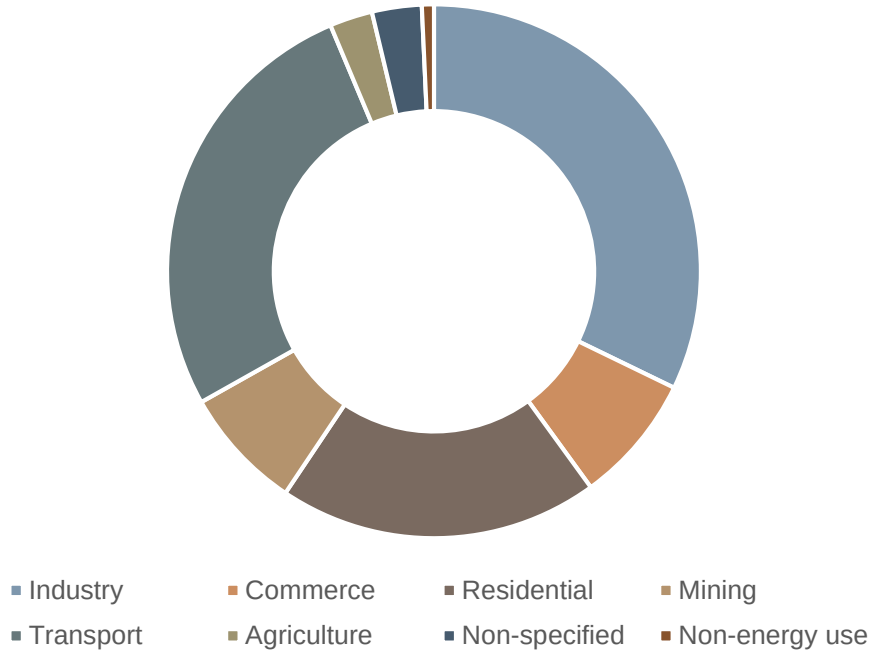


Figure 1-3: Sectorial consumption of energy in South Africa 2006 [13]

The South African sectorial energy consumption is shown in Figure 1-3. Industry, residential and transport sectors are the three major energy consuming sectors. In 2004, they accounted for 79.6% of final energy demand whilst in 2005 and 2006, they accounted for 78.2% and 78.4%, respectively [13]. This study focuses on the industrial sector, specifically

the steel production industry. Steel production plants are large, complex and integrated energy consumers and errors in quantification can therefore be considerable. Increasing energy efficiency in steelmaking is vital to ensure the competitiveness of the industry and to reduce environmental impacts [14].

1.3.2 STEEL PRODUCTION

World steel production figures indicate global development. The world steel production figures for 2013 are shown in Figure 1-4. In 2013, global crude steel production was 1 607 million tonnes (t). Presently, the largest steel manufacturing country is China, which accounted for 48.5% of global steel production in 2013. In 2008 and 2009, yield decreased in the majority of steel manufacturing countries as a consequence of the global recession; in 2010 it began to increase again [15].

Data by the World Steel Association placed South Africa as the 21st largest crude steel manufacturing country globally in 2013. South Africa is also the largest steel manufacturer in Africa, producing about 45% of the total crude steel of the region during 2013 [15].

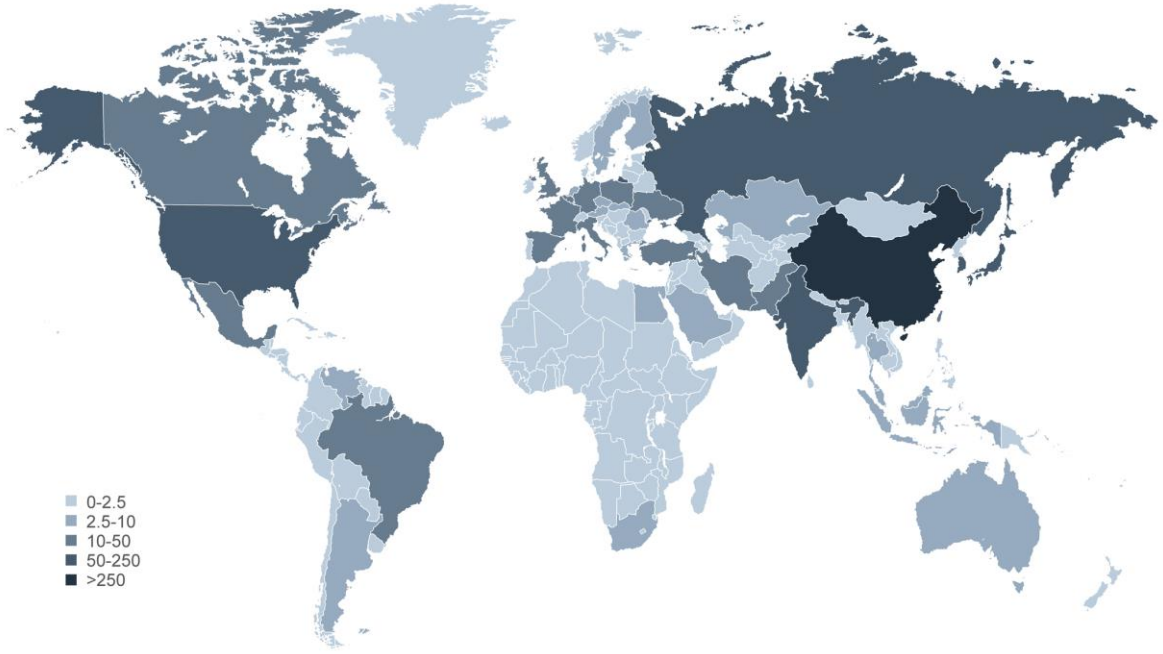


Figure 1-4: World steel production in 2013, adapted from World Steel Association [15]

Total South African crude steel production amounted to 7.1 million tonnes in 2013, an increase of 3.2%, compared with 6.9 million tonnes during 2012 [16]. This represents about 0.4% of world production, which reached 1 606 million tonnes in 2013 according to the World Steel Association [15], an increase of 3% when compared with 2012.

The quantification of the steel production as presented in this section is important. The steel production figures are required for the regulations in the previous section. The production figures are used to calculate energy efficiency savings. It can also be used to determine the competitiveness of the steel plant in the global and local market. Energy efficiency plays a large role in reducing operational costs and increasing competitiveness.

1.4 Research motivation

Steel production facilities are large consumers of various energy commodities. Due to new regulations the need exists to improve the quantification of a plant's energy consumption and production figures. This section will highlight the needs that can be addressed.

The study is internationally relevant since these plants are located all over the world. Energy consumption and steel production reporting is a global requirement. It impacts industrial, environmental and financial sectors. With uniform information available on a global scale, industries can benchmark their performance in these sectors with other countries.

A key motivation for the study is also the continued increase in energy and operational costs of large industrial plants such as steel production facilities. This has put strain on steel manufacturers to remain competitive. By improving the collection of consumption and production information of such plants, informed management decisions can be made. This will affect the cost of the production of steel. It improves awareness in the facility on energy consumption and production.

Current quantification techniques use inaccurate data due to disorganised and decentralised data sources and collecting procedures. More accurate data gathering techniques are needed in order to improve the quality of the energy consumption and production driver data. There is also no standard procedure for the collection of this data.

There are external factors and entities that require accurate and verifiable data on the workings of steel production facilities. Large companies undergo independent audits of their numbers on an annual basis. The data is also provided to government entities for mandatory reporting of energy consumption. This information is also used to determine tax incentives.

Internal factors that also provide motivation for improved quantification techniques are numerous. The data will simplify the auditing and verification of the plant energy consumption and steel production. The improvement of data integrity and accuracy will facilitate the advancement of management of the production plant. Enhanced budgeting and reporting can be used in management strategies that in turn can identify opportunities that can be acted upon.

1.5 Research objectives

The objective of the study is to develop a methodology for the accurate and verifiable quantification of energy consumption and steel production in steel production facilities. The methodology will provide a generic process that can be followed and adapted for any steel producer. It can be implemented on steel plants as the standard procedure for quantification.

The quantification procedure should provide an accurate representation of the steel plant's consumption of different energy commodities and steel production numbers. The information that is used in the procedure must be readily available to plant personnel. The data also needs to be accurate to a degree that can be proven with a level of certainty detailed in the study. The procedure should require minimal information input still to produce these results.

The information gathered by this procedure must conform to global and local information standards and M&V requirements set for the industry. The information must also comply with the requirements of tax incentive regulations and the mandatory provision of energy information to the DoE.

Finally, the study must be validated by implementing the methodology on steel production facilities based in South Africa. The results of the implementation have to be analysed, verified and validated. The results of the research procedure must be compared to published results.

1.6 Overview of dissertation

Chapter 1

An overview of global and South African energy consumption and steel production is provided in this chapter. Current energy reporting regulations are summarised in regard to energy consumption and production. The motivation and objective of the study is stated.

Chapter 2

This chapter provides background on a steel plant's production process, components and energy carriers. A literature review is conducted of energy quantification techniques and local and global standards. The requirements for Measurement and Verification is reviewed.

Chapter 3

A research methodology is developed to quantify energy consumption on a plant. The procedure is presented as a set of steps that can be followed to assist in the process. The procedure consists of identifying, quantifying and normalising the energy consumers on a plant.

Chapter 4

The methodology compiled in the study is implemented on steel production organisations with facilities based in South Africa. The results are analysed, verified and validated against procedure criteria and compared with previous quantification results published.

Chapter 5

The chapter provides the conclusion and final discussion of the study. Recommendations for future study in energy and production quantification is made.

2 LITERATURE REVIEW



Blast furnace [17]

2.1 Introduction

This chapter summarises the literature reviewed for the study. The literature review consists of an overview of steel production facilities, energy carriers, current energy quantification techniques and reporting standards.

An overview of steel production facilities centres on the different components in the process and their energy consumption. The study examines the raw material preparation processes, ironmaking processes and steel production processes. Further, the global benchmark for energy consumption in steel plants is reviewed for comparison with this study.

An overview is provided of the energy carriers consumed within a steel plant. The energy carriers reviewed are electricity, gas and coal. Focus is placed on how the energy carrier is measured and what properties are required for this study.

The current quantification methods in the steel industry are reviewed. To achieve this, the study will look at the world's largest steel producing companies of the largest steel producing countries. Focus will be placed on the companies' published information and the basis of reporting used to obtain the information published.

Finally, an overview of the reporting standards available will be provided. The standards that will be reviewed are those mentioned in the steel producing company reports for the global standard. This study reviews the international measurement standards as well as those available in South Africa for the purpose of utilising this information in the study.

The information presented and reviewed in this chapter will be used to develop a methodology. The methodology can be used to quantify the energy consumption and production drivers that are used and produced within a steel production facility.

2.2 Overview of steel production facilities

2.2.1 OVERVIEW OF PRODUCTION PROCESS

This section provides an overview of the production process in steel facilities. A basic overview of the process of steel production is required, since the study will quantify the energy consumption and production drivers. Attention is placed on the main components and their energy consumption as well as their production output.

Globally, steel is produced via two main routes: the Blast Furnace Basic Oxygen Furnace (BF-BOF) route and Electric Arc Furnace (EAF) route, which are shown in Figure 2-1. Variations and combinations of the production routes also exist throughout the industry [14].

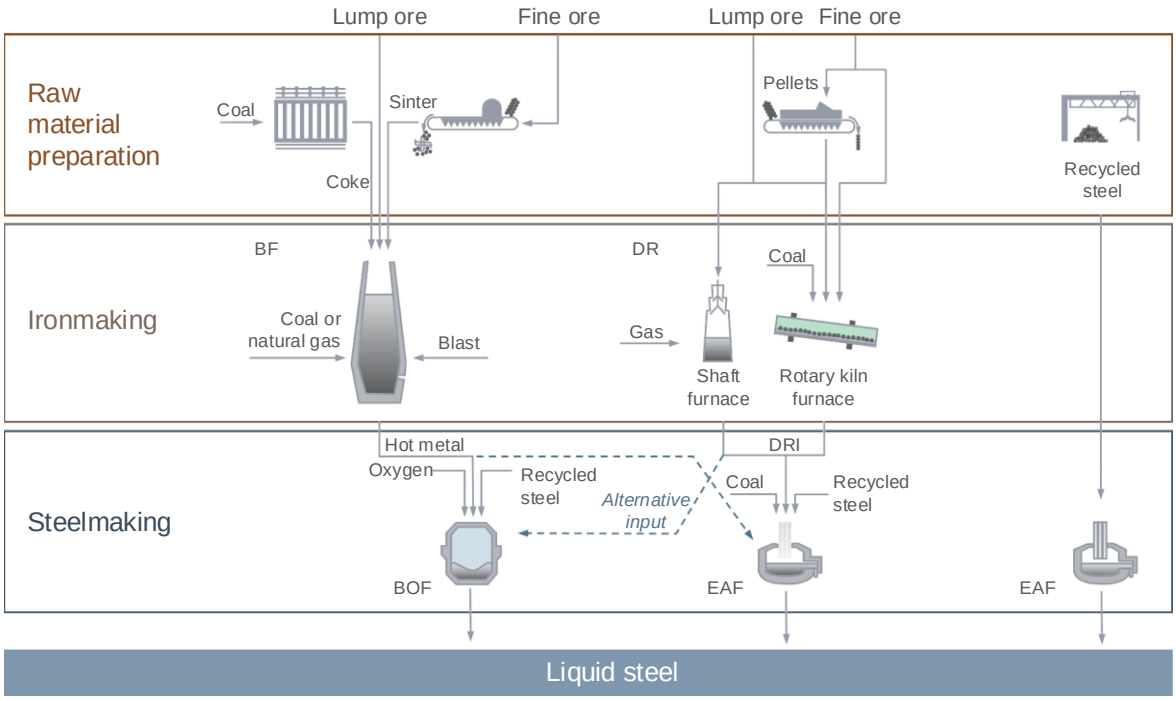


Figure 2-1: Steel production routes, adapted from World Steel Association [14]

The BF-BOF route produces steel predominantly using raw materials such as iron ore, coal, limestone and recycled steel. About 70% of steel is produced using the BF-BOF route. First, iron ores are reduced to iron, also called hot metal or pig iron. Then the iron is converted to steel in the BOF. After casting and rolling or / and coating, the steel is delivered as coil, plate, sections or bars [14].

Steel made in an EAF uses electricity to melt recycled steel. Depending on the plant configuration and availability of recycled steel, other sources of metallic iron such as Direct Reduced Iron (DRI) or hot metal can also be used. Additives, such as alloys, are used to adjust the steel to the desired chemical composition. Electrical energy can be supplemented with oxygen injected into the EAF. Downstream process stages, such as casting, reheating and rolling, are similar to those found in the BF-BOF route. About 29% of steel is produced via the EAF route [14].

Most steel products remain in use for decades before they can be recycled. Therefore, there is not enough recycled steel to meet growing demand using the EAF steelmaking method alone. Demand is met through a combined use of the BF-BOF and EAF production methods. All of these production methods use recycled steel scrap as an input. Consequently, all new steel contains recycled steel [14].

2.2.2 RAW MATERIAL PREPARATION

Coke making

The main raw materials in the iron production process are coke, iron ore and limestone. Coke is produced from coking coal in a carbonisation process. By-products of the coking process are coke oven gas, breeze, tar and benzoyl. The by-products are separated and cleaned in a by-product processing plant and are used as energy carriers in the plant [18].

Coke is a material with high carbon content and porosity. It has high resistance to breakage and low reactivity with gases, particularly CO_2. Coke production is an important part of the integrated iron and steel plants using BF-BOF route, acting as a reducing agent, as a source of thermal energy, and providing physical support for the burden in blast furnace. Coke is produced by heating coking coals up to 1200 °C for several hours in coke ovens to drive off volatile compounds and moisture. Coke production accounts for around 10% of the energy demand in a BF-BOF plant [19], [20].

Sinter plant

The iron ores that are used for iron making have to be pre-treated. The iron ores are made into sinter and pellets. In the sintering plant, iron ore is mixed with breeze or coke and is heated to produce a homogeneous sinter. Mixtures of iron ores are ground and mixed with a fluxing agent to yield pellets [18].

The purpose of the sinter plant is to process fine-grained raw materials into a coarse-grained iron ore sinter, ready to be charged to the blast furnace. Sintering of fine particles into a porous clinker (sinter) is necessary to improve the permeability of the burden, making reduction easier. A high quality sinter has high reducibility, which reduces the intensity of blast furnace operations and reduces coke demand [19].

In the sintering process, a blend of different ores, ferrous containing materials and fine coke particles are deposited on a large travelling grate. The coke at the top of the blend is ignited by gas burners, which can be fuelled by coke oven gas, blast furnace gas, or natural gas. As the grate moves, air is sucked from the top through the mixture, enabling combustion through the entire layer and complete sintering; where the temperatures may reach 1480 °C. At the end of the strand, the material is cooled by air and finished sinter is size-screened [20].

2.2.3 OVERVIEW OF IRON MAKING PROCESSES

Blast furnace

The blast furnace process consists of weighing of the burden, charging of the blast furnace, hot product dispersal from the blast furnace and off gas clean up system. The blast furnace is a tall shaft-type furnace with a vertical stack superimposed over a crucible-like hearth [21].

Iron bearing materials, coke and flux are charged into the top of the shaft. A blast of heated air and also, in most cases, a gaseous, liquid or powdered fuel are introduced through openings at the bottom of the shaft just above the hearth crucible. The heated air burns the injected fuel and most of the coke charged in from the top to produce the heat required by the process and to provide reducing gas that removes oxygen from the ore [21].

The reduced iron melts and runs down to the bottom of the hearth. The flux combines with the impurities in the ore to produce a slag, which also melts and accumulates on top of the liquid iron in the hearth. The hot metal produced is sent to a steelmaking shop or a pig-casting machine. The gas from the top of the furnace goes through the gas cleaning system, and then a portion goes to fire the hot blast stoves with the rest being used in other parts of the plant [21].

Rotary kilns

The Stelco-Lurgi / Republic Steel-National Lead (SL/RN) process is a widely used coal-based DRI-making process. This process generates significant amounts of residual gas, which is used for power generation. The advantage of this technology is its robustness and the potential to use low-quality coal, which makes it well suited for developing countries such as India and South Africa [22].

The iron oxide feed to an SL/RN kiln is in the form of lump or pellet iron ore, reductant (low-cost non-coking coal) and limestone or dolomite. The discharge end is provided with a burner to be used for start-up or to inject reductant. The kiln is divided into two process regions; preheat and reduction [21].

In the preheat section, the charge is heated to about 1000 °C, free moisture is first driven off and reduction to FeO occurs. As the reductant is heated, volatile components are released and part of the gases are burned in the freeboard above the bed by the air injected into the kiln. The charge then passes into the metallisation or reduction zone where the temperature is maintained at about 1100 °C, depending upon the type of charge used. The final metallisation is about 93% and carbon content about 0.1 to 0.2%. The product DRI can be discharged hot or cold [21].

Midrex process

The Midrex direct reduction process is based upon a low pressure, moving bed shaft furnace where the reducing gas moves counter-current to the lump iron oxide ore or iron oxide pellet solids in the bed. The reducing gas is produced from natural gas using Midrex's CO_2 reforming process and their proprietary catalyst. The process can produce cold or hot DRI for use as a scrap substitute feed to a steelmaking melting furnace. Over 50 Midrex modules have been built worldwide since 1969. They have supplied over 60% of the world's DRI since 1989 [21].

Corex process

The iron oxide feed to a Corex reduction shaft is in the form of lump ore or pellets. Non-coking coal is used in the Corex process as the strength of coke needed in the blast furnace is not required. All other coke functions, such as fuel supply, basis for the reduction gas generation and carbonisation of the hot metal can be fulfilled by non-coking coal [21].

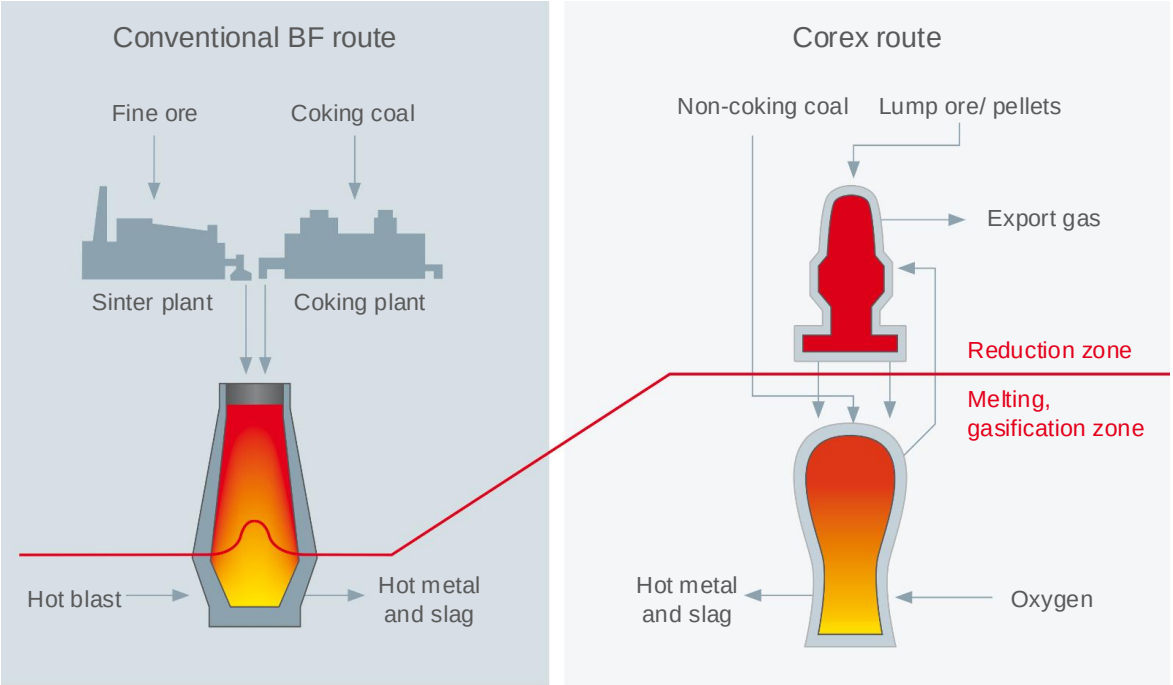


Figure 2-2: Process comparison of BF and Corex, adapted from Siemens VIA [23]

Similar to the blast furnace process, the reduction gas moves in counter flow to the descending burden in the reduction shaft. The reduced iron is discharged from the reduction shaft and transported into the melter gasifier. The gas that is produced by the gasification of coal leaves the melter gasifier at temperatures up to 1050 °C. Undesirable products of coal gasification are destroyed and not released to the atmosphere. After reduction of the iron ore in the reduction shaft, the top gas is cooled and cleaned to obtain high caloric export gas. The main product, the hot metal can be further treated in either EAF or BOF [21].

2.2.4 OVERVIEW OF STEEL MAKING PROCESSES

Basic Oxygen Furnace

Basic Oxygen Furnace (BOF) is a pear shaped vessel where the pig iron, from blast furnace and ferrous scrap, is refined into steel by injecting a jet high-purity oxygen through the hot metal. More specifically, in a BOF [19], [20]:

- The carbon content of pig iron, which is typically 4-5%, is reduced to varying levels below 1% depending on the product specifications;
- Unwanted impurities are removed;
- Concentration of desirable elements is brought to product specifications.

As the reactions taking place in the BOF are highly exothermic, the temperatures in the furnace reach up to 1650 °C. Scrap, or scrap substitutes, that meet purity requirements are often added to control excessive temperature rises. Impurities are dissolved by the added limestone and formed into a slag. During the BOF processes, a gas with high CO content is formed. BOF shops are often followed by secondary metallurgy processes (in ladle or in vacuum) to give the product its final characteristics [19], [20], [24].

Electric Arc Furnace

Electric Arc Furnaces (EAF) are a central part of the production route that is an alternative to the dominant BF-BOF route. EAFs are used to produce carbon steels and alloy steels primarily by recycling ferrous scrap. In an EAF scrap and / or manufactured iron units is melted and converted into high quality steel by using high-power electric arcs formed between a cathode and one (for DC) or three (for AC) anodes. Scrap is by far the most important resource, accounting for about 80% of all electric arc furnace metal feedstock [20], [24].

The iron units are loaded in a basket together with limestone and charged into the furnace. The main task of most modern EAFs is to convert the solid raw materials to liquid crude steel as fast as possible and then refine them further in subsequent secondary steelmaking processes [20], [24].

However, if time is available, almost any metallurgical operation may be performed during the flat bath operation period (after melting), which is usually performed as a pre-treatment to the secondary steelmaking operations. Oxygen and coal powder injection are common treatment operations [20], [24].

2.2.5 CASTING

A wide variety of processes that can be part of finishing are grouped under casting and shaping (rolling). Casting is a stage in finishing operations where the hot metal with the right properties is turned into intermediate, marketable products. Casting can be done as a batch (producing ingots) or continuous (producing slabs, blooms or billets) process [20], [24].

With the trend of a higher integration of the downstream transformation, new technologies are being adopted towards a near net-shape production. These include thick slab casting for thick plates, direct strip casting for sheets, and rod casting. The general idea behind these processes is to go from the molten metal directly to the desired shape with the desired mechanical properties and geometric tolerances with less or even without intermediate processing, thus saving energy and increasing productivity [19], [20].

2.2.6 SHAPING MILLS

Most steel products from the casting operations are processed further to produce finished steel products in a series of rolling and finishing operations. Two common shaping processes, hot- rolling and cold-rolling, are discussed. Steel from the continuous caster is processed in rolling mills to produce steel shapes that are classified according to general appearance, overall size, dimensional proportions and intended use. Slabs are always oblong, blooms are square or slightly oblong and billets are mostly square. Rolling mills are used to produce the final steel shapes that are sold by the steel mill. These shapes include coiled strips, rails and other structural shapes as well as sheets and bars [19], [20].

Hot-rolling

Slabs are reduced in thickness in a hot strip mill. A hot strip mill consists of a reheating furnace that brings the slabs to the correct temperature for rolling, and rolling mills. Slabs can be charged hot directly, after temperature normalisation, from the continuous caster. However, a considerable share of the slabs are first cooled and stored before being milled or scarfed. Rolling normally takes place in two steps. First, slab thickness is reduced in the roughing mill. Next, a further reduction is achieved in the finishing mill. The product is coiled and sold or sent to the cold mill for further processing [19], [20].

