

Framework for operational changes to reduce electricity costs in the South African steel industry

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Abstract

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In the 21st century, energy saving, cost savings and decreasing carbon dioxide emissions have become an important concern for the sustainability of steelworks. The emphasis is on assigning dedicated personnel to reduce energy cost and emissions on iron- and steel-manufacturing plants. Profitability in the steel industry, both globally and locally, has drastically reduced in the last decade.

In South Africa, the production of steel was down by 4.5% year-on-year in 2015. This is due to both a struggling economy and a world surplus in steel supply. The emphasis on cost reduction is therefore even more important in South Africa to stay competitive in the global steel market.

It is important for personnel at iron- and steel-manufacturing plants to be aware of the risks associated with electricity costs and how to mitigate these risks to stay competitive in a difficult and economically struggling industry. There is a lack of knowledge regarding electricity cost savings and personnel do not have the knowledge to achieve electricity savings. There is a need to establish a framework to identify, prioritise and implement electricity cost reduction in the South African steel-producing environment.

There are several energy management systems and approaches that can be used to manage and obtain energy savings. The problem with these systems is the lack of a step-by-step framework that is applicable specifically to steel plants. Typical energy cost reduction strategies focus on large capital expenditure (capex) projects. Steel plants in South Africa have limited capex to spend on energy cost reduction.

The study focuses on opportunities that involve operational changes on steelmaking plants. Many operational changes can be implemented with little to no capex. The impact of these changes can also result in quick benefits.

An operational framework for electricity cost reduction is developed and implemented as part of this study. An identification model is developed to identify projects that can aid in cost saving through reduced capex and operational changes.

The study also focuses on prioritising initiatives. This adds to the efficiency of the steelmaking process. The study also develops an implementation method for electricity cost reduction initiatives.

This framework is developed in such a way that it can form part of a larger energy management strategy. In the present steelmaking environment, ISO 50001 is an integral part of energy reporting and compliance. The framework developed in this study follows the plan-do-check-act cycle as part of ISO 50001 compliance.

After implementing the framework on the two case study plants, a total of R10 050 000 per annum worth of possible savings is projected. One operational change is sustainably implemented and an annual electricity cost saving of R9 million is achieved. If similar operational changes are implemented on more facilities, the electricity cost savings can increase even more. Together with the electricity cost reduction, there is also a reduction in carbon emissions.

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Table of contents

Abstract.....	ii
Acknowledgements	iv
Table of contents	v
List of figures.....	vii
List of tables.....	xi
List of abbreviations	xiv
List of units	xvi
List of chemical formulas	xvii
Chapter 1: Background.....	1
1.1 Introduction	2
1.2 Overview of the iron and steel industry	2
1.3 Previous research applicable to this study.....	13
1.4 Research objectives	24
1.5 Original contributions of this study	26
1.6 Thesis layout.....	28
1.7 Conclusion.....	30
Chapter 2: Operational changes and electricity cost reduction	31
2.1 Introduction	32
2.2 Electrical energy in the steel industry	32
2.3 Existing energy management solution and frameworks.....	39
2.4 Efficient technologies.....	60
2.5 Available funding models.....	66
2.6 Benchmarking in the steel industry	70
2.7 Conclusion.....	72
Chapter 3: Developing a novel framework for reducing electricity costs	73
3.1 Introduction	74
3.2 Facility engagement and planning.....	75
3.3 Evaluate the role player's involvement and requirements	79
3.4 Operational identification.....	91
3.5 System characterisation for identification and prioritisation.....	96
3.6 System analysis for project feasibility and implementation.....	121

3.7	Operational framework roadmap.....	130
3.8	Conclusion.....	133
	Chapter 4: Implementing the framework to reduce electricity costs.....	134
4.1	Introduction	135
4.2	Implement the framework: Case Study 1	135
4.3	Verification and validation of the framework	166
4.4	Implement the framework: Case Study 2	172
4.5	Conclusion.....	191
	Chapter 5: Conclusion and recommendations	192
5.1	Introduction	193
5.2	Summary of work completed in this study.....	193
5.3	Study-specific recommendations.....	195
5.4	Recommendations for expansion of study methods.....	196
5.5	Conclusion.....	197
	References.....	198
	Appendix A: Energy cost risks	207
	Appendix B: Energy management	213
	Appendix C: PDCA cycle	219
	Appendix D: Plant A – Case Study 1	231
	Appendix E: Plant B – Case Study 2.....	241