Cold-rolling

Cold mills produce rolled sheet or tinplate for a variety of uses, e.g. for car bodies to tin cans. This is done by reducing hot rolled coil in thickness. The process begins with the removal of a thin film of iron oxide by a warm acid bath. The strip is then immediately cold rolled in the tandem mill before further oxidation can take place. To make the cold rolled steel soft and malleable it is annealed, which involves heating to about 700°C followed by

slow cooling. After annealing, a number of operations can be carried out, such as pickling, to improve metallurgical properties or to obtain the correct steel specifications for downstream processing [19], [20].

2.2.7 BENCHMARKING OF ENERGY CONSUMPTION

This section provides information on world best practice energy intensity values for production of iron and steel. “World best practice” values represent the most energy-efficient processes that are in commercial use in at least one location worldwide [25].

These benchmark values are expressed in energy use per physical unit of output for each of these commodities and can be seen in Table 2-1. The values are expressed in Megawatt-hour per tonne (MWh/t).

Table 2-1: World best practice primary energy intensity values for iron and steel [25]

TECHNOLOGY	BF – BOF	SMELT – BOF	DRI – EAF	SCRAP – EAF
	MWh/t	**MWh/t**	**MWh/t**	**MWh/t**
Total	5.72	6.56	5.72	2.22

The energy intensity of the different regions in the world that produce steel can be seen in Figure 2-3. The graph shows the specific energy intensity per tonne of liquid steel produced over a period from the year 2000 to 2012. This information can be used to compare steel plants to the current world values.

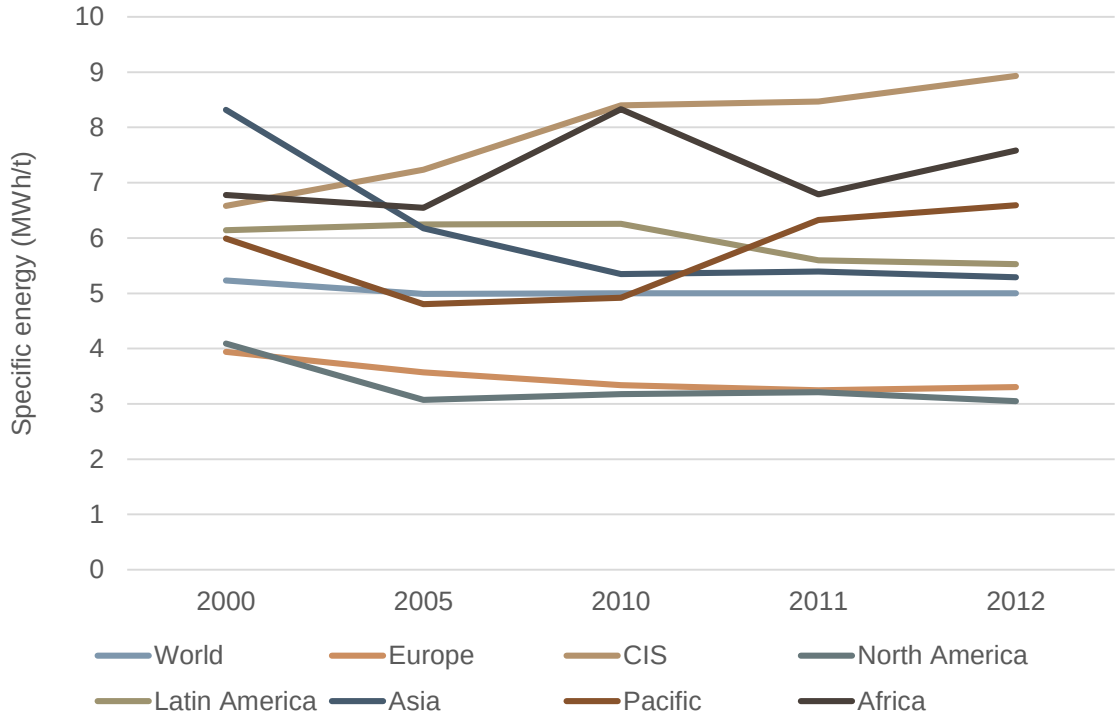


Figure 2-3: World specific energy consumption of steel [26]

2.3 Overview of energy carriers in steel production

2.3.1 ELECTRICITY

Electricity is consumed by most, if not all, components in a steel plant. Electricity is a secondary energy source, also referred to as an energy carrier. That means that consumers acquire electricity from the conversion of other sources of energy, such as coal, natural gas, nuclear, solar or wind energy. These sources of energy are called primary energy sources. The energy sources used to make electricity can be renewable or non-renewable [27].

Electricity is supplied to businesses by the electric power industry through an electric power grid. Electric power is sold by the kilowatt-hour, which is the product of power in kilowatts multiplied by running time in hours. Electric utilities measure power using an electricity meter, which keeps a running total of the electric energy delivered to a customer [28].

2.3.2 GASEOUS FUELS

Properties of gas

In a steel plant, fuel gas is used for burning or heating, mainly by components in raw material preparation, iron making and shaping mills. Fuel gas is any one of a number of fuels that are gaseous under ordinary conditions. Many fuel gasses are composed of hydrocarbons (such as methane or propane), hydrogen, carbon monoxide, or mixtures thereof. Such gasses are sources of heat or light energy that can be readily transported and distributed through pipes from the point of origin directly to the place of consumption [29].

The value of the heat energy is what has to be determined. It is not practical to measure heat for every reaction that occurs and may not even be feasible. Therefore, it is customary to estimate heats of reactions from suitable combinations of compiled standard thermal data. This data is usually the standard heats of formation and combustion [29].

The quantity known as Higher Heating Value (HHV) or Calorific Value (CV) is determined by bringing all the products of combustion back to the pre-combustion temperature, and in particular condensing any vapour produced. This is the same as the thermodynamic heat of combustion since the enthalpy change for the reaction assumes a common temperature of the compounds before and after combustion. The HHV takes into account the latent heat of vaporisation of water in the combustion products [29].

Natural gas

Natural gas is a colourless, highly flammable gaseous hydrocarbon consisting primarily of methane and ethane. It is a type of petroleum that commonly occurs in association with crude oil. Commercial natural gas sold for heating purposes usually contains 85 to 90

percent methane, with the remainder mainly nitrogen and ethane. It usually has a CV value of approximately 38 Megajoule per cubic metre (MJ/m^3) [30].

Methane is colourless, odourless and highly flammable. However, some of the associated gases in natural gas, especially hydrogen sulphide, have a distinct and penetrating odour that imparts a decided odour to natural gas. On the market, natural gas is usually bought and sold not by volume, but by Calorific Value. In practice, purchases of natural gas are usually denoted in much larger units, such as Gigajoule (GJ) [30].

Liquefied petroleum gas

Liquefied Petroleum Gas (LPG) is any of several liquid mixtures of the volatile hydrocarbons, propane and butane. A typical commercial mixture may also contain ethane and ethylene as well as an odorant added as a safety precaution. LPG is recovered from "wet" natural gas by absorption. The finished product is transported by pipeline and by specially built seagoing tankers. Transportation by truck, rail and barge has also developed [31].

2.3.3 COAL

Coalification

Coal is mainly consumed by raw material preparation and iron making processes in a steel plant. Coal is a solid, usually brown or black, carbon-rich material that most often occurs in stratified sedimentary deposits. It is one of the most important primary fossil fuels. Coals may be classified in several ways. One mode of classification is by coal type. The most useful and widely applied classification schemes are those based on the degree to which coals have undergone coalification [32].

Varying degrees of coalification are generally called coal ranks (or classes). Many coal properties are in part determined by rank, including the amount of heat produced during combustion, the amount of gaseous products released upon heating and the suitability of the coals for liquefaction or for producing coke. The general sequence of coalification is from lignite to subbituminous to bituminous to anthracite [32].

The nature of the components in coal is related to the degree of coalification, the measurement of which is rank. Rank is usually assessed by a series of tests, collectively called the proximate analysis, that determine the moisture content, volatile matter content, ash content, fixed-carbon content and calorific value of a coal [33].

Moisture content

Moisture content is determined by heating an air-dried coal sample at 105–110 °C under specified conditions until a constant weight is obtained. In general, the moisture content increases with decreasing rank and ranges from 1 to 40 percent for the various ranks of coal. The presence of moisture is an important factor in both the storage and the utilisation of coals, as it adds unnecessary weight during transportation, reduces the calorific value and poses some handling problems [33].

Volatile matter content

Volatile matter is material that is driven off when coal is heated to 950 °C in the absence of air under specified conditions. It is measured practically by determining the loss of weight. Consisting of a mixture of gases, low-boiling-point organic compounds that condense into oils upon cooling and tars. Volatile matter increases with decreasing rank. In general, coals with high volatile-matter content ignite easily and are highly reactive in combustion [33].

Mineral (ash) content

Coal contains a variety of minerals in varying proportions that, when the coal is burned, are transformed into ash. The amount and nature of the ash and its behaviour at high temperatures affect the design and type of ash-handling system employed in coal-utilisation plants. At high temperatures, coal ash becomes sticky (i.e., sinters) and eventually forms molten slag. The slag then becomes a hard, crystalline material upon cooling and resolidification [33].

Fixed-carbon content

Fixed carbon is the solid combustible residue that remains after a coal particle is heated and the volatile matter is expelled. The fixed-carbon content of a coal is determined by subtracting the percentages of moisture, volatile matter and ash from a sample. Since gas-solid combustion reactions are slower than gas-gas reactions, a high fixed-carbon content indicates that the coal will require a long combustion time [33].

Calorific value

Calorific Value (CV), measured in Megajoule per kilogram (MJ/kg), is the amount of chemical energy stored in a coal that is released as thermal energy upon combustion. It is directly related to rank; some methods use calorific value to classify coals at or below the rank of high-volatile bituminous (above that rank, coals are classified by fixed-carbon content). The calorific value determines in part the value of a coal as a fuel for combustion applications [33]. A method proposed by Mesroghli uses the proximate analysis of coal to determine the CV value [34].

2.4 Current quantification methods in the steel industry

2.4.1 INTERNATIONAL QUANTIFICATION METHODS IN THE STEEL INDUSTRY

This section will investigate the current international methods for quantifying of energy consumption in steel plants. This study will review the annual reports of the largest steel producers in the four largest steel producing countries. Emphasis will be placed on the methods followed to obtain the energy values.

ArcelorMittal is a global steel producing company based in Luxembourg. They believe that independent assurance leads to quality and process improvements. It reassures ArcelorMittal's management and readers that the information published in the annual reports is accurate and material and therefore contributes to building trust and credibility with key stakeholders [35].

ArcelorMittal asked their group auditors, Deloitte Audit, to provide limited assurance on their application of the Global Reporting Initiative (GRI) guidelines (discussed in the next section). The group adopted the GRI's fourth version reporting methodologies in 2014. The previous year, Deloitte provided limited assurance on sustainability performance indicators, in accordance with the International Auditing and Assurance Standards Board's International Standard on Assurance Engagements [35].

The following performance indicators were covered:

- CO_2 per tonne of steel;
- Total CO_2;
- Lost-time injury frequency rate;
- Primary energy consumption.

Deloitte stated a limitation in their findings. The process an organisation adopts to define, gather and report data on its non-financial performance is not subject to the formal processes adopted for financial reporting. Therefore, data of this nature is subject to variations in definitions, collection and reporting methodology with no consistent, accepted standard. This may result in non-comparable information between organisations and from year to year within an organisation as methodologies develop [35].

The accuracy and completeness of the information disclosed is subject to inherent limitations, given their nature and the methods for determining, calculating or estimating such information. They further state that a limited assurance engagement is substantially less in scope than a reasonable assurance engagement and consequently does not enable

them to obtain assurance that they would become aware of all significant matters that might be identified in a reasonable assurance engagement. Accordingly, Deloitte did not express an audit opinion [35].

Nippon Steel & Sumitomo Metal is a steel producing company based in Japan. They have specified the guidelines used for the format of the annual report, but not their methodologies. The guidelines for the report are the fourth version of the GRI sustainability reporting guidelines and the environmental reporting guidelines published by the Japanese Ministry of the Environment [36].

Nucor is a steel producing company based in the United States of America. Their 2013 sustainability report provides a look into Nucor's dedication to continual improvement at all levels of the organisation. The report was developed to reflect the GRI's third version of the sustainability reporting guidelines. At the end of some of the sections, the applicable GRI indicators were included. The specific methodologies have not been indicated [37].

Baosteel is a steel producing company based in China. Baosteel state in their annual report that their board of directors of the company and all its members guarantee that the report is free from any false records, misleading statements or major omissions. They have undertaken individual and joint liabilities for the authenticity, accuracy and completeness of the information contained in the report [38].

Baosteel's report is compiled mainly based on the GRI's third version of the sustainability reporting guidelines and guidelines on corporate social responsibility reporting for Chinese enterprises. Various other documents issued by the Shanghai Stock Exchange have also been referred to. No methodologies for energy quantification are provided [38].

These four companies have not supplied the specific methodologies used for the quantification of their energy consumption or production. They offer assurance to the accuracy of their supplied values, although there is no accepted standard for auditing non-financial information. Their sustainability reports are all based on the GRI sustainability reporting guidelines.

2.4.2 QUANTIFICATION METHODS IN THE SOUTH AFRICAN STEEL INDUSTRY

This section provides an overview of quantification methodologies in South Africa. Current methods for the quantification of energy consumption vary between industrial producers due to the lack of a standard set of instructions and procedures. The energy consumption is usually reported on a yearly basis and this is perceived as an annual task. In many cases, the regular consumption figures are therefore not updated and maintained [39].

Typically, plants use a very basic approach to determine the inputs required for the calculation of total energy and production. A high level of information is used for different energy carriers, and variances in quality is ignored. In the case of coal, there are different types of varying quality. To simplify the process, the plants usually perform an energy content analysis per energy carrier once and then reuse it. No adjustment is made for changing suppliers. In some cases, one constant energy content is used for each energy carrier [39].

Furthermore, no traceable verification documents are linked to the values used. The general auditing process makes use of an independent external audit every few years. However, the auditor does not check whether the process of quantification is correct [35], [39].

No specific literature was found by this study that applies to quantifying energy consumption and production drivers. There is no standard methodology for this in industry.

2.5 Overview of reporting standards

2.5.1 GLOBAL REPORTING INITIATIVE (GRI)



Figure 2-4: Global Reporting Initiative [40]

In the previous section, all the companies that report on their energy consumption refer to the GRI. This section provides an overview of the quantification instructions set in the GRI and refers to and summarises other standards that can be used.

The Global Reporting Initiative (GRI) is a leading organisation in the sustainability field. The GRI promotes the use of sustainability reporting as a way for organisations to become more sustainable and contribute to sustainable development. The GRI has established and developed a sustainability reporting framework that is widely used around the world.

A sustainability report is a report published by a company or organisation about the economic, environmental and social impacts caused by its everyday activities. It also presents the organisation's values and governance model, and demonstrates the link between its strategy and its commitment to a sustainable global economy [40].

The GRI's mission is to make sustainability reporting standard practice for all companies and organisations. Its framework is a reporting system that provides metrics and methods for measuring and reporting sustainability-related impacts and performance [40].

The framework, which includes the reporting guidelines, sector guidance and other resources, enables greater organisational transparency and accountability. This can build stakeholders' trust in organisations and lead to many other benefits. Thousands of organisations use GRI's framework to understand and communicate their sustainability performance [40].

Section 3 on energy of the GRI implementation manual states that an organisation has to report on its energy consumption. Energy includes the fuel consumption from non-renewable and renewable sources in joules or watt-hours, including fuel types used. The report also includes the consumption and sales of the following in joules or watt-hours [40]:

- Electricity;
- Heating;
- Cooling;
- Steam.

The sustainability report should state the organisation's total energy consumption in joules or multiples. The standards, methodologies and assumptions used should also be indicated. Further, the source of the conversion factors used should also be included.

Section 5 on energy of the GRI implementation manual states that an organisation has to report on its energy intensity. Energy intensity reporting is the energy intensity ratio of the organisation-specific metric (the ratio denominator) chosen and the energy. The types of energy included in the intensity ratio are: fuel, electricity, heating, cooling, steam or all of these. The boundary of the ratio energy consumed of the organisation should also be reported [40].

Organisations are expected to report standards, methodologies and assumptions used to calculate and measure energy consumption, with a reference to the calculation tools used. Organisations subject to different standards and methodologies should identify the approach to selecting them. Organisations are expected to select a consistent boundary for energy consumption as well [41].

The documentation sources that are potential sources of information according to the implementation manual include invoices, measurements, calculations or estimations. The reported units may be taken directly from invoices or meters, or converted from the original units to the reported units. The GRI does not have a section on managing uncertainty in measurements uncertainty [41].

2.5.2 INTERNATIONAL ORGANISATION FOR STANDARDISATION (ISO) 50 015 STANDARD



Figure 2-5: International Organisation for Standardisation [42]

The International Organisation for Standardisation (ISO) is an independent, non-governmental organisation, the members of which are the standards organisation of the 165 member countries. It is the world's largest developer of voluntary international standards and facilitates world trade by providing common standards between nations. Nearly twenty thousand standards have been set, covering everything from manufactured products and technology to food safety, agriculture and healthcare [43].

The purpose of this International Standard is to establish a common set of principles and guidelines to be used for Measurement and Verification (M&V) of energy performance and energy performance improvement of the organisation. M&V adds value by increasing the credibility of energy performance and energy performance improvement results. Credible results can contribute to the pursuit of energy performance improvement.

This International Standard can be used by organisations of any size, M&V practitioners or any interested parties, in order to apply M&V to the reporting of energy performance results. The principles and guidance in this international standard can be used independently or in conjunction with other standards and protocols.

This international standard does not specify calculation methods. It establishes general principles and guidelines for the process of M&V of energy performance of an organisation or its components. These principles and guidelines are applicable irrespective of the M&V method used [44].

2.5.3 INTERNATIONAL PERFORMANCE MEASUREMENT & VERIFICATION PROTOCOL



Figure 2-6: International Performance Measurement and Verification Protocol [45]

The International Performance Measurement and Verification Protocol (IPMVP) provides an overview of current best practice techniques available for verifying results of energy efficiency, water efficiency and renewable energy projects. It may also be used by facility operators to assess and improve facility performance [45].

The IPMVP can help in the selection of the M&V approach that best matches a small organisation's requirements for quantifying energy efficiency measures. Two dimensions of energy efficiency performance verification are addressed [45]:

- Savings determination technique using available data of suitable quality;
- Disclosure of data and analysis enabling one party to perform saving determinations while another verifies it.

The IPMVP can measure a whole facilities' performance. This involves the use of utility meters or whole facility sub-meters to assess the energy performance of a total facility. This approach assesses the impact of any energy efficiency measures, but not individually if more than one is applied to an energy meter. It determines the collective savings of all measures applied to the part of the facility monitored by the energy meter. Also, since whole facility meters are used, savings reported include the impact of any other changes made in facility energy use (positive or negative) [45].

Each energy flow into a facility is measured separately by the utility or energy supplier. Where utility supply is only measured at a central point in a campus style facility, sub-meters are needed at each facility or group of facilities on campus for which individual facility performance is to be assessed [45].

Energy data is often derived from utility meters, either through direct reading of the meter, or from utility invoices. Where utility bills are the source of energy use data, it should be recognised that a utility's need for accuracy in meter reading may not be the same as that of savings determination. Utility bills can contain estimated data, especially for small accounts. Sometimes it cannot be determined from the bill itself that data come from an estimate rather than a meter reading [45].

Unreported estimated meter readings create unknown errors for the month of the estimate and the subsequent month when an actual reading is made. However, the first bill with an actual reading after one or more estimates will correct the previous errors in energy quantities. When the fact of an estimate is shown on a utility bill, the associated savings report should reflect this fact [45].

Energy may be supplied indirectly to a facility, through on-site storage facilities for oil, propane or coal. In such situations, information on the energy supplier shipment invoices is not representative of the facility's actual consumption during the period between shipments. Ideally, a meter downstream of the storage facility should be used to measure energy use. However, where there is no such meter, inventory level adjustments for each invoice period should be used to supplement the invoices. The document does not provide a methodology for quantifying energy content of coal or gas [45].

The effort undertaken in determining savings should focus on managing the uncertainty created in the determination process. The savings determination process itself introduces uncertainties through [45]:

- Instrumentation error;
- Modelling error;
- Sampling error;
- Planned and unplanned assumptions.

It is feasible to quantify many, but not all dimensions of the uncertainty in savings determination. Therefore, when planning an M&V process, consideration should be given to quantifying the quantifiable uncertainty factors and qualitatively assessing the unquantifiable. The objective is to consider all factors creating uncertainty, either qualitatively or quantitatively [45].

The IPMVP states that when assessing the instrumentation error, the magnitude of instrumentation errors is given by the manufacturer's specifications. Typically, instrumentation errors are small, and are not the major source of error in estimating savings [45].

2.5.4 MEASUREMENT & VERIFICATION COUNCIL OF SOUTH AFRICA



Figure 2-7: Measurement and Verification Council of South Africa [46]

The mission of the Measurement and Verification Council of South Africa (MVCSA) is to be the independent M&V body that governs Measurement and Verification professionals in order to protect the interest of all Measurement and Verification stakeholders [46].

The South African government introduced tax incentives for companies that can prove energy efficiency savings. One of the primary requirements for companies to benefit from this tax incentive is that they need to make use of independent and registered Measurement and Verification professionals that are certified by the Council of Measurement and Verification Professionals of South Africa (CMVPSA) [46].

The CMVPSA Measurement and Verification guideline for energy efficiency certificates aims to provide background with regard to the M&V requirements surrounding the energy efficiency tax incentive scheme. It also provides a high-level M&V approach that should be followed by registered M&V professionals to issue the required supporting documentation that will be used by SANEDI to issue energy efficiency certificates [46].

This guideline is developed through input from stakeholders and subject to review from government, NEEA, SANEDI, CMVPSA, industry and stakeholders. This guideline will be updated regularly as new developments in the M&V field are realised. The final procedures associated with the energy efficiency tax incentive scheme are under development, which will also make frequent updates a necessity [47].

The guideline only states that data is required for an energy baseline. The M&V process is built on the use of accurate and credible data. No claim can be made towards an energy efficiency tax incentive in the absence of data [47].

2.5.5 SANS 50 010



Figure 2-8: South African Bureau of Standards [48]

General requirements for M&V inspection bodies are laid down in the international standard ISO 17020. SANS 50010: 2011 - Measurement and Verification of Energy Savings, is the technical standard for M&V organisations that wish to demonstrate their technical competence for accreditation purposes. These requirements are quite comprehensive and detailed, but explanations provided in the technical requirements may be helpful to ensure consistent application of the standards [49].

Inspection or examination performed by inspection bodies may fall into two categories, namely functional and analytical. Functional testing is within the scope of ISO 17020. Analytical testing, for example air or metallurgical analysis, is a laboratory activity and does not fall within the scope of ISO 17020. Approved inspection authorities wishing to undertake such laboratory type analytical testing as part of an inspection body will need to do so in accordance with the relevant requirements in ISO 17025: 2005 [49].

The standard specifies that where the whole facility option is used, a measurement boundary shall be drawn around the whole facility. Determination of energy shall be by direct measurement of energy flow or by direct measurement of proxies of energy use that give direct indication of energy use. The energy quantities shall be measured by one or more of the following techniques from section 6.2 and 6.3 of the standard [48]:

- Utility or fuel supplier invoices, or reading utility meters and making the same adjustments to the readings that the utility makes;
- Special meters isolating an energy efficiency intervention to an activity or portion of a facility from the rest of the facility. Measurements can be periodic or continuous;
- When separate measurements of parameters are measured to compute energy use. The appropriate calculation shall be used to determine the energy use.

The whole-facility option involves the use of utility meters, whole-facility meters or sub-meters to assess the energy performance of a total facility. This option determines the collective savings of all energy savings measures applied to the facility monitored by the energy meter. Savings reported under this option shall include the positive or negative effects of any non-energy-savings measure changes made in the facility [48].

Mathematical modelling can assess independent variables if they are cyclical. Regression analysis and other forms of mathematical modelling can determine the number of independent variables to consider in the baseline data. Independent variables shall be measured and recorded at the same time as the energy data. Common independent variables are weather, production volume and occupancy. Weather has many dimensions, but for whole-facility analysis, it is often just dry-bulb temperature [48].

For calculations and mathematical models, the routine adjustments term of the energy savings shall be calculated by developing a valid mathematical model of each energy-use pattern. A model can be as simple as an ordered list of twelve measured monthly energy quantities without any adjustments. However, a model often includes factors derived from regression analysis, which correlate energy to one or more independent variables. Models can also include a different set of regression parameters for each range of conditions, such as summer or winter in buildings with seasonal energy-use variations [48].

The standard states that energy data may be derived from supplier invoices when the invoices are based on actual measured quantities of energy [48].

Energy may also be supplied indirectly to a facility, through on-site storage facilities, such as for liquid fuel, gas or coal. In these situations, actual consumption shall be measured using calibrated measurement equipment. Any measurement equipment shall be checked for accuracy before any data produced may be used for baseline or reporting purposes [48].

Any programme of equipment calibration shall be designed and carried out so as to ensure that wherever applicable, measurements conform to national and international standards of measurement where appropriate.

All measurement instruments shall be calibrated as recommended by the equipment manufacturer, and following procedures of recognised measurement authorities. Measurements shall conform to national and international measurement standards where appropriate. Careful consideration should be given to the measurement equipment that is chosen and also to the application and installation of the equipment [48].

Exact quantification of uncertainty is not required; however, uncertainty shall be taken into account such that more accurate measurements or a more rigorous M&V process cannot invalidate the result [48].

2.5.6 SUMMARY OF REPORTING STANDARDS

This section summarises the recommended data sources and the managing of uncertainty of the local and international standards reviewed in this chapter. Table 2-2 summarises the results of the standards recommendation for data sources and the managing of uncertainty, which will be used to develop a standard methodology.

Table 2-2: Summary of reporting standards

STANDARD	DATA SOURCES	UNCERTAINTY
GRI	Invoices, measurements, calculations, estimations	Not specified
ISO 50 015	Not specified	Not specified
IPMVP	Invoices, measurements	Assess, quantify
CMVPSA	Not specified	Not specified
SANS 50 010	Invoices, measurements, calculations	Manage

Data sources for the quantification of energy and production can be invoices and measurements based on the GRI, IPMVP and SANS 50 010. Calculations are also valid data sources according to the GRI and SANS 50 010. The GRI also states that estimations can be used. The ISO 50 015 standard and CMVPSA M&V guidelines do not provide suggestions for data sources for energy and production. The SANS 50 010 standard also states that where measurement equipment is used these meters have to be calibrated to ensure accuracy.

Only the IPMVP and SANS 50 010 standard mention managing uncertainty. The objective of the IPMVP is to assess all factors creating uncertainty, either qualitatively or quantitatively. The SANS 50 010 standard only requires that uncertainty is managed. However, a more rigorous M&V process must not invalidate the results or display a more conservative value.

No specific methodologies are provided by these standards for individual energy carriers outside of the conversion to a unit of energy. The standards that will be used for the development of a standard methodology for steel manufacturing facilities are the IPMVP and the SANS 50 010. These standards provide more detail in comparison to the others reviewed. However, more focus will be placed on the SANS 50 010 standard since this study focuses on South Africa.

2.6 Conclusion

This chapter conducted a literature study to provide the background on what is needed to complete the study. The literature review consists of an overview of steel production facilities, energy carriers, current energy quantification techniques and reporting standards.

The overview of steel production facilities focuses on the different components in the process and their energy consumption. The study examines the raw material preparation processes, ironmaking processes and steel production processes. Further, the global benchmark for energy consumption in steel plants is reviewed for comparison with this study results.

An overview of the energy carriers consumed within a steel plant is provided. The energy carriers reviewed are electricity, gas and coal. The most important aspects are the measurement units and the properties of gas and coal. Gas requires the HHV of its properties and coal requires a proximate analysis.

The current quantification methods in the steel industry are reviewed. To achieve this, the study will take a look at the world's largest steel producing companies of the largest steel producing countries. The annual reports for four companies are reviewed and the basis for all of these is the GRI's sustainability reporting framework. The companies' information are reviewed by auditors, using financial checks. There is no standard method for quantifying energy and production in steel plants. No literature was found in this study.

Finally, an overview of the reporting standards available is provided. The standards that have been reviewed are the GRI, ISO 50 015, the IPMVP and the SANS 50 010 standards. Emphasis is placed on the measurement of energy and the management of uncertainty.

The information presented and reviewed in this chapter will be used to develop a methodology. The methodology can be used to quantify the energy consumption and production drivers that are used and produced within a steel production facility.

3 METHODOLOGY



Basic Oxygen Furnace ladle [50]

3.1 Introduction

In the previous chapter, an overview of steel production facilities and their energy carriers was provided. The standards of quantification of energy and production drivers was discussed. These discussion points are used in this chapter.

This chapter describes the methodology that has been developed to quantify energy consumption in steel manufacturing facilities. The methodology consists of the steps displayed in Figure 3-1: identify, quantify, normalise and verify.

The first step involves identifying the various energy carriers and production drivers in the facility. This is followed by the quantification of these values by different means. The values are then normalised to figures that allow the various energy carriers and drivers to be compared and aggregated for a complete energy profile. Finally, the values used are verified against the various sources of the values to check compliance with the M&V criteria. If the data used cannot be verified or are non-compliant to standards, the quantification step has to be repeated with compliant sources. This indicated as the feedback loop in Figure 3-1.

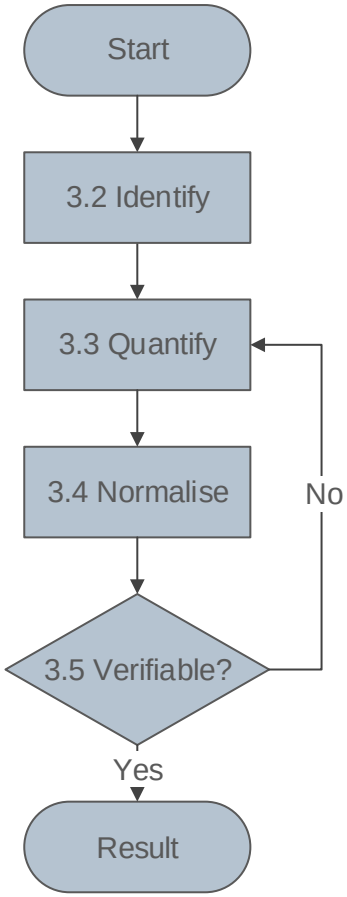


Figure 3-1: Methodology

3.2 Identifying energy carriers and production drivers

3.2.1 IDENTIFY PRODUCTION DRIVERS

A production driver is a plant production output that can be used to benchmark, model and calculate energy consumption. The production driver can also be used to determine the energy efficiency of a plant. The identification of the production driver is shown in Figure 3-2.

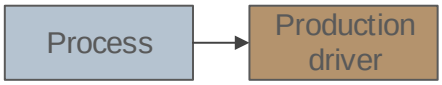


Figure 3-2: Identification of production driver

This is where the identification of the production driver takes place in the methodology. The complexity of a steel production system has the result that there are many candidates for production drivers in the system. Each stage in the production process may have a separate production driver that can indicate performance.

It is recommended to use a basic process flow to assist in the identification of production drivers. The whole facility can be linked to one production driver, while a subsystem can have a different driver. It is therefore important to indicate what production driver is necessary or required. It is possible for a system to have more than one production driver. With regard to the whole facility approach, it is important to select a suitable point in the process as a driver.

Using the final product as a production driver, with the presence of large product stockpiles and lag in the system, may prove the driver lacking in certain aspects. There are also many inherent losses in the system that may not be accounted for in the selection of the final products as drivers. The final products produced by the plant are therefore not a good driver.

Studies have found that the use of liquid steel or iron as a production driver is an accepted practice in industry [35]–[38], [51]. It negates the inherent losses in the mass of the process flow due to it being a primary process product. Further, the production of liquid steel requires the largest portion of the energy consumption of the system.

3.2.2 IDENTIFY ENERGY CARRIERS

The step identifies the data available for the calculation of the energy consumption of a steel production facility. Steel production facilities are complex systems that can use a multitude of different energy carriers to produce their product. Identifying these carriers is essential in creating an energy consumption profile for the facility.

The process of steel production consists of multiple stages as has been explained in the previous chapter. The production process consumes various energy carriers. The process of steel production is complex and consists of multiple stages that it is not difficult to lose track of the different energy consumers. These energy consumers are measured at different measuring points throughout the process.

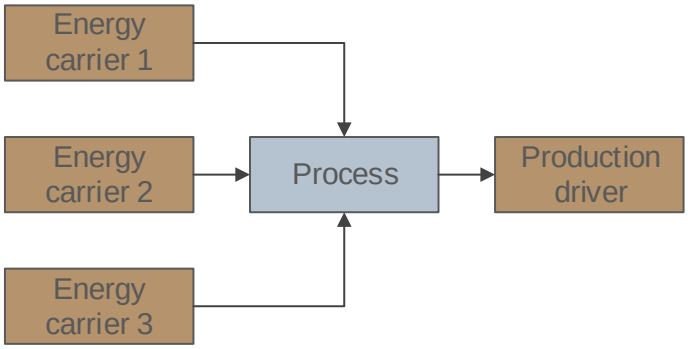


Figure 3-3: Identification of energy carriers

It is recommended to use a basic flow diagram of the plant to help identify the various energy carriers in the system. The energy carriers that were identified in this study are electricity, gas and coal. Most steel production plants employ some or all of these energy carriers in the production of steel. Figure 3-3 indicates the identified energy carriers in a process flow. Once all the energy carriers have been identified, the identification of the production drivers follows.

3.2.3 LEVELS OF ENERGY CARRIER IDENTIFICATION

After the energy carriers have been identified, further breakdown or structuring is required as discussed in this section. Figure 3-4 indicates the breakdown of energy carrier identification. In most cases, each energy carrier can be identified in three levels: the energy carrier, the type and the source. The need for this breakdown is the difference in quality and composition of energy carrier types and sources.



Figure 3-4: Breakdown of energy carrier identification process

Energy carrier

The energy carrier is consumed in the plant, which includes electricity, gaseous fuels and carbonaceous fuels or coal. This is the highest level of identification that can be used on the plant in the quantification of energy. The energy carrier can be identified by simple investigation of a process flow diagram of the plant under analysis.

The energy carrier is also the level that will be used in the methodology from this point on to separate the instructions in the process as there are specific steps required for further analysis of each energy carrier for quantification.

Type

Once the energy carrier has been identified, it can be broken down further into types. This will split the energy carrier down to a specific process or inherent quality. This needs to be identified in order to simplify the grouping of the different energy carriers. The energy carriers under discussion are gas, coal and electricity.

The identification of gas types is relatively simple due to the fact there are not many different types used in steel facilities. Gas is typically split between general types based on quality or composition. The gas types used in steel plants are Liquid Petroleum Gas (LPG) and natural gas. Gasses that are by-products of other energy carriers do not have to be identified if they are consumed within the plant. This will include Coke Oven Gas (COG) and Blast Furnace Gas (BFG). It is, however, necessary to identify the gas if it is sold or otherwise removed from the plant or system and not consumed.

Coal types are more complex to identify due to there being many different coal varieties. The coal types can be split between the qualities to a certain degree, although some coal used in different systems may be close to each other in quality. The size of the coal particles required for different processes can also determine the type of coal. However, a more logical split will be to identify the process, which the coal is used for to group the types together. The processes highlighted in the previous chapter that consume coal will be used to identify the type of coal:

- Direct Reduction (DR);
- Coke making;
- Sintering;
- Pulverised Coal Injection (PCI);
- Corex;
- Furnaces.

The exception to this level of identification may be electricity, since electricity does not have any inherent quality or difference that needs to be identified for the quantification thereof, although an argument can be made for grouping electricity by types of generation, whether it be from an electricity utility, renewable energy or electricity generated by the plant itself.

Source

After the energy carrier has been split into types, it can be divided further into sources. The simplest way to do this is to complete an analysis of the energy carrier suppliers. Each type under the energy carriers is supplied by one certain company or facility. A simple list of suppliers or breakdown of products will aid in the identification of the source, see Figure 3-5.

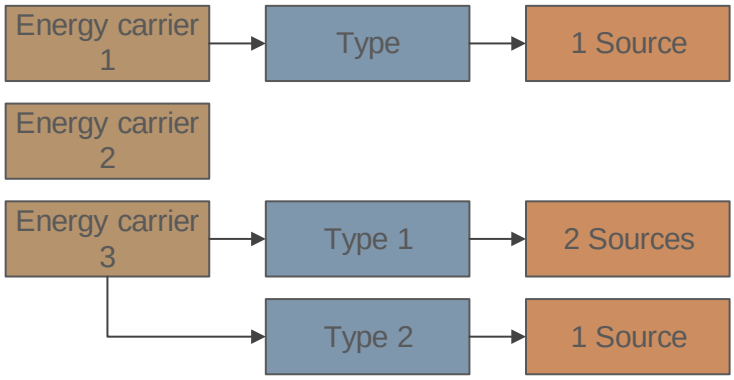


Figure 3-5: Energy carriers with level breakdown identified

The reason for the identification of the source is that each supplier's product may differ from another supplier's in quality. When the energy carrier type is split in this manner, there is no further deviation in quality possible within the type. This will be necessary later in the methodology to help in quantifying the energy consumption. Further steps can now be completed on the energy carriers after the identification has been concluded.

3.2.4 PLANT BOUNDARY IDENTIFICATION

After all the energy carriers and drivers have been identified. The next step is to identify the plant boundary now that the components of the plant are known. This will be the boundary that is selected to represent the plant under the quantification process. This is essentially the selection of the border of the steel manufacturing facility or system where the flow of energy carriers over this boundary will be quantified. This is an important step in the identification process because it specifies the limits of the system under quantification. It also sets the scope of the quantification process.

The selection of the boundary can be for the whole facility as indicated in Figure 3-6. This will be done typically for a plant when the entire energy profile is required. A boundary is selected around the physical entity where energy carriers have been identified entering or exiting the premises. A production driver has also been identified within this boundary. A simple black box approach can be followed after the energy carriers and drivers have been identified to represent the facility.

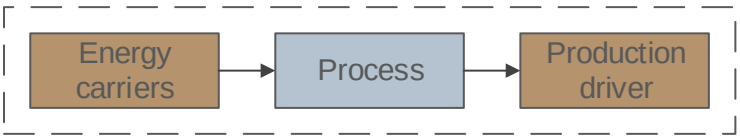


Figure 3-6: Whole facility boundary

Generally, the premises identified as the boundary will fall under one tax entity. This is necessary for the quantification of energy consumption for the purpose of tax incentive applications. When this boundary is selected, all the energy carriers and drivers have to be identified within this tax boundary.

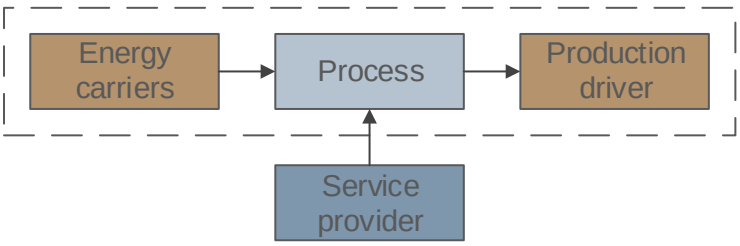


Figure 3-7: Boundary with separate tax entity

In the event where there is another tax entity present on the premises with the facility under quantification, it becomes essential where the boundary is selected. Examples of this can be tenants on premises or separate businesses that provide services to the facility (seen in Figure 3-7). The plant under the quantification process cannot be held accountable for the consumption of another facility within the premises. Once again, a simple flow diagram can be used to identify the boundary around all facilities within a premise.

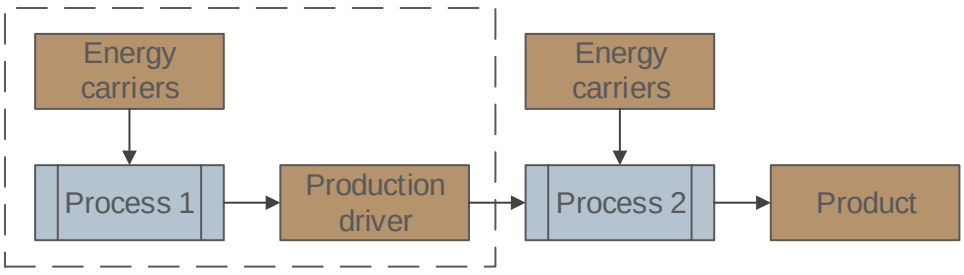


Figure 3-8: Boundary isolating a subsystem

Another boundary can also be made to ring fence a subsystem within the main steel manufacturing plant, indicated in Figure 3-8. This is for when the identification of the energy consumption of the subsystem is desired. This can be a simple or complex system as long as the boundary is clear for the scope of the system required. Once the facility or system boundary has been identified, it can be quantified.

3.3 Quantifying energy carriers and drivers

3.3.1 QUANTIFICATION OF PRODUCTION DRIVERS

The production drivers of the plant have been identified in the previous section. The next step is to quantify the production driver. The production driver is the plant output variable that can be used to indicate the relevant performance of the facility. This product variable may be used by the plant as their production driver, but this does not have to be the case.

The facility will have metering equipment in place throughout the production process. These meters measure the variables that may have been identified as production drivers. The meter can measure the weight or volume of the production drivers. These measurements can be used to quantify the selected production drivers.

When using measurement equipment on site for the quantification of the identified production driver the unit of measurement is important. Each measuring component has a standard unit of measurement. When quantifying the value from the meters used, the unit of measurement should be used with the values obtained for the meter.

It is possible that the final products or by-products of the plant were identified as production drivers. These are the products produced by the plant and are output variables of the facility. Since these are the main products that are produced, there will be invoices generated by the sales of these products. The sales invoices of these products can be used for the quantification of the production drivers as identified.

The suitability of a production driver has to be determined when quantifying it. This involves determining the suitability of the product or output as a production driver with regard to the impact on energy input. The energy consumption the production driver requires of the total energy consumption has to be quantified.

To determine the error of a production driver, the total energy required to produce the driver has to be determined. Energy consumption data is required for the particular section where the energy driver is measured. The percentage of the total energy attributed to the energy driver can then be calculated. This is indicated in Equation 3-1, where the error (e), determined by the fraction of energy required by the driver (E_D), is divided by the total facility energy (E_T). A higher percentage will indicate a more suitable driver.

$$e = \frac{E_D}{E_T} \qquad 3\text{-}1$$

3.3.2 QUANTIFICATION OF ENERGY CARRIERS

After the energy carriers have been identified (following the guidelines explained in the previous section), they can now be quantified. Quantification of energy carriers is the measurement of the consumption quantity thereof. Most steel production facilities measure the energy carriers at multiple points throughout the plant. This section provides options for the quantification of the energy carriers and recommendations for the best point of measurement.

The logical solution for the quantification of energy carriers would be measurement equipment that is located within the plant. Each carrier should be measured at some point throughout the plant. This can be achieved by meters that either measure the energy consumed directly or the volume of the energy carrier consumed.

Measurement equipment would also be located at the supplier of the energy carrier. When a supplier invoices a consumer, the measurement of the quantity is important. This information should be available to the consumer and may prove a suitable source for the quantification of that energy carrier.

If measurement equipment is used to measure the consumption of the energy carrier, it is important to use the unit of measurement of that meter for the quantification thereof. This unit of measurement will be used in the quantification of the energy carrier for an energy carrier specific measure. In this study, the unit of measurement for the different equipment was: kilowatt-hour (kWh) for electricity, kilogram (kg) for coal and some gasses and cubic meters (m^3) for other gasses.

Another important factor of using plant measurement equipment is the location of the meter. The point of measurement has to be the best possible location to represent the actual plant consumption of the required energy carrier. There are factors that will influence the suitability of a location for the measurement of the energy carrier. These factors are changes in energy carrier quality in the process and storage buffers. Multiple measurement locations for coal mass (m) and a single location for Specific Energy (SE) is indicated in Figure 3-9.

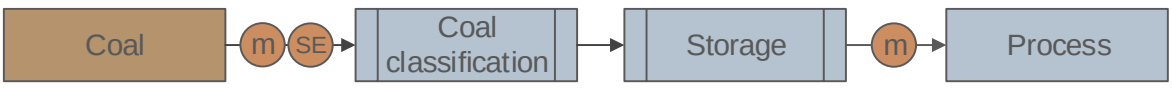


Figure 3-9: Quantification locations of coal

The quality in terms of content analysis of the energy carrier must be identifiable at the point of measurement. It is possible for an energy carrier to be blended in the production process of the plant. This means that the point of measurement should be situated at a location before any blending of the product has occurred. After an energy carrier has been

consumed, some plants measure the quantity of by-products. The quality of the energy carrier has therefore changed and it is not a suitable point of measurement.

Large industrial production facilities have storage buffers (shown in Figure 3-9) that could create a delay in the consumption of coal between when the coal arrives and when it is consumed. It is therefore important to verify that the point of measurement for the coal consumption is after the storage buffer in the production line. This means that the location of the point of measurement is close to the consumption point of the energy carrier [39].

Taking into account the factors outlined in this section, the point of measurement of the energy carrier can be determined. Once the energy carriers have been quantified, the production drivers have to be quantified.

3.4 Energy normalisation

3.4.1 NORMALISATION OF PRODUCTION DRIVERS

The production driver is quantified as in the unit of measurement directly from the meters or invoices. Since the value is measured in a specific unit of measuring, no further conversion is necessary. The value quantified can be used as measured by the metering equipment.

If there were more than one driver, it would be sensible to convert the values to the same order of the International System of Units (SI) − if possible. It would be practical to display the value as the base order SI unit for comparison, later modelling or for use in DoE reports and tax.

3.4.2 NORMALISATION OF ENERGY CARRIERS

When the energy carriers have been identified and quantified, they can be prepared for presentation. In the quantification stage of the methodology, the energy carriers are presented in their original unit of measurement. It is necessary to present the energy carrier as an energy value in reporting and for calculations. This is the process of normalisation where all identified and quantified values are converted to a comparable unit of measurement.

The purpose of energy normalisation is to convert the unit of measurement by way of an energy content value. The energy content value converts the original unit of measurement of the energy carrier to a unit of energy. This has to be completed for each energy carrier that is not measured as a unit of energy.

Normalisation of electricity

Electricity is quantified as an energy value directly from the meters or invoices. Since the value is already measured in a unit of energy, no further conversion is necessary. The value quantified can be used as measured by the metering equipment. All the sources of electricity as identified and quantified can therefore be aggregated.

Normalisation of gas

The identified gas sources are quantified in the meters' unit of measurement. As discussed in the previous section, the unit of measurement for gas usually indicates the volume of the gas quantity. The quantity of gas has to be converted to an energy value for direct comparison with other energy carriers and for use in further calculations. Note that in some cases, the energy value of the gas is already indicated by the supplier.

Some steel manufacturing plants have direct gas supply pipelines into the facility. These pipelines are outfitted with volume flow meters, which measure cubic meters (m^3). This volume quantity needs to be normalised to an energy value. To achieve this, the volume measurement is multiplied with the specific energy value per volume of gas. Equation 3-2 is the formula for the conversion of volume to energy, where *E* is Energy, *V* is Volume and e_v is the specific energy factor by volume [MJ/m^3].

$$E = V \cdot e_v \qquad 3\text{-}2$$

Gas can also be delivered by heavy tanker vehicles to the steel production facility. The delivery is usually measured in a mass value. The mass value also needs to be normalised to an energy value for further use in calculations and comparisons with other energy carriers. To convert the mass value to an energy value, the mass is multiplied by the Specific Energy of the mass of the gas. Equation 3-3 indicates the formula for the conversion of mass to energy quantity, where *E* is Energy, *m* is mass and e_m is the specific energy factor by mass [MJ/kg].

$$E = m \cdot e_m \qquad 3\text{-}3$$

In both Equations 3-2 and 3-3, there is a Specific Energy value by either volume or mass. The Specific Energy value is usually provided by the supplier. The value can be found on supplier invoices for the delivery of the gas. The Specific Energy can also be found in independent laboratory analysis or quality reports of the gas. Further information may be available in supplier quality agreements with the plant.

If the Specific Energy value of the gas is not available, it can be calculated with the use of the product laboratory analysis reports. The reports indicate the composition of the gas supplied to the steel manufacturing facility.

The main components of the gasses in this study are methane, ethane, propane, butane, pentane and sulphur. The Higher Heating Values (HHV) and Molar Mass (MM) of these gasses can be seen in Table 3-1, obtained from the NIST chemistry webbook [52].

Table 3-1: Higher Heating Value and Molar Mass of gasses [52]

GAS	HIGHER HEATING VALUE	MOLAR MASS
	kJ/kg	**g/mole**
Methane	55 521	16.0425
Ethane	51 902	30.07
Propane	50 322	44.1
Butane	49 510	58.12
Pentane & heavier	49 001	72.15
Sulphur	8 644	32.065

Using the HHV of these gasses along with laboratory analyses of the gas, the Specific Energy can be calculated. The Specific Energy of the gas is calculated by multiplying the mass (m) percentage of the gasses in the analysis with their corresponding HHV and aggregating the results. Equation 3-4 indicates the formula for the Specific Energy of the gas.

$$e_m = \sum (HHV_i \cdot m_i\%) \tag{3-4}$$

It is possible that the product quality analyses of the gas energy carrier is presented as Molar Mass percentage. A conversion to mass percentage will be required. Equation 3-5 indicates the conversion formula from Molar Mass percentage to mass percentage for each component of the gas. Mass percentage is *m%*, Molar Mass percentage is *MM%* and the Molar Mass of the gas component is *MM*.

$$m_i\% = \frac{MM_i\% \cdot MM_i}{\sum (MM_i\% \cdot MM_i)} \tag{3-5}$$

Normalisation of coal

There are many types of coal and coal suppliers in use in the steel industry. The quality and composition of the coal can vary significantly due to different coal grades. The normalisation of coal energy consumption is an important step due to the large contribution to the plant total energy consumption.

Coal consumption is measured at various points throughout steel production facilities as stated in the previous section of quantification of energy carriers. The coal consumption is measured in weight consumption. Various measurement equipment returns consumption figures as tonnes [t] or kilograms [kg].

The coal consumption needs to be converted to an energy value for comparison with other energy carriers and further analysis. The coal weight consumption is converted to energy by the multiplication of the coal Calorific Value (CV) measured in MJ/kg.

The most important measure of the quantification is the CV value of coal due to a small variation having a large impact on the energy value [39]. The coal CV values typically range from 25-31 MJ/kg.

The study describes three methods that can be followed for the modelling of this value. Method 1 is selected if batch CV values are available per coal consumption volume. Method 2 uses a CV value from a contract specification. Method 3 models the CV value with inputs from batch coal proximate analyses. Selecting the modelling method depends on what verifiable coal analysis is available [39].

It is important to normalise the basis of all the coal analyses so that the coal basis reflects its state in the process. Table 3-2 shows the conversion ratios of coal analyses on air dry (AD), dry (DB) and as received (AR) basis. The conversion ratios are based on the percentage inherent moisture (IM) and total moisture (TM) content of the coal [53].

Table 3-2: Factors of conversion between coal analyses basis

FROM BASIS	TO AS RECEIVED	TO AIR DRY	TO DRY BASIS
AR	1	$\frac{1 - IM\%}{1 - TM\%}$	$\frac{1}{1 - TM\%}$
AD	$\frac{1 - TM\%}{1 - IM\%}$	1	$\frac{1}{1 - IM\%}$
DB	$\frac{1 - TM\%}{1}$	$\frac{1 - IM\%}{1}$	1

Table 3-2 converts the analysis from the initial basis in the row, to the basis in the column by multiplying it with the corresponding conversion factor. This study has selected to calculate all CV values on AD basis. The reason is that the coal consumed by the plants is stored in covered bunkers and silos after reclaiming, care is taken to keep the coal dry. The coal is dried by the surrounding air before it is measured. However, this coal still contains inherent moisture [39].

Method 1

Method 1 is applied if there are coal analyses available for the coal type per batch consumed. This will include information obtained from analyses from on-site or independent analysis laboratories. This information is sometimes also included on the delivery invoice from the supplier [39].

To determine the CV value for the desired period of quantification, the weighted average is determined with Equation 3-6, where *m* is the weight value of each batch with an accompanying analysis available.

$$\overline{CV} = \frac{\sum(CV_i \cdot m_i)}{\sum m_i} \quad 3\text{-}6$$

Method 2

If Method 1 is not applicable due to the absence of a batch analysis, Method 2 is selected. The requirement for this method is a minimum contractual analysis with a CV value from the supplier. This is usually a contract between the supplier and client that states its commitment to deliver coal of a quality that will exceed or match this minimum specification [39].