List of figures

Figure 1: Global steel consumption 2006–2020	2
Figure 2: Global steel production	3
Figure 3: South African crude steel production downward trend [4]	4
Figure 4: World steel production's upward trend [4]	5
Figure 5: South African steel consumption graph [4].....	6
Figure 6: Production of crude steel in South Africa versus the world [4]	6
Figure 7: South African labour cost increase.....	7
Figure 8: Added capacity and energy gap [9].....	8
Figure 9: Average electricity price in African countries (US cents/kWh) [10].....	9
Figure 10: Eskom average tariff increase versus inflation (consumer price index) [11].....	9
Figure 11: Iron and steelmaking flow sheet [15]	11
Figure 12: Global energy consumption per tonne of crude steel produced	12
Figure 13: Different role players in the steel value chain [16]	14
Figure 14: Different routes for alternative iron and steelmaking processes [20]	20
Figure 15: Illustrative energy benchmark curve for the manufacturing industry	22
Figure 16: Direct electricity sales from Eskom to the manufacturing sectors.....	32
Figure 17: Cost of electricity as a percentage of the total operational costs.....	33
Figure 18: Fuels used for energy	34
Figure 19: Phases of electricity reduction.....	36
Figure 20: Framework for integrative energy management	40
Figure 21: EnMS system model based on the PDCA cycle [35].....	43
Figure 22: Furnace heat balance (Sankey diagram) [38]	48
Figure 23: Project identification process [41].....	53
Figure 24: Master plan methodology	53
Figure 25: Electricity consumption in an integrated steel mill by production plant [42]	55
Figure 26: Arc furnace and boiler theoretical response to electricity prices	57
Figure 27: Flexibility of electricity load of the EAF	58
Figure 28: A typical roadmap [46].....	60
Figure 29: Coal-based MIDREX process	62
Figure 30: Funding model selection diagram [54].....	69
Figure 31: Energy intensity for the blowers supplying the air for the blast furnaces [58]	71

Figure 32: Overview of the framework for operational changes	75
Figure 33: Current energy management operation in South Africa steelmaking plants.....	76
Figure 34: Scope and boundary of the framework.....	79
Figure 35: The role players related to electricity cost savings through operational changes ..	80
Figure 36: KPI tracking flow diagram	87
Figure 37: 12L implementation process flow	90
Figure 38: Intensity graph.....	91
Figure 39: Operational flow.....	92
Figure 40: Process identification	93
Figure 41: Facility identification	94
Figure 42: System characterisation.....	96
Figure 43: Example of steelmaking BOF facility black-box analysis	97
Figure 44: Energy pie chart diagram	100
Figure 45: Sankey diagram for Plant A	101
Figure 46: Example of energy intensity graph.....	102
Figure 47: Total power profile.....	103
Figure 48: Electricity intensity ranking	104
Figure 49: System parameter data required for system characterisation	105
Figure 50: Plant A facility PFD	107
Figure 51: Control diagram for Plant A facility.....	108
Figure 52: Electrical layout example from Plant A	108
Figure 53: PID example from Plant A facility.....	109
Figure 54: Critical evaluation	113
Figure 55: Total facility energy efficiency profile.....	114
Figure 56: Total facility peak clipping profile	115
Figure 57: Total facility load shifting profile	115
Figure 58: Flow of the prioritisation function.....	118
Figure 59: Facility function Graph A.....	120
Figure 60: Facility function Graph B.....	120
Figure 61: Facility prioritisation ranking with each operational change scenario.....	121
Figure 62: System analysis operational flow	122
Figure 63: Initial investigation procedure.....	123
Figure 64: Example of system analysis	125
Figure 65: Simulation flow	128