Method 3

In the absence of a contractual CV specification and batch analyses, Method 3 is selected for determining the CV value for the coal type. Most plants are interested in the composition of coal and not necessarily the heat value of coal due to the composition's direct influence on product quality. This means that there is usually some form of analysis available on the basic composition of the coal [39]. If no lab analysis is available one should be completed.

A method suggested by Mesroghli et al. estimated the CV value of coal using regression analysis. The inputs required from a proximate analysis are: the moisture (M), ash (A) and volatile matter (VM) content of the coal type. The multiple variable model shows a coefficient of determination of 97% between predicted and estimated values. Equation 3-7 from their approach is used to estimate the CV value of the coal [34].

$$CV = 37.777 + 0.647M + 0.387A + 0.089VM \quad 3\text{-}7$$

When utilising Method 3 for the calculation of the CV value for coal, it is important to validate the value obtained with this method. The method will produce a value calculated with empirical information and not experimental information. It is suggested to do a comparison with other coal types with similar properties. A simple error estimation can be completed to accompany the calculated value.

Methodology for coal energy normalisation

Figure 3-10 shows the methodology flow diagram that can be followed for the selection of the CV value of a specific coal. The CV value of coal is selected based on the information available. All CV values are converted to AD basis [39].

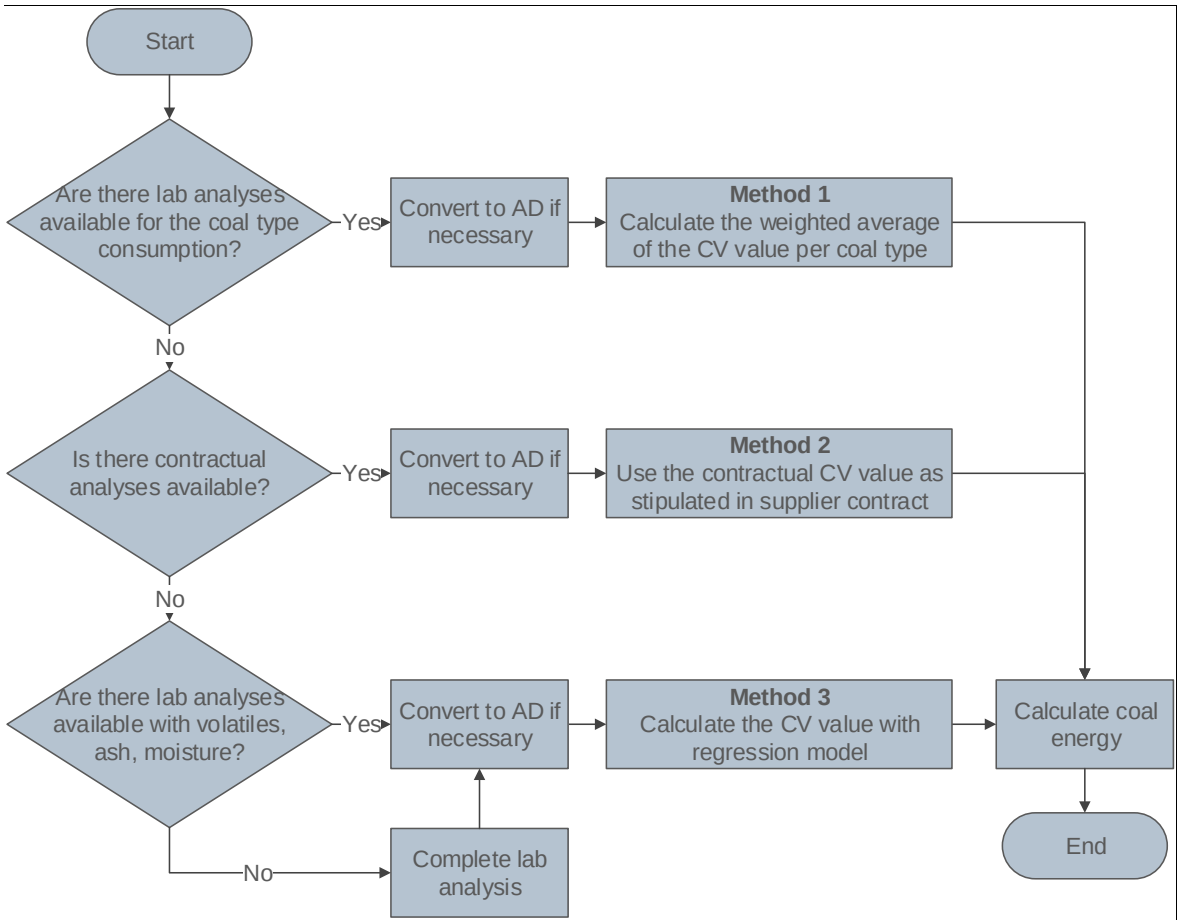


Figure 3-10: Coal energy normalisation methodology [39]

Calculation of coal energy

Once the CV value for each coal type has been determined for the required period, the energy value can be calculated. Equation 3-8 is used to calculate the energy (E) of the coal consumption in J (Joules). This value can then be converted to any equivalent energy value for comparison with other energy carriers or for the summation of the plants' total energy consumption [39].

$$E = \sum (CV_i \cdot m_i) \qquad 3\text{-}8$$

3.4.3 CALCULATION OF TOTAL ENERGY CARRIER AND PRODUCTION DRIVER

The purpose of the normalisation of energy carriers and production drivers is the conversion to the same unit of measurement of energy or quantity. Multiple production drivers can be aggregated if the units of measurement are the same. All the energy carriers can be aggregated for use by the DoE or tax incentives. Equation 3-9 indicates the aggregation of total facility energy (E) consumption. Each energy carrier is added to obtain the total energy consumption.

$$E = \sum E_i \qquad 3\text{-}9$$

3.4.4 MANAGING UNCERTAINTY

The next step in the methodology is to manage the uncertainty in the quantification process. The SANS 50 010 standard states that uncertainty has to be managed and that no exact quantification is necessary. However, a more rigorous M&V process must not disprove the current quantification. Therefore, values have to be conservative for the application [48].

The IPMVP also recommends managing the level of uncertainty. Uncertainty is introduced through instrumentation errors, modelling errors, sampling error and planned and unplanned assumptions. The objective is to consider all factors creating uncertainty, either qualitatively or quantitatively [44].

In this study, uncertainty is managed through the verification and traceability of all information used in the quantification process. The values used are compliant with the international and local standards of M&V in the literature review.

Each energy carrier has to be assessed for uncertainty and errors that may have arisen in the process. The measurement equipment used has to be checked for compliance as specified by the manufacturer. Sampling errors can also be checked for uncertainty.

3.5 Verification and validation

3.5.1 MEASUREMENT AND VERIFICATION CRITERIA

After the energy carriers and drivers have been normalised and aggregated, the measurements used have to be verified. The data quantified has to be verified for the use in mandatory reporting and the claiming of incentives. In order to verify the data, various supporting documentation is required. Having these documents ready will simplify future audits of the energy consumption and drivers, and the M&V thereof [39].

The criteria from literature for the Measurement and Verification of energy carriers and production drivers is reviewed in Section 2.5. This includes the SANS 50 010 standard for M&V of energy efficiency savings [48] and the M&V guideline for energy efficiency certificates [47]. The criteria set by these standards were used to verify the validity of the data obtained in the quantification step of the methodology.

Measurement by means of energy invoices

The quantification of energy consumption has to be the direct measurement thereof as stated in the SANS 50 010 standard. Energy consumption data may be derived from supplier invoices when the invoices are based on actual measured quantities of energy. This means that energy invoices supplied by energy utilities or fuel suppliers may be used for the quantification of energy.

Measurement of electricity consumption can be derived from electricity utility invoices. The utility uses meters that are located at incomers at the plant to measure the plant's electricity consumption. These measurements are aggregated for one month to bill the facility for its electricity consumption. The invoice based on these measurements is a legal document acknowledged by the facility and the utility.

Steel manufacturing facilities do not store electricity. With no storage capacity in the facility, the consumption of electricity occurs directly after it is supplied. Electricity invoices are therefore sufficient for the measurement of consumption of electricity. The documents have to be obtained from the facility for the recording of the electricity consumptions. It is recommended to file the documents for future requirements and audits.

The measurement of gas consumption in this study have also been derived from gas supplier invoices. The gas is sourced to the facility by means of a direct pipeline or heavy transport vehicles. The measurements for the supply of the gas are aggregated to a one-month quantity for billing purposes that is recorded in an invoice. Again, the invoice is a legal agreement between the facility and the gas supplier.

Steel plants have minimum to no capacity for the storage of gas. The delivered gas quantity is therefore consumed without delay. The gas supplier invoices are consequently a sufficient document for the quantification of gas energy consumption. The documents have to be obtained from the facility for the quantification of gas energy consumption. These documents should be filed for reference and in the case of an internal or external audit.

In some cases, the Specific Energy of the energy carrier is included on the energy supplier invoices. Most notably in the invoices of gas and coal, there are instances where the Specific Energy of the energy carrier is also recorded on the supplier invoice. The invoice

may be used to quantify the energy content of the energy carrier since it is a legal agreement between the supplier and the facility.

Calibration of metering equipment

It is possible for an energy carrier to be supplied indirectly to the facility, through on-site storage facilities, such as for liquid fuel, gas or coal. In these situations, actual consumption should be measured using measuring equipment located within the facility. As stated in the SANS 50 010 standard, it is necessary for the measurement equipment to be calibrated to the requirements of the equipment manufacturer.

Coal measurement by equipment is necessary in the presence of large storage facilities and stockpiles in steel plants. Examples of equipment for the measurement of coal consumption are weigh feeders and weighing bridges. The equipment must have set calibration processes in place with personnel responsible for the calibration of the equipment. It is necessary to obtain the documentation of the calibration as proof of the act. The documentation required is usually a calibration certificate or job card.

The measurement of the production driver is done by internal facility meters. Examples of measuring equipment are platform scales, weighing bridges and weighing cranes. The measurement equipment used for the quantification of the energy drivers have to be calibrated to prove the accuracy of the measurements. There have to be calibration processes set in place for the equipment with personnel responsible for performing the calibrations. The documentation that proves the completion of the calibration has to be obtained from the plant. It is of the upmost importance to keep the source documentation filed for future reference.

Measurement of specific energy by means of lab reports

The Specific Energy of an energy carrier is required if it is not measured in a unit of energy. This methodology requires the Specific Energy of the carrier to determine the energy consumption. If the energy invoice does not include the Specific Energy value of the energy carrier, other documentation is required.

Laboratory equipment is used to determine the Specific Energy of an energy carrier. The equipment must be accredited and conform to standards as determined by the manufacturer. The lab analyses the composition of the energy carrier and determines its Specific Energy content. The results of the analysis is documented and reported.

The quantification of the Calorific Value of coal that is not included in the invoices has to be determined by laboratories. The results of these coal analyses are reported as proximate and ultimate analyses. In most cases, the CV value of the coal is included in the analyses.

The laboratory reports are required to verify the figures obtained by the plant. It is of the upmost importance to keep the source document ready for auditing purposes.

The determination of the Specific Energy content of gas has been included by the supplier in the invoices provided in most cases. If the Specific Energy content of the gas is not included, the Specific Energy of the gas has to be determined by a laboratory. In this study, the Specific Energy of the gas is indicated in product quality laboratory reports. The composition of the gas is indicated in these documents and can be used to determine the Specific Energy content of the gas as is discussed in the previous sections.

3.5.2 FAILURE TO MEET MEASUREMENT AND VERIFICATION CRITERIA

This section has described the steps required to determine if the information used is compliant to standards of measurement and verification. The information obtained by the study has to be traced back to source documentation. The documentation required includes energy supplier invoices, calibration certificates of measurement equipment and laboratory analysis of Specific Energy content.

If the information obtained for the energy carriers and drivers does not comply with the criteria set out, it has to be rejected. Other sources of information have to be obtained to quantify the energy carriers and drivers. In Figure 3-1, this is indicated as the feedback loop between the steps of verification and quantification. With the verification of the quantification information complete, the validation of the information obtained can be completed.

3.5.3 VALIDATION OF INFORMATION OBTAINED

Once the verification step is completed, the energy and driver values are quantified. A method of validation of the information obtained by the methodology is to compare the values with published information from other steel manufacturing companies with similar layouts. Direct comparison of the information obtained is impractical and illogical since the size of the facilities differs substantially. This will serve as a high level check only and will determine if the values are within the correct range.

$$I = \frac{E}{D} \qquad 3\text{-}10$$

Basic benchmarking is recommended to check if the figures obtained are valid in the country of measurement. The specific energy intensity required to produce one unit of steel can be used to validate the information against other countries with plants with similar process layouts. Equation 3-10 indicates specific intensity, where E is energy and D is the production driver of the facility. This value can then be compared to the world energy intensity figures discussed in the literature review.

A SANS accredited Measurement and Verification body has to validate and compile a report for a section 12L tax application. The final values of the quantification are the contents of such a report. This can also be used as validation for the values if it is available.

The M&V body has to report on the accuracy of the data. To do this they will audit the quantification process that has been followed. They will verify the source documentation such as utility bills, delivery notes, calibration certificates etc. They will check the calculations. The values supplied to them will also be spot checked on a site visit.

3.6 Conclusion

This chapter describes the methodology that was developed to quantify energy consumption in steel manufacturing facilities. The methodology consists of the following steps: identify, quantify, normalise and verify.

The identification step in the methodology identifies the energy carriers that are consumed in the facility. The energy carriers are broken into types and sources to account for different product qualities. The potential production drivers that can be used to access energy performance are identified. Once these factors have been identified, the facility or process boundary can be identified.

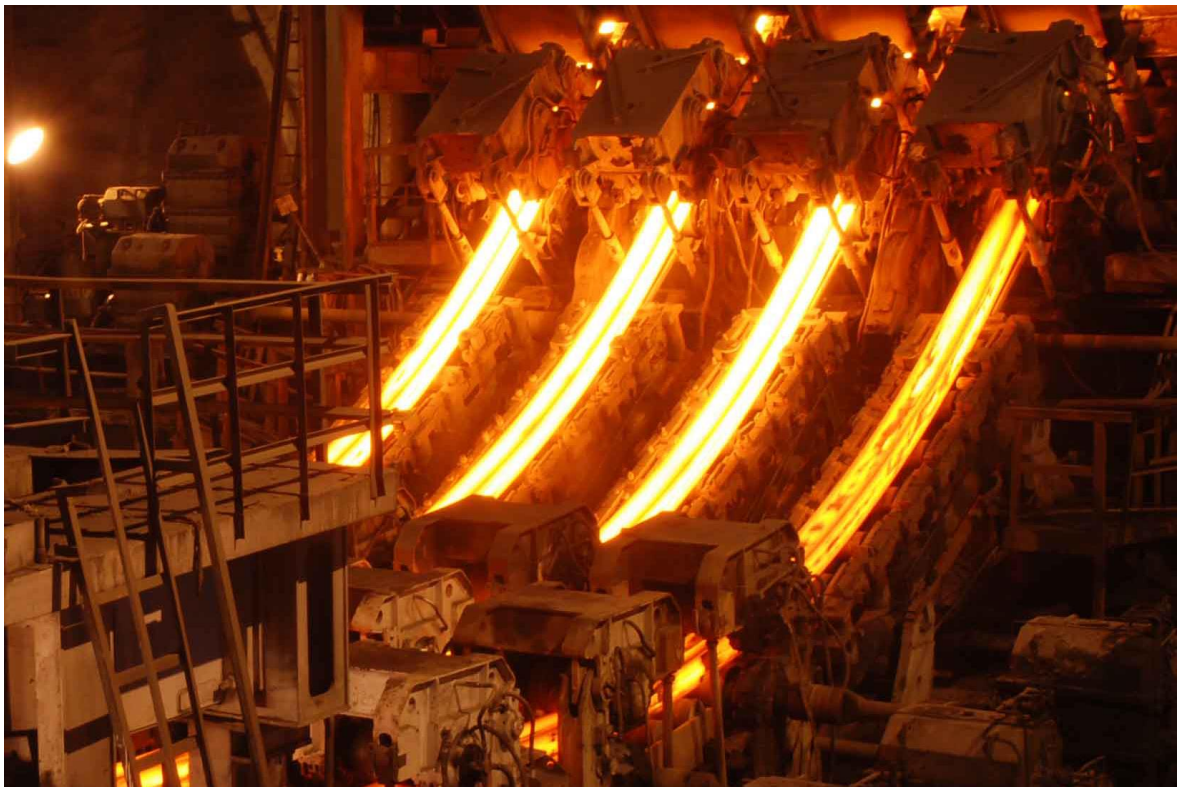
The quantification step in the methodology uses the methods of international and local standards in the literature review to quantify the energy carriers and production drivers that have been identified. The energy carriers that are not measured in units of energy also require Specific Energy information.

The normalisation step of the methodology converts the quantified values for energy carriers to a comparable unit of energy. The normalisation steps for each energy carrier that requires conversion (gas and coal) are specified. The final step in the normalisation steps is to aggregate all the energy carriers to a single energy value and to present the production drivers. Uncertainty that has been introduced by the quantification methodology has to be managed.

Once the energy carriers and production drivers have been normalised, the information used has to be verified. The information used is checked to be compliant with the standards in literature, specifically the SANS 50 010 standard. The standard states that utility invoices and calibrated metering equipment must be used for information. If the information does not comply with the standards, another source of quantification must be identified, quantified and normalised.

The results of the methodology have to be validated by comparison with similar local or international results that are found in the literature. The world benchmarks are used to check the specific energy intensity value calculated from the information obtained by the methodology. In the next chapter, the methodology that has been developed is implemented on case studies. The results of the implementation will validate the methodology.

4 RESULTS



Continuous casters [54]

4.1 Introduction

In this chapter, the methodology that has been developed is validated with four case studies. Different plants have been selected for the case studies. The methodology is to quantify the energy consumption and production driver for the plants selected. The first case study is discussed in detail. The other case studies are discussed briefly with only the main differences and results presented.

The results for the four case studies are listed after the methodology has been followed. The energy carriers and drivers are identified, quantified, normalised and verified. The main results are then quantified energy consumption and production driver values for the year of 2013. The results are presented as monthly consumption and production values.

Verification of the information obtained is an important step for an accurate value for the plant's energy consumption and production driver. The source documents and relevant techniques used from the methodology developed are listed.

The validation of the results is the next step once the results have been quantified and verified. The verification step is to complete a calculation of the intensity of the plant with the energy consumption and production driver. The intensity value is then compared to results published by other countries.

4.2 Case study 1

4.2.1 FACILITY LAYOUT

The first case study in validating the methodology described in Section 3 has been completed on a steel production facility based in South Africa. The steel plant has a capacity to produce 3 million tonnes of liquid steel per annum. It produces various flat steel products consisting of coils and plate products of various grades of finishing.

The basic process layout of the steel production facility is shown in Figure 4-1. The iron-making process consists of a sinter plant and two blast furnaces. The direct reduction plant has six rotary kilns producing Direct Reduction Iron (DRI). The coke-making department consists of 6 coke batteries.

The main steel-making facility is the oxygen steel making facility, which consists of three basic oxygen furnaces. It produces various steel grades for automotive, plate, tin as well as draw and wall ironing applications. The electric steel-making route consists of three Electric Arc Furnaces. It produces steel for mainly plate mill, pipe and galvanised applications.

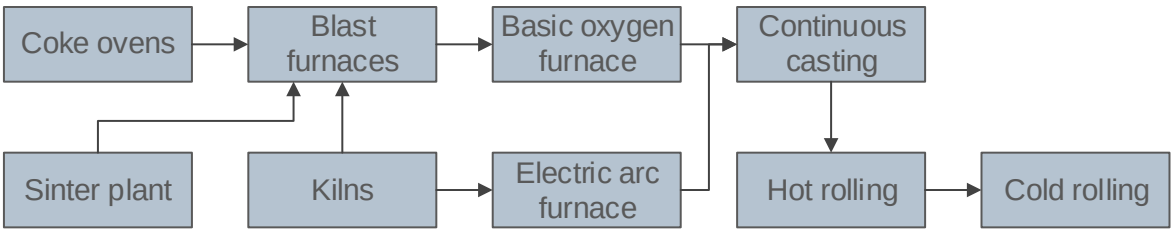


Figure 4-1: Process layout of case study 1

The plant has implemented various energy and cost saving strategies to improve profitability. One of the main changes is the decommissioning of the EAFs. With this change, DRI has been routed to the blast furnaces as seen in Figure 4-1. This strategy has the potential to increase efficiency, which will be observed with the application of this research methodology. The plant is expecting savings on energy over the period of 2012 to 2013.

4.2.2 IDENTIFYING ENERGY CARRIERS AND DRIVERS

Identify energy carriers

The first step in the methodology is to identify (Section 3.2) the energy carriers consumed by the facility. The energy carriers consumed by the plant are identified using plant layouts and consulting with personnel on site. The energy carriers are electricity, gas and coal.

Electricity is consumed throughout the entire plant. Most components in the facility require electricity. The consumers of electricity at the facility are numerous. The largest consumers of electricity are the compressed air plant, hot strip mill, sinter plant and BOF plant.

Gas is consumed by many components on the facility. The largest consumers are the hot strip mill, blast furnace and hot dip galvanising plant. Coal is consumed by the production of primary steel only at the facility. The consumers are the coke ovens, kilns and blast furnaces.

Identify production drivers

The potential production drivers have to be identified following the energy carriers. In Figure 4-1, all the products from the blast furnace and onward in the process can qualify as a suitable production driver. The drivers that will be discussed are liquid iron and liquid steel and the final products sold as they are the most obvious production drivers.

The logical selection of the energy driver would be the final products sold that leave the premises. These figures are well documented and measured. However, not every product requires the same amount of energy to produce and cannot easily be aggregated. There are large stockpiles present, which cause a lag in the system from energy use until production. These figures have not been used.

The production of liquid iron from the blast furnaces would also work as a suitable production driver. There would be no production losses from further downstream processing. This measurement has not been used due to uncertainty in accuracy.

Further downstream from the blast furnaces is Liquid Steel Equivalent production from the EAF and BOF furnaces. Minimum losses occur in the process from liquid iron. A high percentage of energy is consumed by the production of liquid steel. This is also a very important point in the process since the facility reports on this figure. It is also an accepted practice in industry [35]–[38], [51]. For these reasons, this value has been identified as the energy driver for this case study as shown in Figure 4-2.

Levels of energy carrier identification

The next step in the identification process of the methodology is to break the energy carriers down to levels. The levels of identification as seen in Figure 4-2 are the energy carrier, type and its source. Electricity does not need to be identified further since only type and source is present. Gas has been identified to only one type in this case study, natural gas, which is sourced from a single supplier.

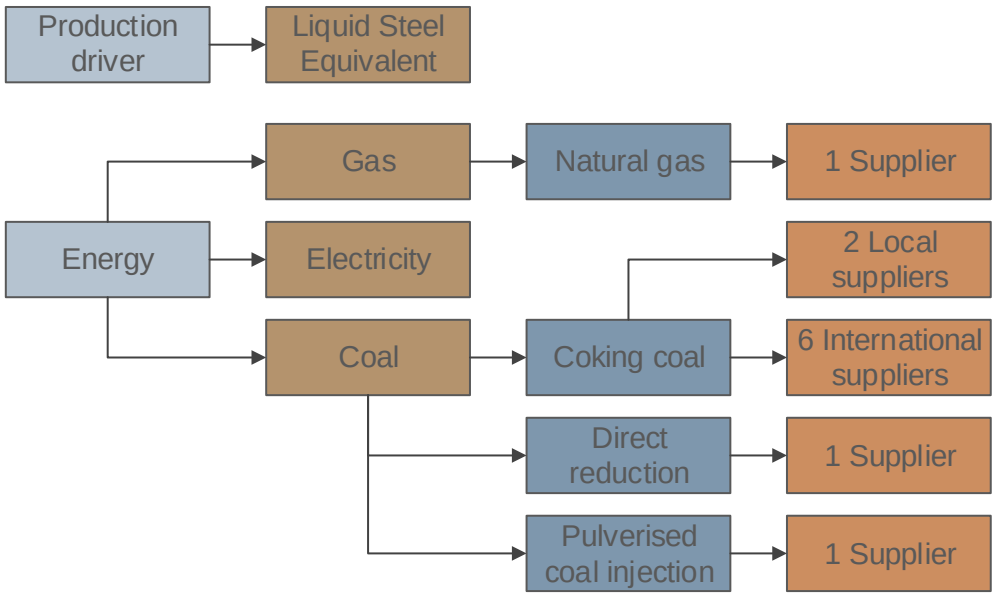


Figure 4-2: Identification step of case study 1

Coal has been identified as three types in this study: coking coal, direct reduction coal and pulverised coal for injection. The consumers of these coal types are the coke ovens and the blast furnaces. Coking coal is sourced by 8 suppliers, 2 local and 6 international suppliers. Direct reduction coal and coal for pulverised coal injection is sourced by one supplier respectively. Each source supplies different coal qualities.

Plant boundary identification

The energy carriers and production drivers have been identified. The next step is to identify the boundary used for the quantification of energy and production driver. The purpose of the study is to quantify the entire facility consumption and production driver. For this reason, a whole facility selection will be employed.

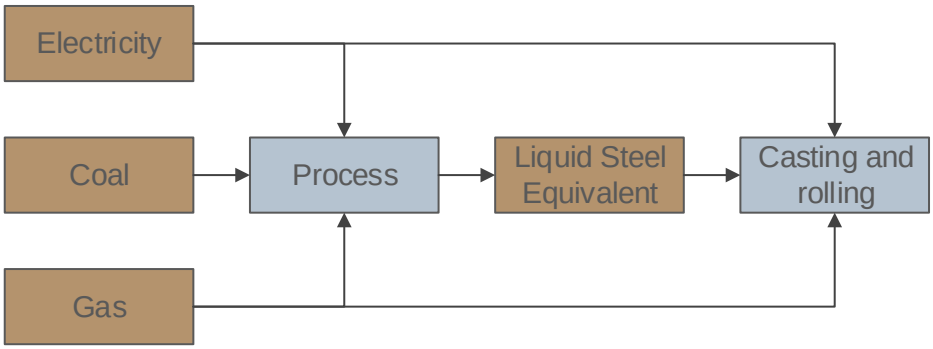


Figure 4-3: Boundary selection of case study 1

Figure 4-3 indicates the whole facility boundary identification. The energy carriers are consumed by the whole plant, which consists of primary and secondary processes (casting and rolling). The process is derived from Figure 4-1. The production driver of the facility has been identified as Liquid Steel Equivalent. This will be used for the quantification.