Figure 66: Example of simulation in PTB	129
Figure 67: ISO 50001 roadmap.....	131
Figure 68: Black-box analysis for the sinter and BOF facilities of Plant A	140
Figure 69: Breakdown of energy source in terms of costs (R) for Plant A	141
Figure 70: Sankey diagram to identify the size of the different energy streams	145
Figure 71: Plant A total facility power	146
Figure 72: Electricity intensity comparison for Plant A	147
Figure 73: Operational change identification flow	149
Figure 74: Compressor plant total power profile	151
Figure 75: Model output and prioritisation for operational changes	151
Figure 76: Plant A compressed air system layout.....	155
Figure 77: Linear regression scatter plot	158
Figure 78: Baseline power profile.....	159
Figure 79: Plant A compressor plant facility simulation layout	162
Figure 80: Baseline simulation versus operational change simulation.....	164
Figure 81: Black-box analysis for the bar mill facility and billet mill facility for Plant B....	177
Figure 82: Breakdown of energy source in cost percentage contribution	178
Figure 83: Sankey diagram to identify the size of the different energy streams	179
Figure 84: Plant B total facility power comparison	180
Figure 85: Electricity intensity comparison for Plant B	181
Figure 86: Identification of operational change initiative flow	182
Figure 87: Model output and prioritisation for operational changes	183
Figure 88: Sinter plant layout	185
Figure 89: Sinter stock level and cumulative production	189
Figure 90: Proposed operational change strategy power profile	189
Figure 91: Electricity cost increase relative to overconsumption [9]	208
Figure 92: ECS price increase with default monthly allocation [9].....	208
Figure 93: Multi-stage energy management implementation model [64]	214
Figure 94: Advanced organizational model based on ISO 50001 [64].....	215
Figure 95: DSM process steps and the accompanied stakeholders [67].....	218
Figure 96: Sequential structured approach to overcome energy management barriers [71] .	220
Figure 97: PCM strategy [80]	228
Figure 98: Typical energy manager appointment letter	231
Figure 99: Plant A facility black-box analysis.....	232

Figure 100: Plant A facility black-box analysis continued.....	233
Figure 101: Plant A energy input-output data in GJ	234
Figure 102: Tinplating operational change identification flow	235
Figure 103: Hot dip galvanising operational change identification flow	235
Figure 104: Compressor plant operational change identification flow.....	236
Figure 105: Electro-galvanising operational change identification flow.....	236
Figure 106: Prioritisation model calculation example for three facilities.....	239
Figure 107: Example of savings report for Plant A compressor plant facility	240
Figure 108: Plant B facility black-box analysis	241
Figure 109: Plant B facility black-box analysis (continued)	242
Figure 110: Prioritisation model calculation example for two facilities.....	244
Figure 111: Possible report for Plant B.....	245

List of tables

Table 1: NCPC-SA case study energy efficiency achievement [17]	16
Table 2: Summary of previous studies with their limitations	25
Table 3: Energy usage by process [19]	34
Table 4: Percentage usage of electricity by industrial user [29]	37
Table 5: DSM interventions and their potential savings by end user [29]	38
Table 6: Energy saving DSM potential [29]	39
Table 7: Energy savings on the steel mill by area [38]	49
Table 8: UNIDO steel industry portfolio [39]	51
Table 9: 12I capital investment [54]	67
Table 10: Energy champion tasks and responsibilities	78
Table 11: KPI critical selection table	85
Table 12: COWS method for easily prioritising between different KPIs	85
Table 13: Scenarios for Eskom IDM funding	88
Table 14: Tariff for electricity in South Africa in 2016	88
Table 15: Facility identification sheet	95
Table 16: System characterisation parameters	98
Table 17: Energy balance input and output sheet	98
Table 18: Total power usage ranking	103
Table 19: Electricity intensity ranking	104
Table 20: TOU tariff structure	110
Table 21: DSM initiative ranking	110
Table 22: DSM initiative evaluation	110
Table 23: Critical evaluation Question Set 2	111
Table 24: Critical evaluation Question Set 3	112
Table 25: Ranking of fixed variables	116
Table 26: Possible rankings for Facility A to Facility L	119
Table 27: System analysis steps	126
Table 28: Simulation legend	129
Table 29: Summary and description of Plant A's role players	138
Table 30: Identified facilities on Plant A	139
Table 31: Energy balance sheet for the facilities on Plant A	142