4.2.3 QUANTIFYING ENERGY CARRIERS AND DRIVERS

Quantification of energy carriers

The identification step of the energy carriers has been completed. The next step is to quantify (Section 3.3) what has been identified. The three energy carriers each have to be measured. Of these energy carriers, two have different energy contents that also need to be quantified. Figure 4-4 indicates the different measurement points for the identified energy carriers that will be discussed in this section.

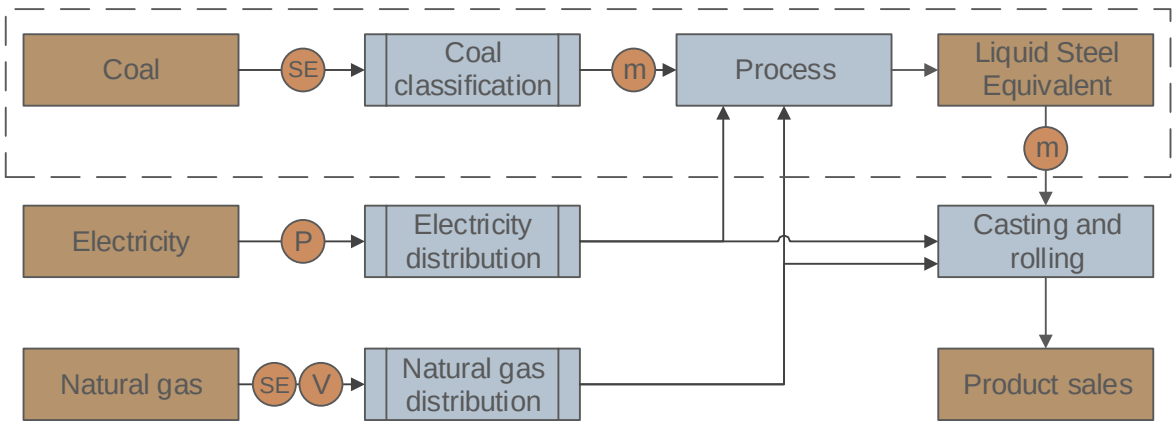


Figure 4-4: Quantification overview of case study 1

The first energy carrier that will be quantified is electricity. There are a few options available for the measurement of electricity consumption. On the plant side, there are check meters on the utility incomers for bill verification purposes. Also available are meters that measure the consumption of each plant, although these meters are not present on all plants. These options are also not calibrated.

The plant electricity is supplied by one energy utility. The plant is billed each month with invoices that are measured by power meters (P) on all the incomers, indicated in Figure 4-4. The invoices have been selected as the quantification measure for electricity. Figure 4-5 indicates the quantification of electricity from two electricity accounts measured in kWh, the two accounts are added together.

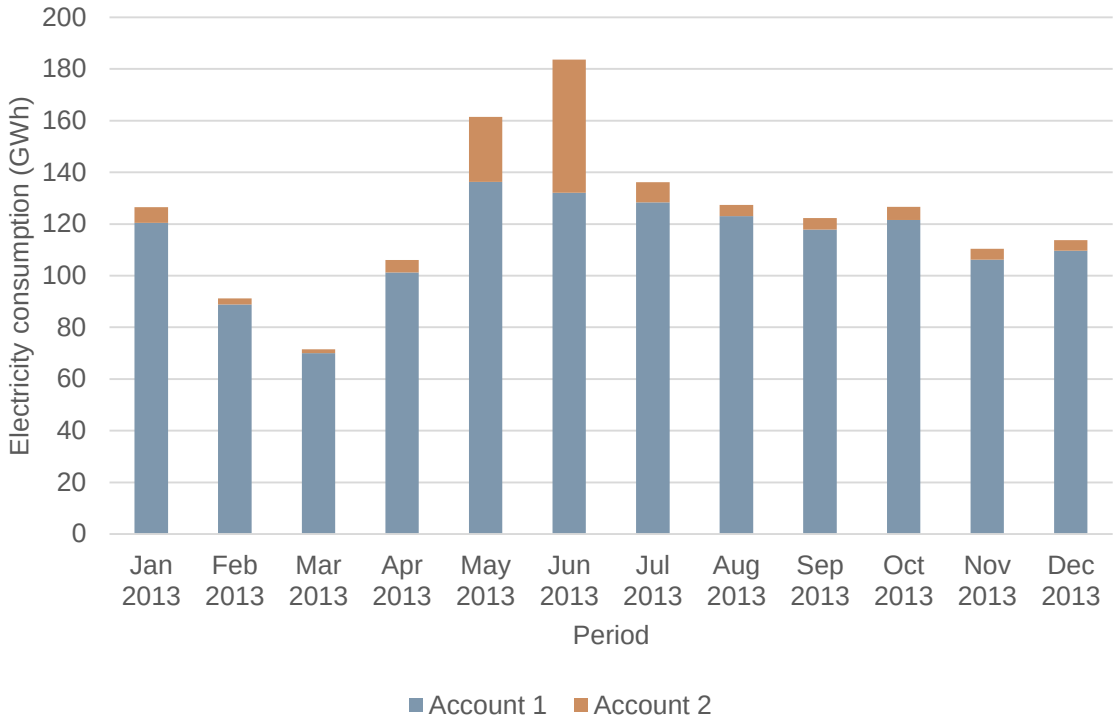


Figure 4-5: Quantification results of electricity consumption for case study 1

Gas is the next energy carrier that will be quantified. Natural gas is the only gas type identified. There are various options present to quantify the plant's gas consumption. The plant has check meters available on the gas main line that supplies the gas for bill verification. Flow meters are also available for each section that uses gas. None of the meters are calibrated.

The facility's natural gas is supplied by a single energy utility. The plant is billed each month for gas consumption measured by the utility. Flow meters (V) on the main gas pipeline are indicated in Figure 4-4. The utility also determines the gas Specific Energy (SE). The utility's invoices have been selected as the quantification measure for the gas consumption.

Figure 4-6 indicates the quantified gas consumption values. The invoices indicate gas consumption in GJ.

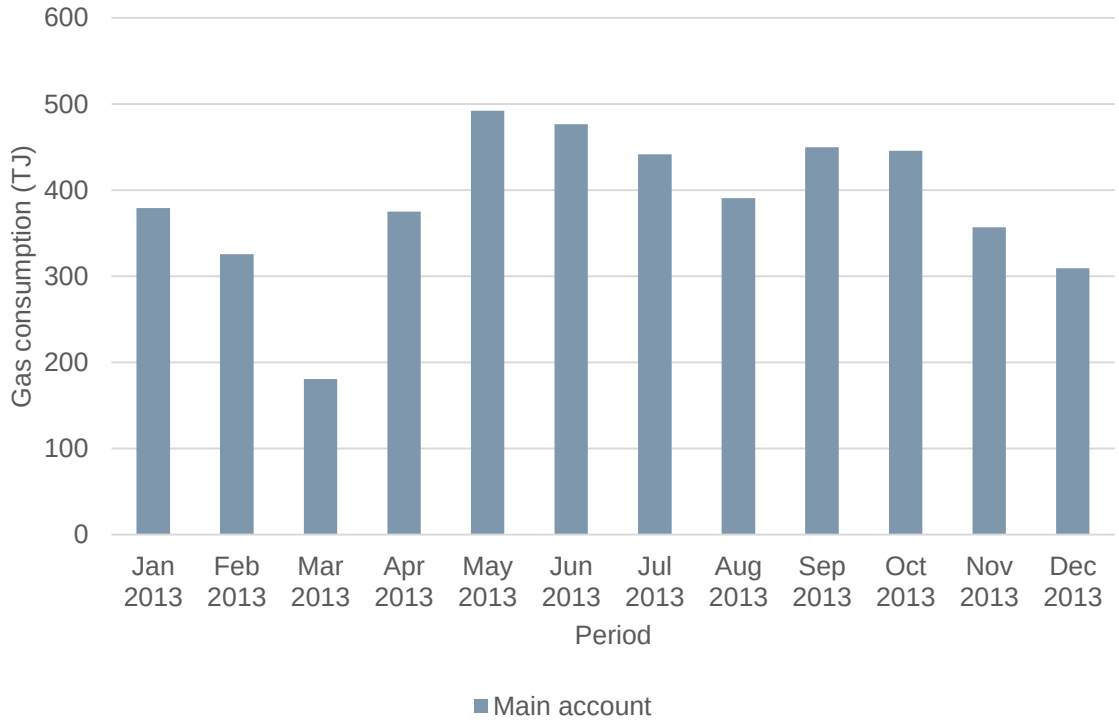


Figure 4-6: Quantification results of gas consumption for case study 1

The quantification of coal consumption follows. Firstly, an overview of coal handling will be provided and discussed. From Figure 4-4, it is observed that coal goes through classification of the different coal types and sources. Thereafter, the coal is consumed by the process. There are, however, three types of coal in this case study and more detail of coal handling is required.

Figure 4-7 provides more detail on coal handling, the bordered section of Figure 4-4. Coal is classified into PCI coal, coking coal and DR coal. PCI coal is injected or consumed by the blast furnace. Coking coal is consumed by the coke ovens to produce coke for the blast furnace. Finally, DR coal is used by the kilns as feed and injection coal. There are numerous suppliers of the different coal types that have to be quantified.

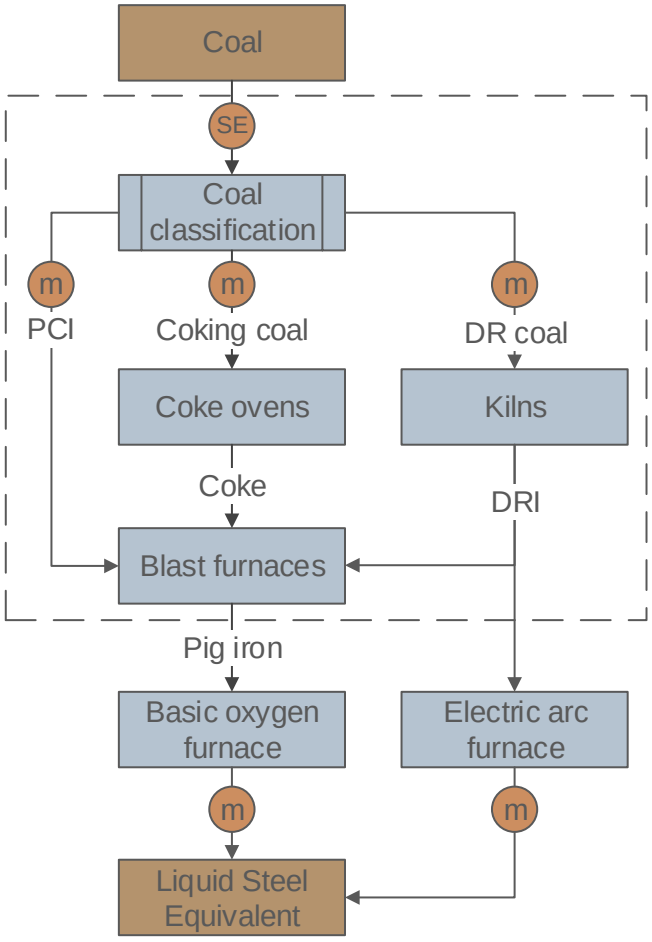


Figure 4-7: Quantification overview of coal and steel for case study 1

The coal quantification points available can now be discussed. Each coal supplier invoices the plant for the quantity of coal purchased. The invoices are not a suitable quantification measure for the coal consumption due to the presence of large coal stockpiles. Some supplier invoices are, however, necessary for the quantification of coal Specific Energy.

There are various plant meters available that measure coal consumption throughout the process. The coal is weighed on arrival from the supplier, but this measurement is disqualified for the same reason as the invoices; large coal stockpiles. The best measurement point would be just before the consumption of coal by the process. The coal is, however, blended or crushed in the process and the individual energy content of each coal supplier is indeterminable.

The measurement points that have been selected for the quantification of coal are located before the crushing or blending of the coal. There is a minimum stockpile of coal after these measurement points and the coal Specific Energy can still be identified. The bordered section of Figure 4-7 is shown in more detail in Figure 4-8. The detailed layout of the coal measurement for quantification of the various coal types is shown in this Figure.

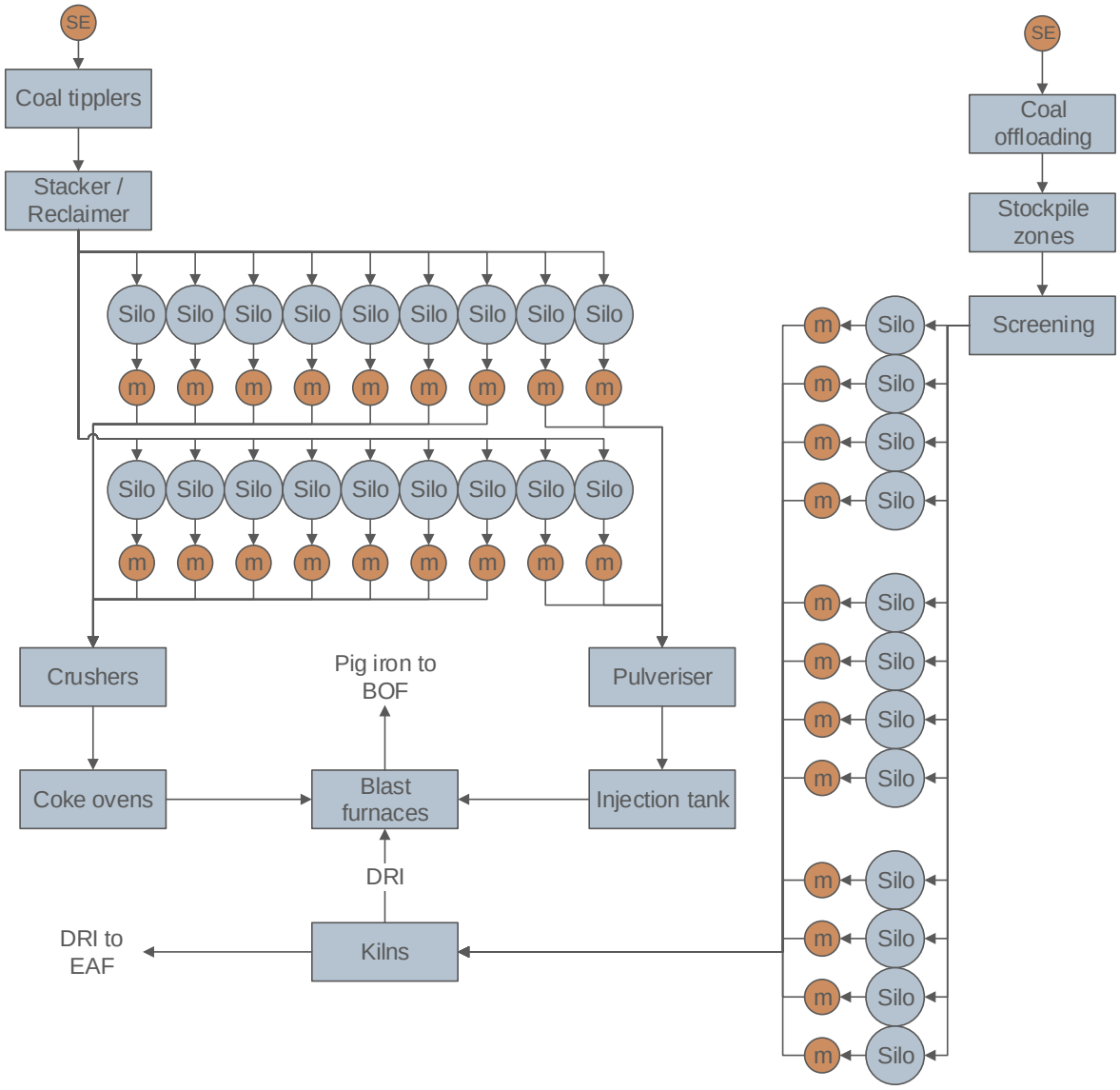


Figure 4-8: Quantification measurement detail of coal for case study 1

The coking coal and PCI coal is received by train, tipped and stacked in a coal stockpile yard by supplier. The coal is then reclaimed as required by the process where it is stored in silos. Specific silos are reserved for each type of coal and supplier. Coking coal is then measured by 14 weigh feeders (m) and crushed for use in the coke ovens to produce coke. PCI coal is also measured by four weigh feeders and pulverised before consumption by the blast furnace.

Similarly, DR coal is offloaded, stockpiled, reclaimed, screened by particle size and stored in silos. Thereafter, the coal is measured by 12 weigh feeders and is consumed by the kilns to produce Direct Reduced Iron (DRI) for the EAF and blast furnace.

Figure 4-9 shows the results of the quantification of coal consumption by the plant. The different identified coal types and suppliers are measured in tonnes. There are six imported and two local coking coals, as well as a DR and PCI coal supplier.

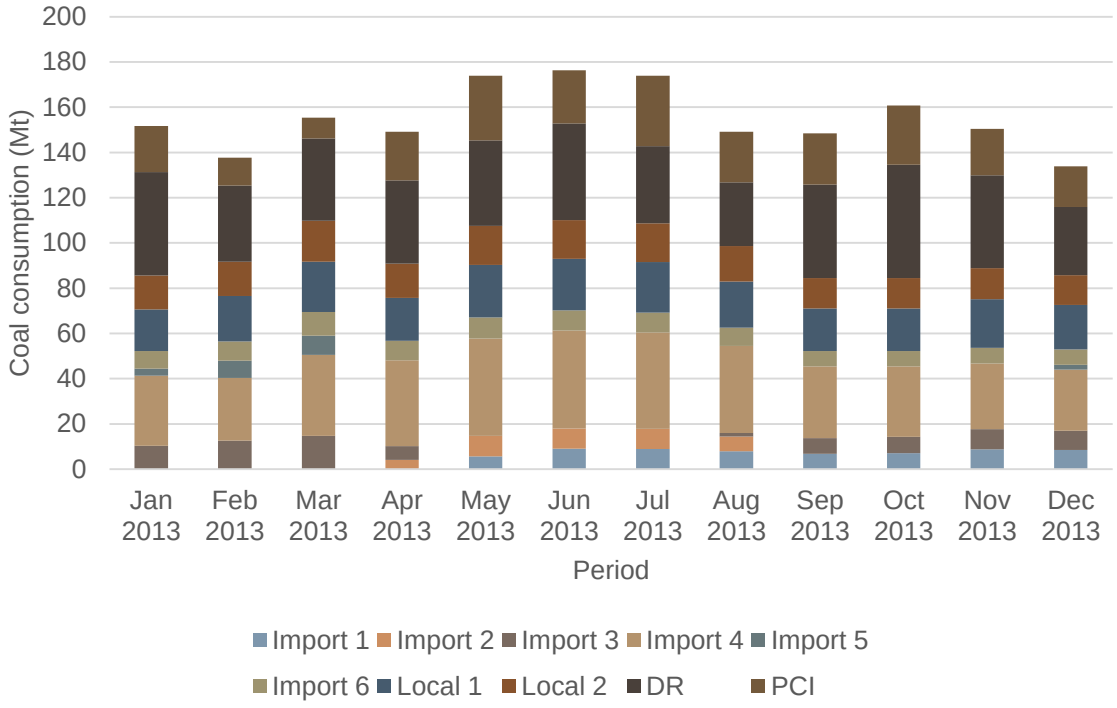


Figure 4-9: Quantification results of coal consumption for case study 1

Quantification of production drivers

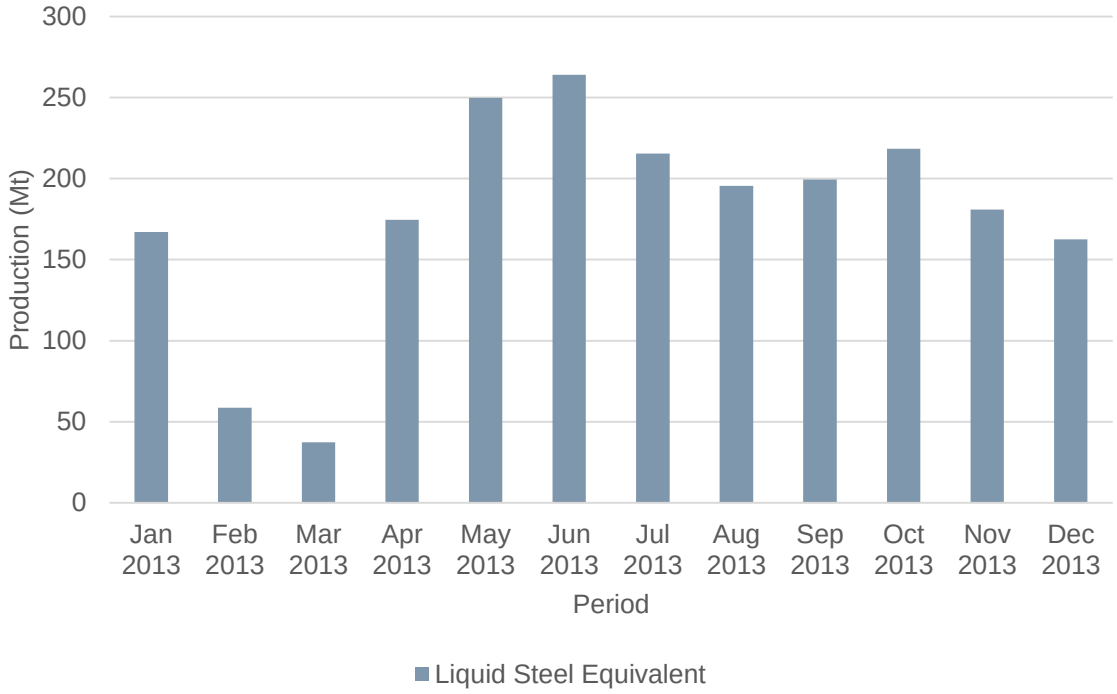


Figure 4-10: Quantification results of LSE production for case study 1

Liquid Steel Equivalent (LSE) is measured at a single stage in the process. LSE has been identified as the production driver for energy performance. The BOF and EAF produce LSE, which is measured on platform scales (m), indicated in Figure 4-7. The results of the quantification of LSE for the selected period is shown in Figure 4-10. The scales measure LSE production in tonnes. An incident with the BOF resulted in lower production in February and March 2013. The BOF was repaired and the EAF restarted in this period. Coke was still produced in this period, resulting in the maintained coal consumption. The coke can be stored or sold.

The suitability of LSE as the plant's production driver of energy performance has to be determined. Equation 3-1 is used to determine the error in the selection of the production driver. The equation has been used on each energy carrier to indicate the percentage of energy used to produce the production driver. Figure 4-11 indicates the results of the error check. 100% of coal, 47% of electricity and 26% of gas is consumed in the production of LSE. The total energy consumed by the production of LSE is a high value of 91%.

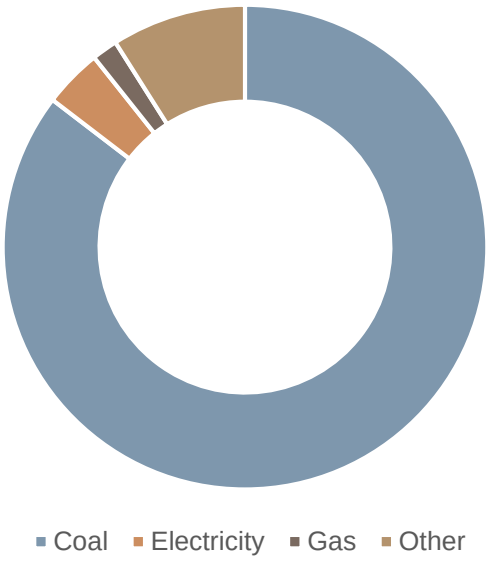


Figure 4-11: Energy consumption by production driver

4.2.4 ENERGY NORMALISATION

Normalisation of energy carriers

The next step of the research methodology is to normalise (Section 3.4) the values quantified in the quantification step of the case study. The energy carriers that do not require normalisation are electricity and gas, although gas is converted from GJ to kWh so that it is comparable to the other energy carriers.

The normalisation of coal is completed by determining a Specific Energy or Calorific Value for the coal. The method of determining the CV value of coal is discussed in Section 3.4.1. The method that was followed for each coal supplier is indicated in Table 4-1.

Table 4-1: Normalisation methods for case study 1

TYPE	NORMALISATION METHOD
Coal	
Import 1	Method 1
Import 2	Method 1
Import 3	Method 1
Import 4	Method 1
Import 5	Method 1
Import 6	Method 1
Local 1	Method 1
Local 2	Method 1
DR	Method 1
PCI	Method 1

The CV value of the imported coking coal suppliers have been determined with the use of Method 1. The CV value was quantified by the use of laboratory reports for each vessel received, as will be discussed later in this chapter. The normalisation factor results of the CV value in AD basis are indicated in Table 4-2. The CV values range from 31.7 – 32.65 GJ/t. The high CV values of the imported coals are due to high quality and low inherent moisture on the lab analyses.

Table 4-2: Normalisation factors for imported coking coal of case study 1

PERIOD	IMPORT 1	IMPORT 2	IMPORT 3	IMPORT 4	IMPORT 5	IMPORT 6
	GJ/t	**GJ/t**	**GJ/t**	**GJ/t**	**GJ/t**	**GJ/t**
2013	31.76	32.65	31.88	32.36	31.7	33.64

The CV values of local coking coal and non-coking coal (DR and PCI) have been determined by the use of Method 1 of the research methodology. The train deliveries were accompanied by laboratory reports for local coking coal 1, DR and PCI coal. The CV value of local coking coal 2 was supplied by analyses reported by the mine. The results of the normalisation factors is indicated in Table 4-3. The CV values range from 26.28 – 29.99 GJ/t. The coals used for Direct Reduction are of lower quality with high ash content resulting in a lower CV value.