Table 32: Critical evaluation applied on Plant A's facilities	149
Table 33: Facility identification and prioritisation result for Plant A.....	152
Table 34: Plant A compressor specifications.....	153
Table 35: Compressed air consumers and operational requirements.....	154
Table 36: Data required for simulation of operational changes.....	159
Table 37: Baseline simulation assumptions.....	160
Table 38: PTB simulation components used and their application for this application	161
Table 39: Process change measure optimised assumptions.....	163
Table 40: Energy efficiency savings achieved.....	165
Table 41: Cost savings achieved annually	166
Table 42: Framework elements verified	166
Table 43: Standard conditions for air.....	167
Table 44: Inlet conditions	167
Table 45: Theoretical compressor power reduction calculation	168
Table 46: Verification of project cost indicators and implementation time	171
Table 47: Summary and description of Plant B's role players	174
Table 48: Identified facilities on Plant B	175
Table 49: Critical evaluation applied on Plant B facilities	182
Table 50: Facility identification and prioritisation result for Plant B.....	183
Table 51: Sinter plant operational assumptions	186
Table 52: Operational change scenario calculation	187
Table 53: Data required for simulating operational changes	187
Table 54: Electricity cost saving calculation results.....	188
Table 55: Project feasibility result summary	190
Table 56: Global warming potential of greenhouse gases [62]	210
Table 57: Coke-making energy efficiency measures.....	222
Table 58: Blast furnace energy efficiency measures	223
Table 59: Hot blast stoves energy efficiency measures	224
Table 60: BOF energy efficiency improvement measures	224
Table 61: Casting energy efficiency improvement measures	225
Table 62: Hot rolling energy efficiency improvement measures.....	225
Table 63: Cold rolling and finishing product energy efficiency improvement measures.....	226
Table 64: Plant A total power facility ranking.....	237
Table 65: Plant A facility intensity ranking.....	237

Table 66: Plant A prioritisation ranking	238
Table 67: Plant B facility power ranking	243
Table 68: Plant B facility intensity ranking	243
Table 69: Plant B prioritisation ranking.....	243

List of abbreviations

AMSA	ArcelorMittal South Africa
BFG	blast furnace gas
BOF	basic oxygen furnace
Capex	capital expenditure
CDM	Clean Development Mechanism
CER	certified emissions reductions
COG	coke oven gas
COWS	criteria-options-weights-score
CP	compressor plant
DRI	direct reduction iron
DSM	demand side management
EAF	electric arc furnace
ECS	Energy Conservation Scheme
EE	energy efficiency
EnMS	energy management system
EnPI	energy performance indicator
ESCo	energy services company
HP	high pressure
HVAC	heating, ventilation and air-conditioning
IDM	Integrated Demand Management
IEE	Industrial Energy Efficiency
ISO	International Organization for Standardization
KPI	key performance indicator
LP	low pressure
LS	load shifting
MCEP	Manufacturing Competitiveness Enhancement Programme
M&V	measurement and verification
NCPC-SA	National Cleaner Production Centre of South Africa
NPV	net present value
Opex	operational expenditure
PC	peak clipping

List of abbreviations

PCI	pulverised coal injection
PCM	performance-centred maintenance
PDCA	plan-do-check-act
PFD	process flow diagram
PID	process and instrumentation diagram
PTB	Process Toolbox
ROI	return on investment
SANEDI	South African National Energy Development Institute
SANS	South African National Standards
SARS	South African Revenue Services
SCADA	supervisory control and data acquisition
SEU	significant energy user
TOU	time-of-use
TRT	top-pressure recovery turbine
UNFCCC	United Nations Framework convention on Climate Change
UNIDO	United Nations Industrial Development Organization
US	United States
VAT	value added tax
VSD	variable speed drive

List of units

°C	degree Celsius
c	cent (South African cent unless otherwise specified)
d	day
GJ	gigajoule
GWh	gigawatt-hour
h	hour
K	kelvin
kJ	kilojoule
kg	kilogram
kgCE	kilogram of coal equivalent
kPa	kilopascal
kVA	kilovolt-ampere
kW	kilowatt
kWh	kilowatt-hour
m	metre
m ³	cubed metre
MJ	megajoule
MPa	megapascal
mt	metric ton
MW	megawatt
MWh	megawatt-hour
Pa	pascal
s	second
SEK	Swedish krona (Swedish currency)
Sm ³	standard cubed metre
t	tonne
TCE	tonne of coal equivalent
TWh	terawatt-hour
USD	United States dollar
yr	year
ZAR	South African rand