Table 4-3: Normalisation factors for local coking and non-coking coal of case study 1

PERIOD	LOCAL 1	LOCAL 2	DR	PCI
	GJ/t	**GJ/t**	**GJ/t**	**GJ/t**
2013	29.43	29.99	26.28	28.71

The coal energy of each supplier can be determined by using Equation 3-8 of the methodology. The CV value is multiplied by the mass quantity. The results of the coal energy calculation for case study 1 is shown in Figure 4-12. The coal energy is calculated in GJ and converted to kWh.

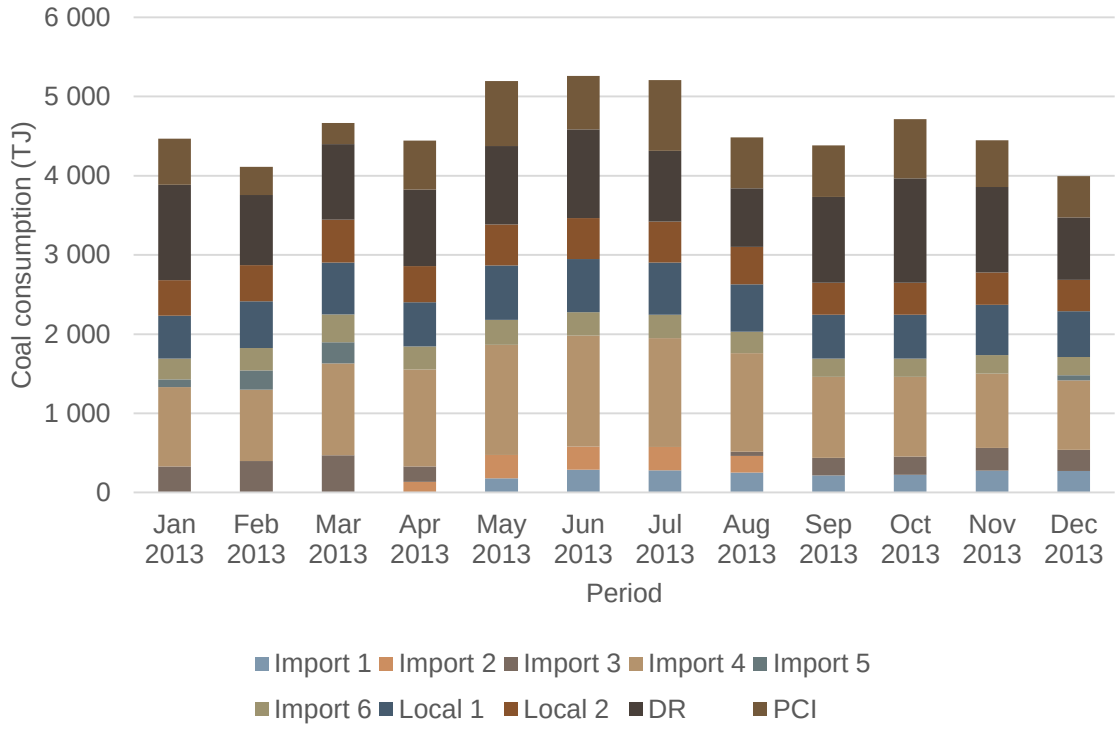


Figure 4-12: Normalisation results of coal consumption for case study 1

Calculation of total energy carriers and production driver

After all the energy carriers have been normalised, the total energy consumption can be determined. Equation 3-9 is used to aggregate all energy carriers consumed. The results for each energy carrier and the total energy consumed is quantified in Figure 4-13.

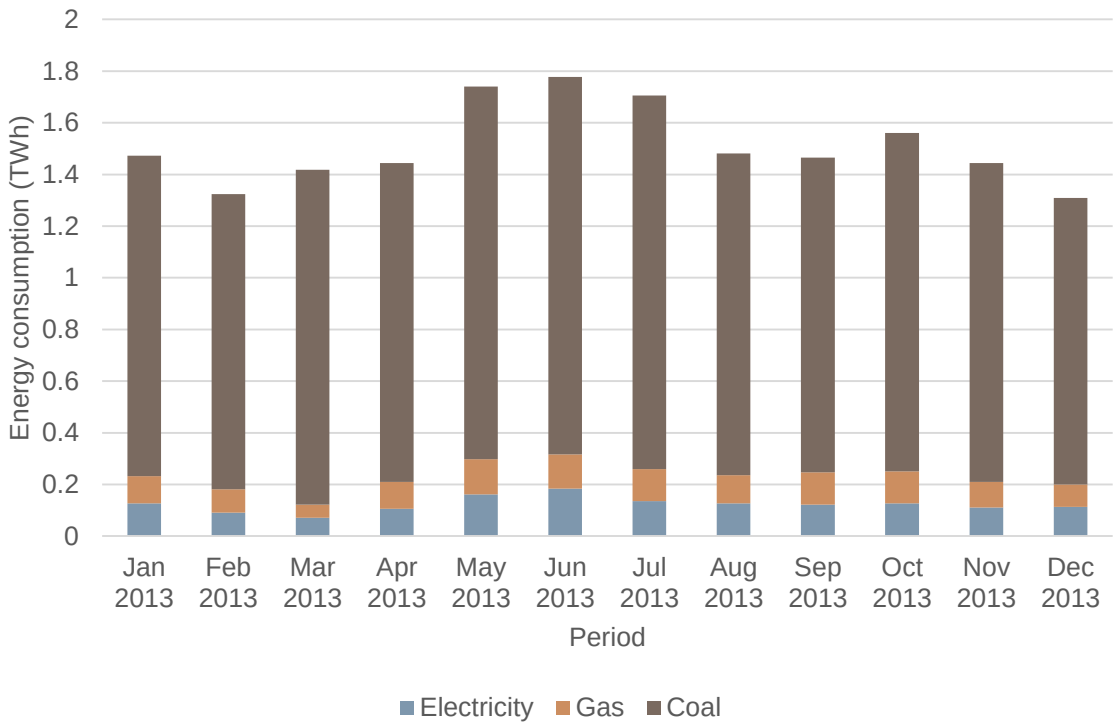


Figure 4-13: Quantification results of energy consumption for case study 1

The quantification of total energy consumption and production driver of case study 1 is shown in Table 4-4. The facility consumed 18 144 141 414 kWh energy and produced 2 123 676 t of liquid steel for the year 2013. The information presented in this case study can be seen in more detail in Appendix A.

Table 4-4: Quantification of energy consumption and production driver for case study 1

PERIOD	ENERGY CARRIERS	PRODUCTION DRIVER
	kWh	**t**
Jan 2013	1 472 736 115	167 056
Feb 2013	1 324 006 231	58 689
Mar 2013	1 418 103 707	37 317
Apr 2013	1 444 350 515	174 518
May 2013	1 741 005 344	249 785
Jun 2013	1 777 600 078	263 990
Jul 2013	1 705 880 307	215 491
Aug 2013	1 481 541 469	195 555
Sep 2013	1 465 014 401	199 457
Oct 2013	1 560 223 287	218 462
Nov 2013	1 444 611 248	180 913
Dec 2013	1 309 068 710	162 443
Total	**18 144 141 414**	**2 123 676**

Managing uncertainty

Uncertainty is managed throughout the methodology by its compliance with standards. Every value used is traceable to a document of the value or a calibration document of the meter for that value. All the source documentation for the information has been obtained and (specifically in the case of CV values for coal) no sampling error has been made.

The measurement equipment used in the quantification process is calibrated according to standard. The accuracy for electricity utility meters above 10 MVA is within 0.5% [53]. The accuracy for gas utility meters is 1%. The accuracy for the plant coal meters are 0.25% for most coal types and 1% for DR coal. The liquid steel meter accuracy in the plant is 0.4%.

Using the accuracies, the uncertainty of electricity, gas and coal is ±7 383 960 kWh, ±12 846 422 kWh and ±63 501 286 kWh respectively. The total uncertainty of the energy carriers and production driver is ±83 731 669 kWh (0.46%) and ±8 495 t (0.4%), respectively.

4.2.5 VERIFICATION AND VALIDATION

Measurement and verification criteria

The next step in the methodology is to verify (Section 3.5) the information used in the case study. The information has to be verified with criteria set by the standards discussed in the literature review. The quantification information that complies with the criteria are invoices, calibrated measurement equipment and laboratory reports as discussed in the previous chapter.

The verification method of the energy carriers and production driver quantification of case study 1 is presented in Table 4-5. The electricity and gas consumption of the facility is measured by invoices billed to the plant by the energy utility. The quantification of coal consumption and Liquid Steel Equivalent is performed via calibrated measurement equipment. These verification methods are for the quantification step of the methodology.

Table 4-5: Verification method of quantification value for case study 1

TYPE	VERIFICATION METHOD	COMPLIANCE
Electricity		
Account 1	Invoices	SANS 50 010 Section 6.2
Account 2	Invoices	SANS 50 010 Section 6.2
Gas		
Natural gas	Invoices	SANS 50 010 Section 6.2
Coal		
Import 1	Calibrated meter	SANS 50 010 Section 6.3
Import 2	Calibrated meter	SANS 50 010 Section 6.3
Import 3	Calibrated meter	SANS 50 010 Section 6.3
Import 4	Calibrated meter	SANS 50 010 Section 6.3
Import 5	Calibrated meter	SANS 50 010 Section 6.3
Import 6	Calibrated meter	SANS 50 010 Section 6.3
Local 1	Calibrated meter	SANS 50 010 Section 6.3
Local 2	Calibrated meter	SANS 50 010 Section 6.3
DR	Calibrated meter	SANS 50 010 Section 6.3
PCI	Calibrated meter	SANS 50 010 Section 6.3
Production driver		
Liquid steel equivalent	Calibrated meter	SANS 50 010 Section 6.3

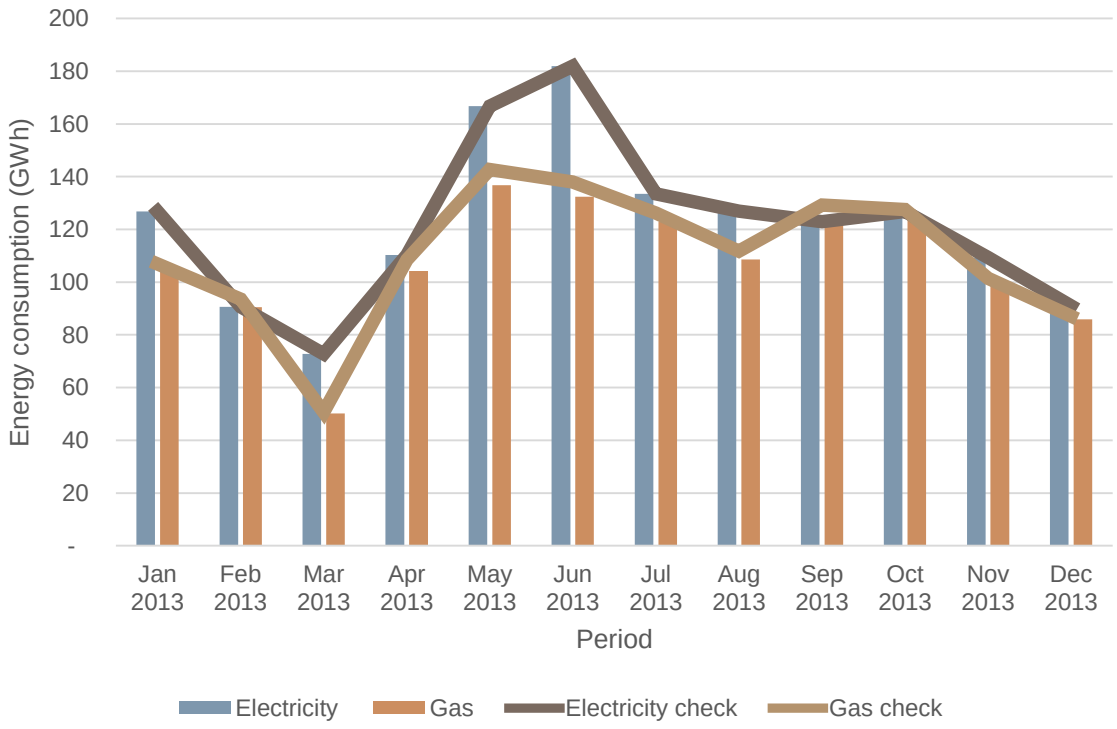


Figure 4-14: Invoice verification meter data comparison

The plant verification meter comparison with electricity and gas energy consumption is indicated in Figure 4-14. The error check is 1.2% and 2.9% for electricity and gas, respectively. The check meters are uncalibrated and non-compliant to standards. Conversely, the electricity check is satisfactory. The gas check meter shows an error of 2.9%, which indicates the importance of meter calibration and could be improved by calibration. The utility meter is, however, calibrated according to standard.

The verification of the energy carrier normalisation factor is indicated in Table 4-6. Coal is the only energy carrier in this case study that needed to be normalised. The imported coking coals were normalised using laboratory reports that were performed on each coal vessel. Local coking coal 1, DR and PCI coals were normalised using laboratory reports accompanying each train delivery. Local coking coal 2 was normalised using laboratory reports that were supplied by the mine the coal was sourced from.

Table 4-6: Verification method of normalisation value for case study 1

TYPE	VERIFICATION METHOD	COMPLIANCE
Coal		
Import 1	Lab report with vessel invoice	SANS 50 010 Section 6.2
Import 2	Lab report with vessel invoice	SANS 50 010 Section 6.2
Import 3	Lab report with vessel invoice	SANS 50 010 Section 6.2
Import 4	Lab report with vessel invoice	SANS 50 010 Section 6.2
Import 5	Lab report with vessel invoice	SANS 50 010 Section 6.2
Import 6	Lab report with vessel invoice	SANS 50 010 Section 6.2
Local 1	Lab report with train invoice	SANS 50 010 Section 6.2
Local 2	Lab report from mine	SANS 50 010 Section 6.3
DR	Lab report with train invoice	SANS 50 010 Section 6.2
PCI	Lab report with train invoice	SANS 50 010 Section 6.2

Validation of information obtained

The first level of validation is to calculate the energy intensity of the plant. Equation 3-10 of the research methodology is applied totals of the energy carriers and the production drivers. The results of the calculation is shown in Table 4-7 for 2012 and 2013. An energy intensity improvement has been observed over this period from 8 628 kWh/t to 8 544 kWh/t.

Table 4-7: Energy intensity of case study 1

PERIOD	ENERGY INTENSITY
	kWh/t
2012	8 628
2013	8 544

Comparison of energy intensity with international results in literature indicates that the plant compares to that of the Commonwealth of Independent States (CIS) and Africa [25], [26]. This is acceptable for an old plant found in this case study.

The results of this study have also been verified by an independent professional Measurement and Verification team certified by SANAS. They checked the compliance of the information of case study 1 with the standards set by the SANS 50 010 standard. The process, calculations and supporting documents have been verified in an audit. The purpose was the measurement of energy efficiency achieved by the facility. The values quantified in this case study and reported by the M&V team have been approved by SANEDI for a 12L tax incentive.

4.2.6 COMPARISON WITH PLANT REPORTED RESULTS

The methodology has been applied to case study 1 in full. To analyse the results obtained, a comparison with the plant's estimate is shown in Table 4-8. The plant used the same compliant measurement for the quantification of the production driver and no error is observed.

There is an error of 8.92% between the plant's old estimation and this study's new model. The main reason for this difference is the normalisation factors of the coals used. The plant used the same CV values each year and did not compensate for new suppliers. The extreme case in the estimation is for Import 6 where the verified value is 33.64 GJ/t versus the plant's 26.5 GJ/t.

Table 4-8: Comparison of methodology and plant results for case study 1

METHOD	ENERGY CARRIERS	PRODUCTION DRIVER
	kWh	**t**
Old	16 658 632 173	2 123 676
New	18 144 141 414	2 123 676
Error	**-8.92%**	**0%**

4.3 Case study 2

4.3.1 FACILITY LAYOUT

The case study was completed on a steel production facility that is based in South Africa. The plant has the capacity to produce 1.9 million tonnes of liquid steel per annum. It produces various long steel products including structural, profile, bar and wire products of various material finishes.

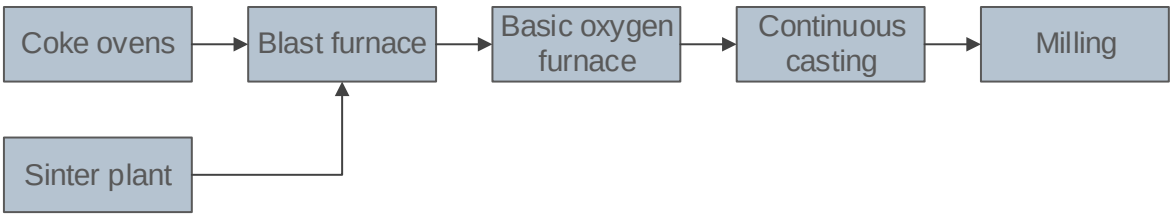


Figure 4-15: Process layout of case study 2

The basic process layout of case study 2 can be seen in Figure 4-15. The iron-making process consists of a sinter plant and blast furnace. The coke-making department has four coke oven batteries of which three are in operation. The plant has three BOFs in operation that provide liquid steel for secondary metallurgy. The continuous casters produce blooms for various rolling operations. The plant has a billet mill, medium mill, bar mill and rod mill.

4.3.2 IDENTIFYING ENERGY CARRIERS AND PRODUCTION DRIVERS

The energy carriers have to be identified as the first step of the methodology. The energy carriers have been identified as electricity, gas and coal (indicated in Figure 4-16), using a similar process to case study 1. Most components in the plant require electricity to operate. The largest consumers are the sinter plant, BOF plant, secondary metallurgy and the wire mill. Gas is consumed by numerous components with the largest being the blast furnace, billet and wire mill. Coal is consumed by the production of primary steel only. The consumers are the coke plant, sinter plant and blast furnace.

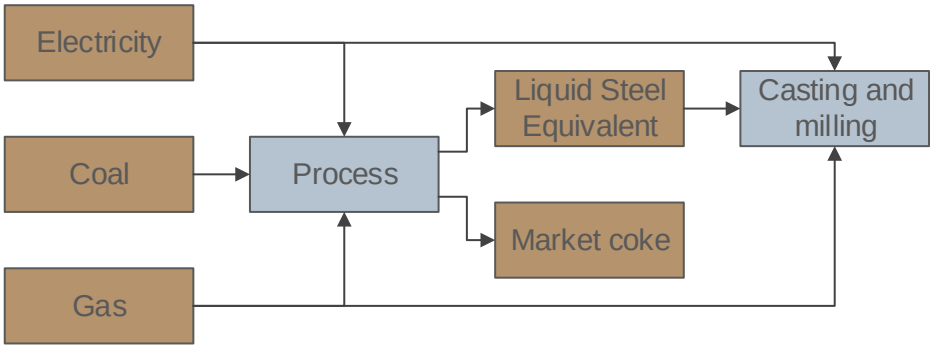


Figure 4-16: Boundary selection of case study 2

The levels of identification for each energy carrier, except electricity, also need to be completed. Gas has been identified to one type, natural gas, which is sourced from a single supplier. There are three types of coal: coking coal, PCI coal and anthracite. Coking coal is sourced by six international and two local suppliers. PCI and anthracite is sourced by a single supplier each.

The identification process of the production drivers is similar to that of case study 1. Various products of the process were assessed as production drivers. This includes the production of liquid iron from the blast furnace, final products produced and sold. The production driver that has been selected for this case study is Liquid Steel Equivalent indicated in Figure 4-16.

A whole facility boundary is used as indicated in Figure 4-16. The energy carriers are consumed by the process, casting and milling. The production driver is produced by the process. Market coke produced by the process is sold and needs to be subtracted from the quantification.

4.3.3 QUANTIFICATION ENERGY CARRIERS AND PRODUCTION DRIVERS

The next step in the methodology is to quantify the energy carriers and production drivers identified. The quantification process is very similar to case study 1. Measurement points were identified for each energy carrier type and source as well as the production driver. Measurement points were also specified for the energy carriers that require Specific Energy.

4.3.4 ENERGY NORMALISATION

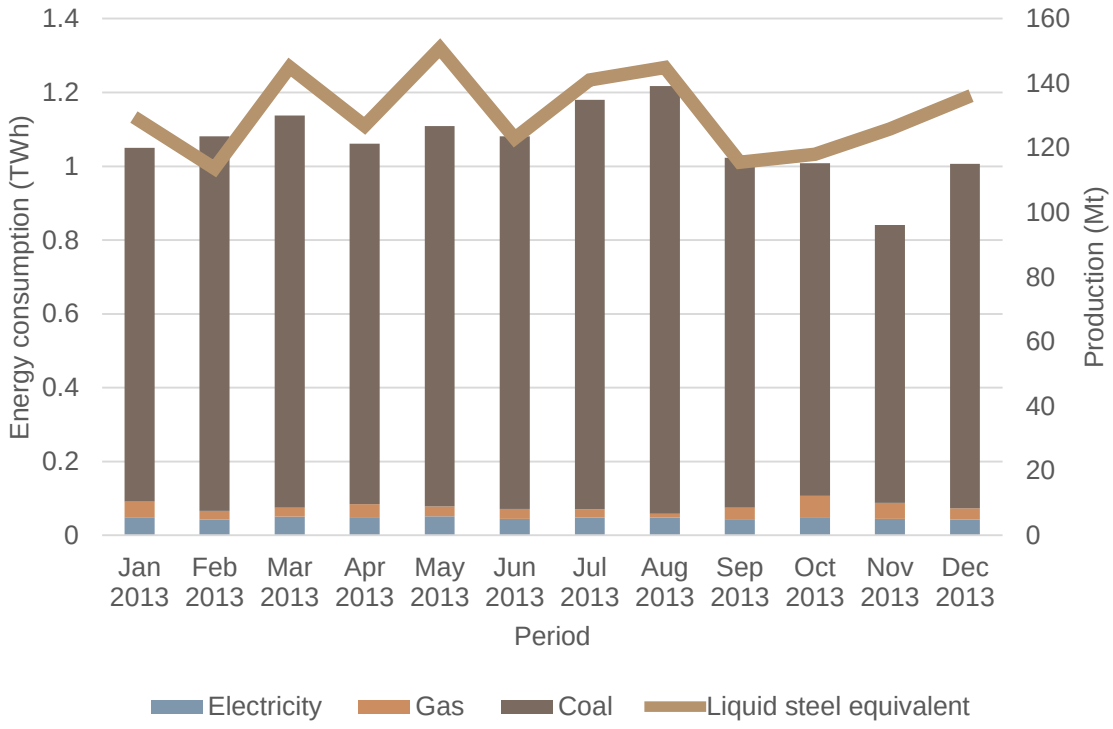


Figure 4-17: Quantification results of energy consumption and driver for case study 2

The next step in the research methodology is to normalise the values that have been quantified to a comparable unit of measurement. This step is very similar to that of case study 1. A CV value is required for each type and supplier of coal. Method 1 was used for the majority of the coal suppliers, with the exception of PCI and anthracite, which was

normalised with Method 3. Figure 4-17 indicates the results of the normalisation of the energy carriers and drivers. The lower energy at the end of 2013 is due to maintenance on the market coke battery.

4.3.5 RESULTS, VERIFICATION AND VALIDATION

The quantification results of total energy consumption and production driver of case study 2 are shown in Table 4-10. The facility consumed 12 795 729 744 kWh energy and 1 568 268 t of liquid steel was produced for the year 2013. There is an error of 10.24% between the plant's old independent estimation and this study's new model. The main reason for this difference is the normalisation factors of the coals used. The plant used the same CV values each year and did not compensate for new suppliers.

Uncertainty is managed similar to case study 1. The total uncertainty of the energy carriers and production driver are ±43 377 151 kWh (0.34%) and ±3 137 t (0.2%), respectively.

Table 4-9: Energy intensity of case study 2

PERIOD	ENERGY INTENSITY
	kWh/t
2013	8 159

The next step in the methodology is to verify the information used in the case study. The information was verified with criteria set in the methodology. The quantification information used are invoices, calibrated measurement equipment and laboratory reports similar to case study 1. The results of this study have also been verified by an independent professional Measurement and Verification team.

Table 4-10: Comparison of methodology and plant results for case study 2

METHOD	ENERGY CARRIERS	ENERGY DRIVER
	kWh	**t**
Old	11 607 111 366	1 568 268
New	12 795 729 744	1 568 268
Error	**-10.24%**	**0.00%**

The first level of validation is to calculate the energy intensity of the plant. The results of the calculation for 2013 are shown in Table 4-9. An energy intensity of 8 159 kWh/t has been calculated. The plant energy intensity compares to that of the CIS and Africa.

4.4 Case study 3

4.4.1 FACILITY LAYOUT

Case study 3 was completed on a steel manufacturing facility based in South Africa. The plant has the capacity to produce 1.3 million tonnes of liquid steel per year. The plant produces ultra-thin hot rolled coils primarily for the export market.

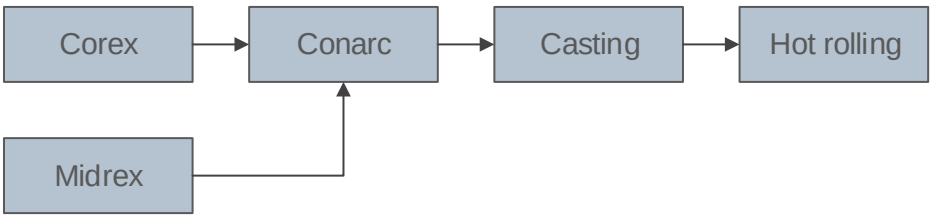


Figure 4-18: Process layout of case study 3

The basic layout for the plant can be seen in Figure 4-18. The plant combines the Corex and Midrex processes into a continuous production process. This replaces the need for coke ovens and blast furnaces. The steel making process consists of a Conarc furnace. A thin slab caster provides slabs for a hot strip mill and temper mill to produce ultra-thin hot rolled coils.

4.4.2 IDENTIFYING ENERGY CARRIERS AND PRODUCTION DRIVERS

The energy carriers have to be identified as the first step of the methodology. The energy carriers have been identified as electricity, gas and coal (indicated in Figure 4-19), using a similar process to case study 1.

Most components in the plant require electricity to operate. The largest consumers are the Conarc plant, oxygen plant, Midrex process and the hot strip mill. Gas is consumed by numerous components with the largest being the Midrex process, secondary metallurgy and the hot strip mill. Coal is consumed by the production of primary steel only. The consumer is the Corex process.

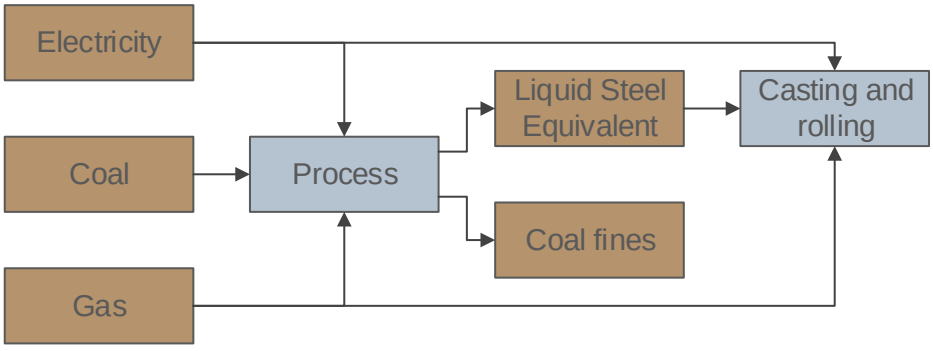


Figure 4-19: Boundary selection of case study 3

The levels of identification for each energy carrier, except electricity, also need to be completed. Gas has been identified to one type, Liquid Petroleum Gas (LPG), which is sourced from a single supplier. There are three types of coal in this case study: Corex coal, coke and anthracite. Corex is sourced from two local suppliers. Coke and anthracite is sourced from a single supplier each.

The identification process of the production drivers is similar to that of case study 1. Various products of the process were assessed as production drivers. This includes the production of liquid iron from the Corex process, final products produced and sold. The production driver that has been selected for this case study is Liquid Steel Equivalent indicated in Figure 4-19.

A whole facility boundary is used as indicated in Figure 4-19. The energy carriers are consumed by the process, casting and rolling. The production driver is produced by the process. Coal fines reclaimed in the process are sold and need to be subtracted from the quantification.

4.4.3 QUANTIFICATION ENERGY CARRIERS AND PRODUCTION DRIVERS

The next step in the methodology is to quantify the energy carriers and production drivers identified. The quantification process is very similar to case study 1. Measurement points were identified for each energy carrier type and source as well as the production driver. Measurement points were also specified for the energy carriers that require Specific Energy.

4.4.4 ENERGY NORMALISATION

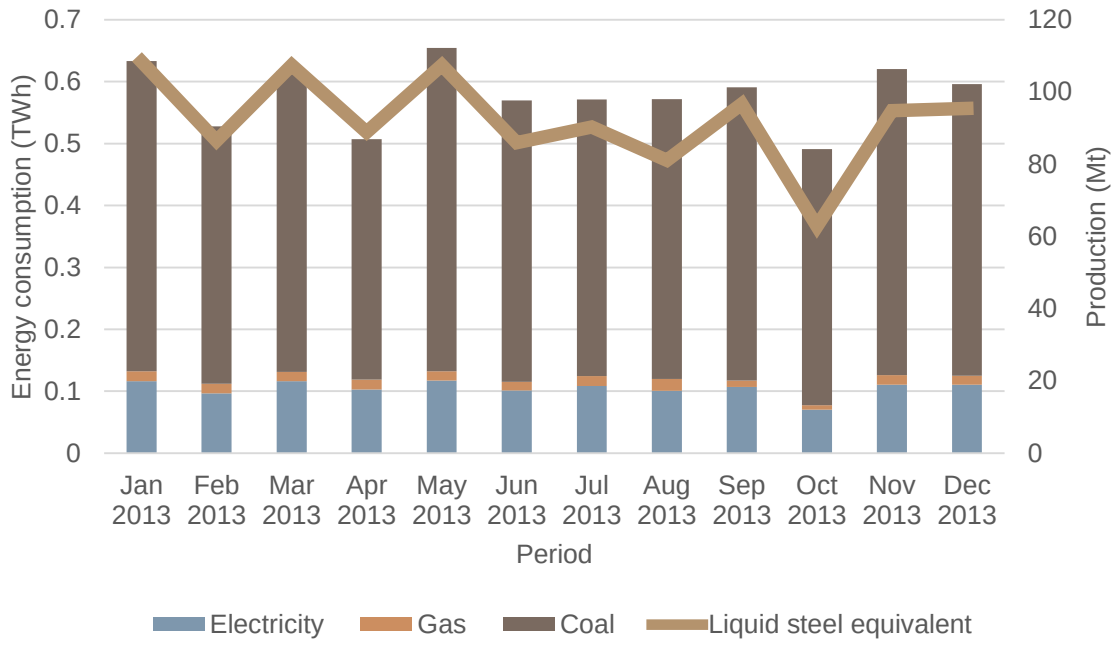


Figure 4-20: Quantification results of energy consumption for case study 3

The next step in the research methodology is to normalise the values that have been quantified. A CV value is required for each type and supplier of coal like case study 1 as well as LPG. Method 1 was used for all of the coal suppliers, with the exception of anthracite, which was normalised with Method 3. The CV value for LPG was determined as outlined in the methodology. The results of the normalisation of the energy carriers and drivers are indicated in Figure 4-20.

4.4.5 RESULTS, VERIFICATION AND VALIDATION

The quantification results of total energy consumption and production driver of case study 3 are shown in Table 4-12. The facility consumed 6 950 287 968 kWh energy and 1 105 662 t of liquid steel was produced for the year 2013. There is an error of 1.21% between the plant's old independent estimation and this study's new model. The main reason for this difference are the normalisation factors of the coals used. The plant used the same CV values each year and did not compensate for new suppliers.

Uncertainty is managed similar to case study 1. The total uncertainty of the energy carriers and production driver are ±77 760 290 kWh (1.12%) and ±1 106 t (0.1%), respectively.

Table 4-11: Energy intensity of case study 3

PERIOD	ENERGY INTENSITY
	kWh/t
2013	6 286

The next step in the methodology is to verify the information used in the case study. The information was verified with criteria set in the methodology. The quantification information used are invoices, calibrated measurement equipment and laboratory reports similar to case study 1.

Table 4-12: Comparison of methodology and plant results for case study 3

METHOD	ENERGY CARRIERS	ENERGY DRIVER
	kWh	**t**
Old	7 035 118 300	1 105 662
New	6 950 287 968	1 105 662
Error	**1.21%**	**0.00%**

The first level of validation is to calculate the energy intensity of the plant. The results of the calculation for 2013 are shown in Table 4-11. An energy intensity of 6 286 kWh/t has been calculated. The plant energy intensity compares to that of Asia and Latin America.

4.5 Case study 4

4.5.1 FACILITY LAYOUT

The case study was completed on a steel production facility that is based in South Africa. The plant has the capacity to produce 0.9 million tonnes of cast steel per annum. It produces various medium and heavy structural sections and ultra-thick plates. The facility also has a large market in the sale of process by-products.

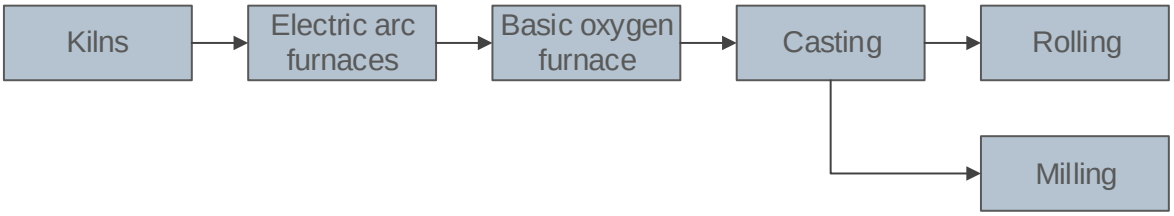


Figure 4-21: Process layout of case study 4

The basic process layout of case study 4 can be seen in Figure 4-21. The direct reduction plant has ten rotary kilns producing Direct Reduction Iron. The iron-making plant consists of seven EAFs. The facility has three BOFs in operation that provide liquid steel for secondary metallurgy. The continuous casters produce slabs, billets and blooms for various rolling operations. The plant has a structural mill and rolling mill.

4.5.2 IDENTIFYING ENERGY CARRIERS AND PRODUCTION DRIVERS

The energy carriers have to be identified as the first step of the methodology. The energy carriers have been identified as electricity, gas and coal (indicated in Figure 4-22), using a similar process to case study 1. Most components in the plant require electricity to operate. The largest consumer is the iron making process. Gas is consumed by numerous processes with the largest being the rolling mills and the iron making process. Coal is consumed by the production of primary and secondary steel. The consumers are the iron-making and steel plant.

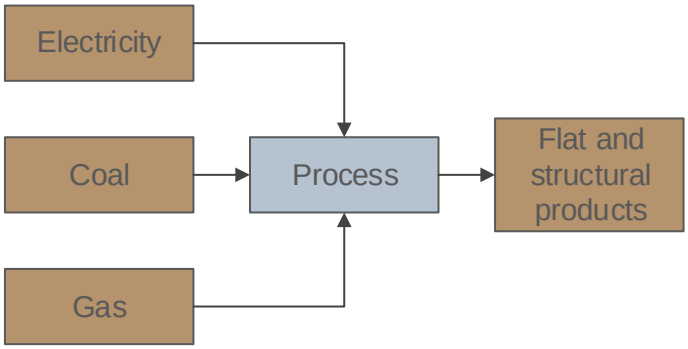


Figure 4-22: Boundary selection of case study 4

The levels of identification for each energy carrier, except electricity, also need to be completed. Gas has been identified to one type, natural gas, which is sourced from a single supplier. There are three types of coal: duff coal, metallurgical coal and anthracite. Duff coal is sourced by five suppliers, metallurgical coal by 11 suppliers and anthracite by 10 suppliers.

The identification process of the production drivers is similar to that of case study 1. Various products of the process were assessed as production drivers. This includes the production of liquid iron and steel from the iron and steel making processes. The production drivers that have been selected are the sales of flat and structural steel products indicated in Figure 4-16.

A whole facility boundary is used as indicated in Figure 4-16. The energy carriers are consumed by the entire process. The production drivers (flat and structural products) are produced by the process. This boundary is used for the quantification step of the methodology.

4.5.3 QUANTIFICATION ENERGY CARRIERS AND PRODUCTION DRIVERS

The next step in the methodology is to quantify the energy carriers and production drivers identified. The quantification process is very similar to case study 1. Measurement points were identified for each energy carrier type and source as well as the production drivers. Measurement points were also specified for the energy carriers that require Specific Energy.

4.5.4 ENERGY NORMALISATION

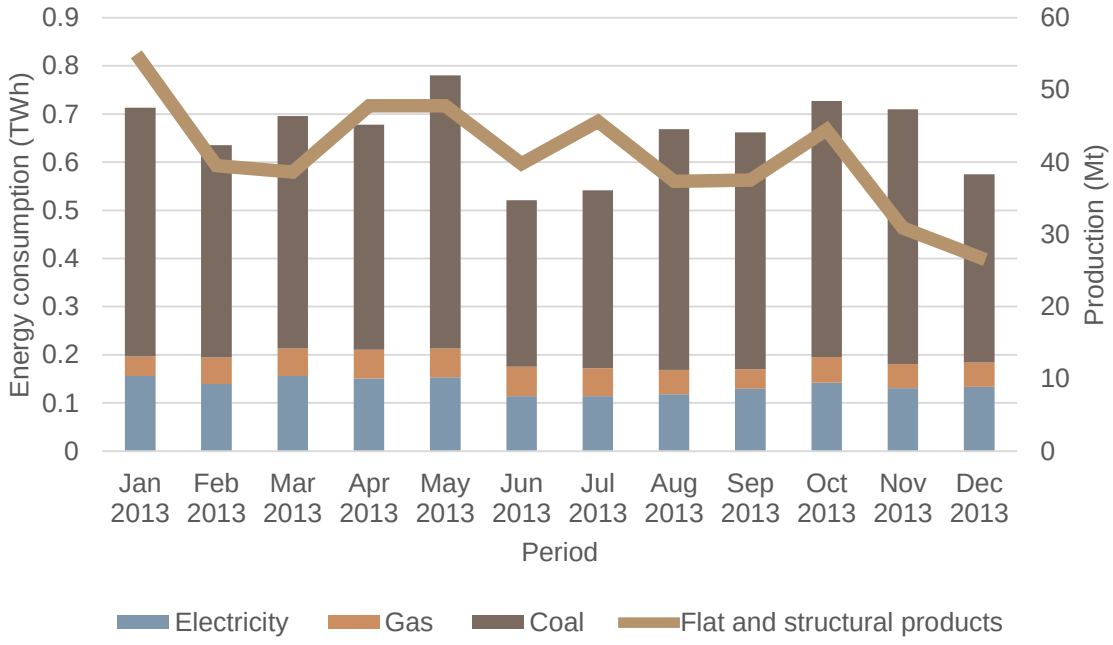


Figure 4-23: Quantification results of energy consumption for case study 4

The next step in the research methodology is to normalise the values that have been quantified. This step is similar to that of case study 1. A CV value is required for each type and supplier of coal. Both Methods 1 and 2 were used for the normalisation of duff and metallurgical coal suppliers. Anthracite suppliers were normalised with Method 1. Figure 4-23 shows the results of the normalisation of the energy carriers and drivers.

4.5.5 RESULTS, VERIFICATION AND VALIDATION

The quantification results of total energy consumption and production driver of case study 4 are shown in Table 4-14. The facility consumed 7 907 305 917 kWh energy and 490 462 t of liquid steel was produced for the year 2013. There is an error of 2.37% between the plant's old independent estimation and this study's new model. The main reason for this difference are the normalisation factors of the coals used. The plant used a single CV value.

Uncertainty is managed similar to case study 1. The total uncertainty of the energy carriers and production driver are ±28 629 156 kWh (0.36%) and ±1 226 t (0.25%), respectively.

Table 4-13: Energy intensity of case study 4

PERIOD	ENERGY INTENSITY
	kWh/t
2013	16 122

The next step in the methodology is to verify the information used in the case study. The information was verified with criteria set in the methodology. The quantification information used is invoices, calibrated measurement equipment, laboratory reports and contract specifications similar to case study 1.

Table 4-14: Comparison of methodology and plant results for case study 4

METHOD	ENERGY CARRIERS	ENERGY DRIVER
	kWh	**t**
Old	8 098 881 075	490 462
New	7 907 305 917	490 462
Error	**2.37%**	**0.00%**

The first level of validation is to calculate the energy intensity of the plant. The results of the calculation for 2013 are shown in Table 4-13. An energy intensity of 16 122 kWh/t has been calculated. The plant energy intensity is above international values due to a different production driver than the benchmark. Due to the high energy intensity, an additional check was completed. The plant target energy intensity for 2013 was 15 387 kWh/t and they reported an intensity of 16 503 kWh/t, which is the same order as this study's methodology.

4.6 Conclusion

The methodology that has been developed has been validated with four case studies. Different plants have been selected for the case studies. The facility layout and main components of all the plants have been presented. The energy carriers and drivers have been identified, quantified, normalised and verified for each case study.

In the identification step for each case study, the plant energy carriers and production drivers have been identified. The energy carriers have been broken down to the different types and sources. After the identification of the energy carriers and production drivers, the facility boundary for the quantification can be selected.

Following the quantification step of the methodology for the case studies results in the measurement of the different energy carrier types and sources as well as the production drivers. The meters and layout for each required variable have been identified and the data gathered. Sources of measurement are supplier invoices and measurement equipment. The production driver suitability has also been calculated.

The normalisation step of the methodology has been applied to convert the quantified values for the energy carriers to a comparable unit of energy (in this study kWh). Coal and gas are converted with the measurement of a CV value.

The main results are then quantified energy consumption and production driver values for the year of 2013. The results are presented as a monthly values.

Verification of the information obtained is an important step for an accurate value for the plant's energy consumption and production driver. The source documents, applicable standard and relevant techniques used from the methodology developed has, therefore, been listed.

The validation of the results quantified was the next step once the results have been quantified and verified. The validation step is to calculate the energy intensity of the plant with the energy consumption and production driver. The intensity value is then compared to results published by other countries. The case studies compare to benchmarks in Africa, Asia and Latin America.

Finally, the results of the methodology have been compared to the plant estimate for each case study. Differences in estimation of the energy carriers have been observed of 9%, 10%, 1% and 2% for the four case studies respectively. The main reason for the difference is in the estimation of CV values for coal. The production driver values for the case studies are identical to the plant estimate due to the use of the same calibrated measurement point.

5 CONCLUSION



Galvanised steel coils [55]

5.1 Conclusion

This chapter concludes the study by reviewing the motivation, objective, methodology and results. A key motivation for the study is the continued increase in energy and operational costs of large industrial plants like steel production facilities. This has put strain on steel manufacturers to remain feasible. Improving on the collection of consumption information of such plants will impact the cost of the production of steel.

The study is also relevant internationally since these plants are located all over the world. Energy consumption and steel production reporting is a global requirement due to the impact on industrial, environmental and financial sectors. With complete information available on a global scale, industries can benchmark their performance in these sectors with other countries.

Large companies undergo independent audits of their financial, energy, production and environmental numbers on an annual basis. The data is also provided to government entities for mandatory reporting of energy consumption. They will also use this information to determine tax incentives and to calculate carbon tax when it is implemented.

The data will simplify the auditing and verification of the plant energy consumption and steel production. The improvement of data integrity and accuracy will facilitate the advancement of management of the production plant. Enhanced budgeting and reporting can be used in management strategies.

Current quantification techniques use inaccurate data due to disorganised and decentralised data sources and collection procedures. More accurate data gathering techniques are needed to improve the quality of the energy and production driver data.

The objective of the study is to develop a methodology for the accurate and verifiable quantification of energy consumption and steel production in steel production facilities. The methodology will provide a generic process that can be followed and adapted for any steel producer. It can be implemented on steel plants as the standard procedure for quantification.

The quantification procedure should provide an accurate representation of the steel plant’s consumption of different energy commodities and steel production drivers. The information that is used in the procedure must be readily available to plant personnel.

Implementing the procedure on a steel production plant has to be a simple process to conduct with consistent results. It should be achievable in the shortest time that will still produce information that is a reliable quantification of production and consumption figures of the plant.

The information gathered by this procedure must conform to information standards set for the industry. The ISO standards for continued improvement of energy consumption, tax incentive regulations, mandatory provision of energy information requirements and M&V requirements are some of the standards that will be considered in the study.

The study provides an overview of steel production facilities that focuses on the different components in the process and their energy consumption. The study examines the raw material preparation processes, ironmaking processes and steel production processes. Further, the global benchmark for energy consumption in steel plants is reviewed for comparison with this study results.

An overview of the energy carriers consumed within a steel plant has been provided. The energy carriers reviewed are electricity, gas and coal. The most important aspects are the measurement units and the properties of gas and coal. Gas requires the HHV of its properties and coal requires a proximate analysis.

The current quantification methods in the steel industry were reviewed. To achieve this, the study examines the world's largest steel producing companies of the largest steel producing countries. The annual reports for four companies were reviewed and the basis for all of these was the GRI's sustainability reporting framework. The companies' information has been reviewed by auditors using financial checks.

An overview of the reporting standards available has been provided. The standards that have been reviewed are the GRI, ISO 50 015, the IPMVP and the SANS 50 010 standards. Emphasis has been placed on the measurement of energy and the management of uncertainty.

The methodology developed can be used to quantify the energy consumption and production drivers that are used and produced within a steel production facility. The methodology consists of the following steps: identify, quantify, normalise and verify.

The identification step in the methodology identifies the energy carriers that are consumed in the facility. The energy carriers are broken into types and sources to account for different product qualities. The potential production drivers that can be used to access energy performance are identified. Once these factors have been identified, the facility or process boundary can be identified.

The quantification step in the methodology uses the methods of international and local standards in the literature review to quantify the energy carriers and production drivers that have been identified. The energy carriers that are not measured in units of energy also require Specific Energy information.

The normalisation step of the methodology converts the quantified values for energy carriers to a comparable unit of energy. The normalisation steps for each energy carrier that requires conversion (gas and coal) are specified. The final step in the normalisation step is to aggregate all the energy carriers to a single energy value and to present the production drivers. Uncertainty that has been introduced by the quantification methodology is addressed and managed.

Once the energy carriers and production drivers have been normalised, the information used has to be verified. The information used is checked to be compliant with the standards in literature, specifically the SANS 50 010 standard. The standard states that utility invoices and calibrated metering equipment must be used for information. If the information does not comply with the standards, another source of quantification must be identified, quantified and normalised.

The results of the methodology have to be validated by comparison with similar international results that are found in the literature. The world benchmarks are used to check the specific energy intensity value calculated from the information obtained by the methodology.

The methodology that has been developed has been validated with four case studies. Different plants have been selected for the case studies. The facility layout and main components of all the plants have been presented. The energy carriers and drivers have been identified, quantified, normalised and verified for each case study.

In the identification step for each case study, the plant energy carriers and production drivers have been identified. The energy carriers have been broken down to the different types and sources. After the identification of the energy carriers and production drivers, the facility boundary for the quantification can be selected.

Following the quantification step of the methodology for the case studies results in the measurement of the different energy carrier types and sources as well as the production drivers. The meters and layout for each required variable have been identified and the data gathered. Sources of measurement are supplier invoices and measurement equipment. The production driver suitability has also been calculated.

The normalisation step of the methodology has been applied to convert the quantified values for the energy carriers to a comparable unit of energy (in this study kWh). Coal and gas are converted with the measurement of a CV value.

The main results are the quantified energy consumption and production driver values for the year of 2013. The results are presented as a monthly consumption and production values.

Verification of the information obtained is an important step for an accurate value for the plant's energy consumption and production driver. The source documents, applicable standard and relevant techniques used from the methodology developed have, therefore, been listed.

The validation of the results quantified was the next step, once the results have been quantified and verified. The validation step is to calculate the energy intensity of the plant with the energy consumption and production driver. The intensity value is then compared to results published by other countries. The case studies compare to benchmarks in Africa, Asia and Latin America.

Finally, the results of the methodology have been compared to the plant estimate for each case study. Differences in estimation of the energy carriers have been observed of 9%, 10%, 1% and 2% for the four case studies, respectively. The main reason for the difference is in the estimation of CV values for coal. The production driver values for the case studies are identical to the plant estimate due to the use of the same calibrated measurement point.

5.2 Recommendations

This section details recommendations for future studies. The quantification methodology developed in this study is presented as a generic procedure. This study implements this procedure on steel manufacturing facilities. A recommendation is to utilise the procedure in other industrial sectors or even different sectors entirely.

This study focuses on the quantification of a steel plant's energy consumption and production drivers. The methods used to achieve this can be adapted to quantify a plant's carbon footprint. The carbon dioxide emissions have recently become an important factor in industry. The emissions will be required to determine carbon tax in South Africa when it is implemented.

The methodology focuses on a whole facility approach to energy consumption and simple production drivers. This is useful for reporting purposes on the whole plant in annual report and mandatory reporting, but not necessarily for use by the plant itself. A recommendation is to adapt the methodology to quantify the energy consumption and production drivers to use on different plants, sections and subsystems within the facility.

Large manufacturing facilities such as steel plants are difficult to model with only a single production driver. Other production drivers can, therefore, be quantified with the same procedure for the purpose of more complex modelling. The production drivers can be used for models developed for use by a facility.

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APPENDIX A DETAIL RESULTS

Table A-1: Total energy carriers for case study 1

PERIOD	ELECTRICITY	GAS	COAL	TOTAL ENERGY
	kWh	**kWh**	**kWh**	**kWh**
Jan 2013	126 454 037	105 321 111	1 240 960 967	1 472 736 115
Feb 2013	91 226 032	90 531 111	1 142 249 088	1 324 006 231
Mar 2013	71 503 853	50 205 000	1 296 394 854	1 418 103 707
Apr 2013	106 019 094	104 212 222	1 234 119 199	1 444 350 515
May 2013	161 405 827	136 777 777	1 442 821 740	1 741 005 344
Jun 2013	183 620 277	132 414 166	1 461 565 635	1 777 600 078
Jul 2013	136 201 847	122 762 777	1 446 915 683	1 705 880 307
Aug 2013	127 381 080	108 537 500	1 245 622 889	1 481 541 469
Sep 2013	122 259 926	124 999 166	1 217 755 309	1 465 014 401
Oct 2013	126 606 440	123 809 722	1 309 807 125	1 560 223 287
Nov 2013	110 367 820	99 130 277	1 235 113 151	1 444 611 248
Dec 2013	113 745 828	85 941 388	1 109 381 494	1 309 068 710
Total	**1 476 792 061**	**1 284 642 217**	**15 382 707 136**	**18 144 141 414**

Table A-2: Electricity invoices for case study 1

PERIOD	ACCOUNT 1	ACCOUNT 2	TOTAL ELECTRICITY
	kWh	**kWh**	**kWh**
Jan 2013	120 419 044	6 034 993	126 454 037
Feb 2013	88 891 946	2 334 086	91 226 032
Mar 2013	70 049 743	1 454 110	71 503 853
Apr 2013	101 213 433	4 805 661	106 019 094
May 2013	136 327 939	25 077 888	161 405 827
Jun 2013	132 097 623	51 522 654	183 620 277
Jul 2013	128 354 181	7 847 666	136 201 847
Aug 2013	122 983 050	4 398 030	127 381 080
Sep 2013	117 791 154	4 468 772	122 259 926
Oct 2013	121 561 423	5 045 017	126 606 440
Nov 2013	106 152 809	4 215 011	110 367 820
Dec 2013	109 610 635	4 135 193	113 745 828
Total	**1 355 452 980**	**121 339 081**	**1 476 792 061**

Table A-3: Imported coking coal consumption tonnes for case study 1

PERIOD	IMPORT 1	IMPORT 2	IMPORT 3	IMPORT 4	IMPORT 5	IMPORT 6
	t	t	t	t	t	t
Jan 2013	0	0	10 275	30 981	3 106	7 806
Feb 2013	0	0	12 525	27 761	7 653	8 486
Mar 2013	0	0	14 761	35 815	8 459	10 454
Apr 2013	0	4 089	6 153	37 868	0	8 670
May 2013	5 599	9 086	0	43 018	0	9 376
Jun 2013	9 030	8 976	0	43 293	0	8 853
Jul 2013	8 881	9 000	0	42 480	0	8 795
Aug 2013	7 935	6 499	1 608	38 455	0	8 019
Sep 2013	6 754	0	7 008	31 638	0	6 859
Oct 2013	7 027	0	7 282	31 121	0	6 822
Nov 2013	8 698	0	8 960	29 039	0	6 987
Dec 2013	8 521	0	8 388	27 143	2 041	6 876
Total	**62 445**	**37 649**	**76 961**	**418 610**	**21 258**	**98 004**

Table A-4: Local coking coal and non-coking coal consumption tonnes for case study 1

PERIOD	LOCAL 1	LOCAL 2	DR	PCI
	t	t	t	t
Jan 2013	18 400	15 027	45 735	20 279
Feb 2013	20 047	15 159	33 694	12 410
Mar 2013	22 184	18 081	36 374	9 287
Apr 2013	18 897	15 225	36 686	21 569
May 2013	23 226	17 276	37 673	28 579
Jun 2013	22 738	17 236	42 651	23 548
Jul 2013	22 370	17 169	34 066	31 138
Aug 2013	20 341	15 789	28 155	22 379
Sep 2013	18 707	13 564	41 202	22 687
Oct 2013	18 730	13 474	50 156	26 124
Nov 2013	21 478	13 711	40 972	20 541
Dec 2013	19 579	13 226	30 070	18 053
Total	**246 699**	**184 936**	**457 434**	**256 593**

Table A-5: Local coking coal 1 consumption tonnes for January 2013 for case study 1

PERIOD	LOCAL 1
	t
2013-01-01	845
2013-01-02	889
2013-01-03	593
2013-01-04	649
2013-01-05	909
2013-01-06	1 114
2013-01-07	803
2013-01-08	852
2013-01-09	905
2013-01-10	755
2013-01-11	616
2013-01-11	-616
2013-01-12	533
2013-01-12	-533
2013-01-13	819
2013-01-13	-819
2013-01-14	638
2013-01-14	-638
2013-01-14	49
2013-01-15	636
2013-01-16	582
2013-01-17	771
2013-01-18	752
2013-01-19	451
2013-01-20	632
2013-01-21	619
2013-01-22	731
2013-01-23	616
2013-01-24	642
2013-01-25	556
2013-01-26	218
2013-01-27	703
2013-01-28	726
2013-01-29	813
2013-01-30	421
2013-01-31	170
Total	**18 400**

Table A-6: Local coking coal 1 CV value calculation for 2013 for case study 1

PERIOD	CV (DB)	CONVERTED CV (AD)	DRY TONNES
	GJ/t	GJ/t	t
2013-01-01	29.81	28.62	3 966.98
2013-01-02	29.81	28.62	3 898.67
2013-01-05	30.32	29.11	3 972.24
2013-01-13	30.48	29.26	3 926.30
2013-01-19	29.98	28.78	3 898.03
2013-01-27	29.87	28.68	4 006.32
2013-01-31	30.01	28.81	4 017.44
2013-02-03	30.38	29.16	4 015.93
2013-02-12	29.85	28.66	3 999.37
2013-02-14	29.85	28.66	3 935.30
2013-02-19	29.91	28.71	3 910.20
2013-02-21	29.91	28.71	3 936.45
2013-02-25	30.54	29.32	4 035.09
2013-03-02	30.19	28.98	3 982.05
2013-03-31	30.08	28.88	4 257.57
2013-04-08	30.16	28.95	4 184.51
2013-04-15	29.95	28.75	4 140.19
2013-04-17	30.02	28.82	4 184.53
2013-04-23	30.02	28.82	4 226.23
2013-04-28	30.46	29.24	4 241.13
2013-05-11	30.34	29.13	4 129.02
2013-05-15	29.87	28.68	4 224.02
2013-05-19	30.15	28.94	4 177.49
2013-05-20	30.34	29.13	4 172.44
2013-05-23	30.2	28.99	4 136.32
2013-05-26	30.42	29.20	1 035.44
2013-05-27	30.42	29.20	4 108.56
2013-05-31	30.59	29.37	4 081.86
2013-06-01	30.59	29.37	4 242.87
2013-06-07	30.48	29.26	3 788.04
2013-06-08	30.48	29.26	3 604.07
2013-06-17	30.13	28.92	3 890.40
2013-06-26	29.85	28.66	4 292.40
2013-06-29	30.73	29.50	3 976.56
2013-07-06	30.22	29.01	3 538.50
2013-07-09	30.21	29.00	3 957.89
2013-07-13	29.88	28.68	4 173.76
2013-07-29	30.21	29.00	4 341.06
2013-08-10	30.26	29.05	3 925.10
2013-08-14	30.38	29.16	3 979.59
2013-08-23	29.92	28.72	4 040.24

2013-08-29	30	28.80	4 010.60
2013-08-31	30	28.80	4 278.08
2013-09-03	30.32	29.11	4 008.99
2013-09-13	36.8	35.33	4 303.85
2013-09-16	30.26	29.05	3 946.14
2013-09-23	29.95	28.75	3 984.38
2013-10-06	30.12	28.92	4 162.19
2013-10-08	53.4	51.26	3 908.13
2013-10-13	30.24	29.03	4 085.61
2013-10-20	30.35	29.14	3 960.66
2013-10-22	30.15	28.94	4 241.36
2013-11-02	30.29	29.08	4 282.43
2013-11-05	30.45	29.23	3 950.70
2013-11-09	30.19	28.98	3 566.37
2013-11-10	30.19	28.98	3 971.28
2013-11-15	30.19	28.98	4 160.02
2013-11-17	30.17	28.96	3 285.44
2013-11-19	30.31	29.10	3 611.47
2013-11-25	30.29	29.08	3 392.43
2013-11-28	30.07	28.87	3 896.01
2013-12-01	30.07	28.87	3 755.33
2013-12-09	29.98	28.78	3 759.58
Weighted average		**29.43**	

Table A-7: Imported coking coal 4 CV value calculation for 2013 for case study 1

PERIOD	DRY TONNES	CV (AD)
	t	**GJ/t**
2013-01-17	63 000	32.09
2013-02-11	146 600	32.36
2013-07-08	72 000	32.60
2013-08-07	145 800	32.54
2013-10-10	70 909	32.50
2013-11-30	138 600	32.09
Weighted average		**32.36**

Table A-8: Production driver for January 2013 for case study 1

PERIOD	BOF	BOF TO EAF
	t	t
2013-01-01	178	-
2013-01-02	8 427	303
2013-01-03	5 429	1 787
2013-01-04	4 379	664
2013-01-05	3 999	981
2013-01-06	5 917	-
2013-01-07	5 537	-
2013-01-08	4 861	438
2013-01-09	7 797	187
2013-01-10	7 124	279
2013-01-11	6 641	1 242
2013-01-12	2 863	-
2013-01-13	4 641	636
2013-01-14	7 791	663
2013-01-15	6 326	1 264
2013-01-16	7 250	962
2013-01-17	5 700	802
2013-01-18	3 301	1 314
2013-01-19	6 439	1 781
2013-01-20	6 199	1 422
2013-01-21	5 976	1 793
2013-01-22	3 636	1 650
2013-01-23	3 615	1 596
2013-01-24	2 232	1 410
2013-01-25	3 097	946
2013-01-26	4 378	610
2013-01-27	4 375	1 034
2013-01-28	4 198	494
2013-01-29	169	-
2013-01-30	167	156
2013-01-31	-	-
Total	**167 056**	

Table A-9: Total energy carriers for case study 2

PERIOD	ELECTRICITY	GAS	COAL	TOTAL ENERGY
	kWh	**kWh**	**kWh**	**kWh**
Jan 2013	48 921 642	42 186 667	959 263 349	1 050 371 658
Feb 2013	43 003 863	23 063 611	1 014 697 085	1 080 764 560
Mar 2013	50 595 038	24 071 389	1 063 175 353	1 137 841 780
Apr 2013	47 051 708	37 063 056	976 891 370	1 061 006 133
May 2013	51 550 761	26 577 222	1 030 755 083	1 108 883 066
Jun 2013	44 732 595	26 511 944	1 009 817 509	1 081 062 048
Jul 2013	48 144 562	22 711 111	1 109 487 051	1 180 342 724
Aug 2013	47 666 251	10 806 111	1 158 558 394	1 217 030 756
Sep 2013	43 827 193	31 194 722	947 905 746	1 022 927 661
Oct 2013	46 798 791	60 249 167	900 941 843	1 007 989 801
Nov 2013	44 709 533	43 072 500	753 519 157	841 301 190
Dec 2013	42 456 029	30 745 556	933 006 781	1 006 208 366
Total	**559 457 966**	**378 253 056**	**11 858 018 723**	**12 795 729 744**

Table A-10: Production driver for case study 2

PERIOD	LIQUID STEEL
	t
Jan 2013	128 458
Feb 2013	113 624
Mar 2013	144 970
Apr 2013	126 879
May 2013	150 790
Jun 2013	122 997
Jul 2013	140 973
Aug 2013	144 853
Sep 2013	115 543
Oct 2013	118 016
Nov 2013	125 847
Dec 2013	135 318
Total	**1 568 268**

Table A-11: Imported coking coal consumption tonnes for case study 2

PERIOD	IMPORT 1	IMPORT 2	IMPORT 3	IMPORT 4	IMPORT 5	IMPORT 6
	t	t	t	t	t	t
Jan 2013	0	0	16 164	25 722	4 065	5 779
Feb 2013	0	0	13 349	30 581	9 608	6 449
Mar 2013	0	0	10 093	41 232	0	8 080
Apr 2013	0	7 493	2 092	31 790	0	7 142
May 2013	4 522	10 700	0	27 947	0	8 519
Jun 2013	7 268	6 222	0	32 971	0	9 045
Jul 2013	7 723	0	0	42 270	0	9 656
Aug 2013	9 682	0	4 503	43 527	0	10 063
Sep 2013	8 608	0	8 604	31 955	0	6 888
Oct 2013	9 028	0	8 995	30 696	0	7 212
Nov 2013	6 865	0	11 826	17 995	0	5 774
Dec 2013	7 264	0	14 752	22 284	3 497	6 965
Total	**60 961**	**24 415**	**90 378**	**378 970**	**17 170**	**91 573**

Table A-12: Local coking coal and non-coking coal tonnes for case study 2

PERIOD	LOCAL 1 MARKET	LOCAL 1	LOCAL 2	PCI	ANTHRACITE	MARKET COKE
	t	t	t	t	t	t
Jan 2013	34 101	28 190	8 060	13 592	2 688	25 498
Feb 2013	10 145	32 451	6 067	17 172	2 007	7 586
Mar 2013	20 227	33 358	7 292	17 013	3 301	15 146
Apr 2013	33 286	25 971	7 636	21 002	4 175	24 932
May 2013	36 227	28 231	8 279	16 988	6 917	27 127
Jun 2013	31 981	30 048	8 089	13 376	3 318	24 020
Jul 2013	32 297	31 835	10 509	17 337	4 410	25 645
Aug 2013	20 869	36 251	8 417	13 283	5 678	16 598
Sep 2013	22 750	28 520	5 643	13 368	2 999	18 056
Oct 2013	0	29 766	4 508	13 394	2 844	0
Nov 2013	9 243	23 866	4 841	13 329	3 819	8 318
Dec 2013	16 016	28 783	5 894	13 183	5 185	14 078
Total	**267 143**	**357 269**	**85 236**	**183 037**	**47 340**	**207 005**

Table A-13: Normalisation factors of imported coking coal for case study 2

PERIOD	IMPORT 1	IMPORT 2	IMPORT 3	IMPORT 4	IMPORT 5	IMPORT 6
	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t
2013	31.76	32.65	31.88	32.36	31.7	33.64

Table A-14: Normalisation factors of local coking and non-coking coal for case study 2

PERIOD	LOCAL 1 MARKET	LOCAL 1	LOCAL 2	PCI	ANTHRACITE	MARKET COKE
	GJ/t	**GJ/t**	**GJ/t**	**GJ/t**	**GJ/t**	**GJ/t**
2013	28.91	28.95	29.99	26.03	31.08	27.4

Table A-15: Verification method of quantification value for case study 2

TYPE	VERIFICATION METHOD	COMPLIANCE
Electricity		
Main account	Invoices	SANS 50 010 Section 6.2
Gas		
Natural gas	Invoices	SANS 50 010 Section 6.2
Coal		
Import 1	Calibrated meter	
Import 2	Calibrated meter	SANS 50 010 Section 6.3
Import 3	Calibrated meter	SANS 50 010 Section 6.3
Import 4	Calibrated meter	SANS 50 010 Section 6.3
Import 5	Calibrated meter	SANS 50 010 Section 6.3
Import 6	Calibrated meter	SANS 50 010 Section 6.3
Market	Calibrated meter	SANS 50 010 Section 6.3
Local 1	Calibrated meter	SANS 50 010 Section 6.3
Local 2	Calibrated meter	SANS 50 010 Section 6.3
PCI	Calibrated meter	SANS 50 010 Section 6.3
Anthracite	Calibrated meter	SANS 50 010 Section 6.3
Market coke	Calibrated meter	SANS 50 010 Section 6.3
Energy driver		
Liquid steel	Calibrated meter	SANS 50 010 Section 6.3

Table A-16: Verification method of normalisation value for case study 2

TYPE	VERIFICATION METHOD	COMPLIANCE
Coal		
Import 1	Lab report with vessel invoice	SANS 50 010 Section 6.2
Import 2	Lab report with vessel invoice	SANS 50 010 Section 6.2
Import 3	Lab report with vessel invoice	SANS 50 010 Section 6.2
Import 4	Lab report with vessel invoice	SANS 50 010 Section 6.2
Import 5	Lab report with vessel invoice	SANS 50 010 Section 6.2
Import 6	Lab report with vessel invoice	SANS 50 010 Section 6.2
Market	Lab report with vessel invoice	SANS 50 010 Section 6.2
Local 1	Lab report with train invoice	SANS 50 010 Section 6.2
Local 2	Lab report from mine	SANS 50 010 Section 6.3
PCI	Lab report from mine	SANS 50 010 Section 6.3
Anthracite	Lab report from plant	SANS 50 010 Section 6.3
Market coke	Lab report from plant	SANS 50 010 Section 6.3

Table A-17: Total energy carriers for case study 3

PERIOD	ELECTRICITY	GAS	COAL	TOTAL ENERGY
	kWh	**kWh**	**kWh**	**kWh**
Jan 2013	116 148 040	16 163 333	500 660 131	632 971 505
Feb 2013	96 753 116	15 219 583	415 897 859	527 870 558
Mar 2013	116 131 768	14 966 111	486 087 286	617 185 165
Apr 2013	102 872 308	16 140 556	387 914 319	506 927 183
May 2013	117 274 561	15 100 556	522 231 169	654 606 286
Jun 2013	101 025 022	14 308 056	454 408 740	569 741 817
Jul 2013	108 516 231	15 951 667	446 687 501	571 155 399
Aug 2013	100 715 446	18 900 833	452 138 060	571 754 339
Sep 2013	106 677 297	10 615 000	473 566 511	590 858 808
Oct 2013	70 036 139	7 477 500	413 547 878	491 061 517
Nov 2013	110 763 664	15 038 056	494 306 339	620 108 058
Dec 2013	110 582 611	14 188 611	471 276 111	596 047 333
Total	**1 257 496 203**	**174 069 861**	**5 518 721 904**	**6 950 287 968**

Table A-18: Production driver for case study 3

PERIOD	LIQUID STEEL
	t
Jan 2013	108 346
Feb 2013	86 448
Mar 2013	107 407
Apr 2013	88 899
May 2013	107 440
Jun 2013	85 917
Jul 2013	90 316
Aug 2013	81 090
Sep 2013	96 717
Oct 2013	62 802
Nov 2013	94 834
Dec 2013	95 446
Total	**1 105 662**

Table A-19: Coal consumption tonnes for case study 3

PERIOD	COREX 1	COREX 2	COKE	ANTHRACITE	FINES SALES
	t	t	t	t	t
Jan 2013	46 594	20 141	9 354	82	9 831
Feb 2013	34 970	20 785	8 421	88	8 997
Mar 2013	38 335	25 218	8 860	84	7 892
Apr 2013	31 758	21 015	7 075	92	8 385
May 2013	38 007	31 205	9 501	89	9 272
Jun 2013	30 903	30 962	7 820	66	9 170
Jul 2013	36 577	23 514	7 836	77	8 664
Aug 2013	33 426	26 900	7 347	111	7 636
Sep 2013	27 219	36 824	8 880	86	9 685
Oct 2013	28 950	25 485	10 001	94	9 330
Nov 2013	23 215	40 509	10 380	103	7 944
Dec 2013	30 468	32 301	9 902	87	9 821
Total	**400 422**	**334 859**	**105 377**	**1 057**	**106 627**

Table A-20: Normalisation factors of coal for case study 3

PERIOD	COREX 1	COREX 2	COKE	ANTHRACITE	FINES SALES
	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t
2013	27.61	26.71	25.99	27.70	27.20

Table A-21: Verification method of normalisation value for case study 3

TYPE	VERIFICATION METHOD	COMPLIANCE
Electricity		
Main account	Invoices	SANS 50 010 Section 6.2
Gas		
LPG	Invoices	SANS 50 010 Section 6.2
Coal		
Corex 1	Calibrated meter	SANS 50 010 Section 6.3
Corex 2	Calibrated meter	SANS 50 010 Section 6.3
Coke	Calibrated meter	SANS 50 010 Section 6.3
Anthracite	Calibrated meter	SANS 50 010 Section 6.3
Coal fines	Calibrated meter	SANS 50 010 Section 6.3
Energy driver		
Liquid steel	Calibrated meter	SANS 50 010 Section 6.3

Table A-22: Verification method of normalisation value for case study 3

TYPE	VERIFICATION METHOD	COMPLIANCE
Coal		
Corex 1	Lab report with train invoice	SANS 50 010 Section 6.2
Corex 2	Lab report with train invoice	SANS 50 010 Section 6.2
Coke	Lab report with vessel invoice	SANS 50 010 Section 6.2
Anthracite	Lab report from plant	SANS 50 010 Section 6.3
Coal fines	Average of Corex coal	SANS 50 010 Section 6.2

Table A-23: Total energy carriers for case study 4

PERIOD	ELECTRICITY	GAS	COAL	TOTAL ENERGY
	kWh	**kWh**	**kWh**	**kWh**
Jan 2013	155 916 761	40 440 556	516 478 947	712 836 264
Feb 2013	139 507 909	54 885 000	440 724 639	635 117 548
Mar 2013	155 930 980	57 082 778	482 471 559	695 485 316
Apr 2013	150 768 395	59 659 722	467 602 899	678 031 016
May 2013	153 339 622	60 023 056	566 903 146	780 265 824
Jun 2013	114 472 266	60 870 833	345 858 332	521 201 432
Jul 2013	114 223 630	57 934 167	369 648 731	541 806 528
Aug 2013	118 295 478	50 504 722	499 931 253	668 731 453
Sep 2013	129 710 844	40 195 833	492 137 717	662 044 394
Oct 2013	142 270 722	53 256 111	531 680 946	727 207 780
Nov 2013	130 464 799	50 303 333	529 312 378	710 080 510
Dec 2013	133 655 086	50 110 556	390 732 211	574 497 852
Total	**1 638 556 492**	**635 266 667**	**5 633 482 758**	**7 907 305 917**

Table A-24: Total production drivers for case study 4

PERIOD	FLAT PRODUCTS	STRUCTURAL PRODUCTS	LIQUID STEEL
	t	t	t
Jan 2013	18 934	35 234	54 167
Feb 2013	15 831	23 683	39 514
Mar 2013	14 613	24 022	38 635
Apr 2013	13 656	34 155	47 811
May 2013	16 846	30 976	47 822
Jun 2013	13 134	26 642	39 776
Jul 2013	15 862	29 787	45 650
Aug 2013	15 921	21 435	37 356
Sep 2013	15 862	21 684	37 546
Oct 2013	19 858	24 605	44 463
Nov 2013	16 542	14 327	30 869
Dec 2013	8 289	18 565	26 853
Total	**185 348**	**305 114**	**490 462**

Table A-25: Duff and metallurgical coal consumption tonnes for case study 4

PERIOD	DUFF 1	DUFF 2	DUFF 3	DUFF 4	DUFF 5	MET 1	MET 2	MET 3
	t	t	t	t	t	t	t	t
Jan 2013	14 510	0	0	6 084	0	0	2 996	10 093
Feb 2013	7 594	0	5 021	0	0	0	5 493	10 559
Mar 2013	9 061	0	7 191	0	0	31	5 051	11 739
Apr 2013	10 443	0	5 861	0	75	34	3 043	22
May 2013	13 065	778	7 694	0	0	104	1 992	0
Jun 2013	11 853	4 809	2 968	0	0	0	1 178	0
Jul 2013	7 409	10 837	0	0	0	70	4 017	0
Aug 2013	197	19 381	0	0	0	102	0	0
Sep 2013	0	15 397	0	0	0	92	0	0
Oct 2013	0	21 154	0	0	0	0	0	0
Nov 2013	0	14 761	0	0	0	210	0	0
Dec 2013	0	14 384	0	0	0	415	0	0
Total	**74 131**	**101 500**	**28 734**	**6 084**	**75**	**1 059**	**23 769**	**32 413**

Table A-26: Metallurgical coal consumption tonnes for case study 4

PERIOD	MET 4	MET 5	MET 6	MET 7	MET 8	MET 9	MET 10	MET 11
	t	t	t	t	t	t	t	t
Jan 2013	20 036	6 163	0	6 836	998	0	0	0
Feb 2013	19 975	5 671	0	4 040	0	0	0	0
Mar 2013	20 631	3 207	6 550	0	0	0	0	0
Apr 2013	21 867	11 182	1 090	0	0	0	8 196	0
May 2013	27 661	9 205	0	0	0	0	13 058	0
Jun 2013	13 392	4 088	940	0	0	0	5 010	0
Jul 2013	10 491	5 572	0	0	0	5 779	3 258	0
Aug 2013	533	8 992	0	0	0	10 959	9 409	11 423
Sep 2013	0	9 818	0	0	0	13 423	12 218	10 028
Oct 2013	0	7 034	6 653	0	0	13 580	6 886	13 167
Nov 2013	0	9 372	4 429	0	0	11 777	9 609	14 536
Dec 2013	0	4 857	3 484	0	0	6 155	7 947	10 853
Total	**134 586**	**85 162**	**23 145**	**10 876**	**998**	**61 674**	**75 590**	**60 007**

Table A-27: Anthracite consumption tonnes for case study 4

PERIOD	ANT 1	ANT 2	ANT 3	ANT 4	ANT 5
	t	t	t	t	t
Jan 2013	135	0	0	0	0
Feb 2013	126	363	0	0	0
Mar 2013	159	1 078	0	0	0
Apr 2013	176	520	0	0	0
May 2013	271	1 344	578	0	0
Jun 2013	179	2 859	0	0	0
Jul 2013	187	541	0	0	0
Aug 2013	195	1 004	0	1 442	0
Sep 2013	176	1 581	0	0	0
Oct 2013	209	519	0	0	0
Nov 2013	223	0	0	0	0
Dec 2013	162	0	0	0	1 440
Total	**2 198**	**9 809**	**578**	**1 442**	**1 440**

Table A-28: Anthracite consumption tonnes for case study 4

PERIOD	ANT 6	ANT 7	ANT 8	ANT 9	ANT 10
	t	t	t	t	t
Jan 2013	3 025	540	0	0	0
Feb 2013	2 084	0	0	0	0
Mar 2013	2 030	0	0	0	0
Apr 2013	1 835	0	0	0	300
May 2013	2 150	0	0	399	0
Jun 2013	238	0	0	0	0
Jul 2013	1 869	0	0	0	0
Aug 2013	2 520	0	0	0	0
Sep 2013	2 471	0	0	0	0
Oct 2013	1 104	0	0	0	0
Nov 2013	4 001	0	1 143	0	0
Dec 2013	2 100	0	0	0	0
Total	**25 426**	**540**	**1 143**	**399**	**300**

Table A-29: Normalisation factors of duff and metallurgical coal for case study 4

PERIOD	DUFF 1	DUFF 2	DUFF 3	DUFF 4	DUFF 5	MET 1	MET 2	MET 3
	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t
2013	26.04	27.10	25.00	25.00	25.00	25.00	26.04	26.13

Table A-30: Normalisation factors of metallurgical coal for case study 4

PERIOD	MET 4	MET 5	MET 6	MET 7	MET 8	MET 9	MET 10	MET 11
	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t
2013	26.04	26.16	26.13	26.04	25.00	28.08	26.13	28.19

Table A-31: Normalisation factor of anthracite for case study 4

PERIOD	ANTHRACITE
	GJ/t
2013	27.53

Table A-32: Verification method of quantification value for case study 4

TYPE	VERIFICATION METHOD	COMPLIANCE
Electricity		
Main account	Invoices	SANS 50 010 Section 6.2
Gas		
Natural gas	Invoices	SANS 50 010 Section 6.2
Coal		
Duff	Calibrated meter	SANS 50 010 Section 6.3
Metallurgical	Calibrated meter	SANS 50 010 Section 6.3
Anthracite	Calibrated meter	SANS 50 010 Section 6.3
Energy driver		
Flat products	Calibrated meter	SANS 50 010 Section 6.3
Structural products	Calibrated meter	SANS 50 010 Section 6.3

Table A-33: Verification method of normalisation value for case study 4

TYPE	VERIFICATION METHOD	COMPLIANCE
Coal		
Duff 1	Lab report from plant	SANS 50 010 Section 6.3
Duff 2	Mine specification	SANS 50 010 Section 6.3
Duff 3	Plant specification	SANS 50 010 Section 6.3
Duff 4	Plant specification	SANS 50 010 Section 6.3
Duff 5	Plant specification	SANS 50 010 Section 6.3
Met 1	Plant specification	SANS 50 010 Section 6.3
Met 2	Lab report from plant	SANS 50 010 Section 6.3
Met 3	Lab report from plant	SANS 50 010 Section 6.3
Met 4	Lab report from plant	SANS 50 010 Section 6.3
Met 5	Lab report from plant	SANS 50 010 Section 6.3
Met 6	Lab report from plant	SANS 50 010 Section 6.3
Met 7	Lab report from plant	SANS 50 010 Section 6.3
Met 8	Plant specification	SANS 50 010 Section 6.3
Met 9	Mine specification	SANS 50 010 Section 6.3
Met 10	Lab report from plant	SANS 50 010 Section 6.3
Met 11	Mine specification	SANS 50 010 Section 6.3
Anthracite	Lab report from plant	SANS 50 010 Section 6.3