List of chemical formulas

CH ₄	methane
CO	carbon monoxide
CO ₂	carbon dioxide
H ₂	hydrogen
HFC	hydrofluorocarbon
N ₂ O	nitrous oxide
SF ₆	sulphur hexafluoride

Chapter 1: Background



Steel in the molten form¹

¹ Endress+Hauser Oy, “Cooling water leakage detection,” Endress+Hauser Oy, 2014. [Online]. Available: <http://www.fi.endress.com/en/Endress-Hauser-group/industry-instrumentation-expertise/primaries-metal/safety/converter>. [Accessed 2 October 2016].

1.1 Introduction

The first chapter is an introductory chapter and presents a brief overview of the steel industry and its electricity consumption. An operational framework for electricity cost reduction in the South African steel industry is presented as a viable solution to improve the competitiveness amidst an economic growth strain period. The operational framework will entitle changes to operations to obtain electricity cost savings with minimum or no capital expenditure (capex).

Energy management strategies involving frameworks for operational electricity cost reduction are reviewed. The focus of the critical reviews is on electricity cost reductions in the South African steel industry. The findings are used and conveyed into a formulated research objective presented in Section 1.4.

1.2 Overview of the iron and steel industry

1.2.1 Global economic growth strain

Ernest & Young Advisory Services reported on the global economic situation in the steel and iron industry. China has traditionally been seen as the driver of global steel demand growth. Figure 1 shows the fluctuation in the global steel demand and the forecasted decline in demand up to 2020 [1].

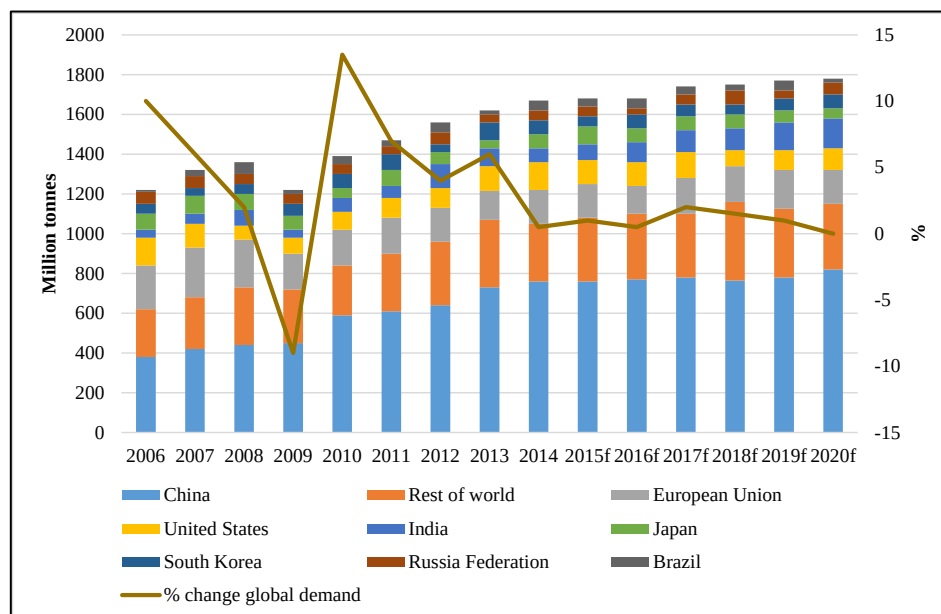


Figure 1: Global steel consumption 2006–2020²

² Adapted from [1]

For the first time since 1996, the demand for Chinese steel declined 3.4% year-on-year in 2014. The report predicts that it will further decline by 0.5% in 2015 and 2016. The report found that steel production growth slowed in 2014. It is expected that by 2030, Chinese steel demand will be down from 700 mt in 2014 to approximately 567 mt. Figure 2 shows the actual steel production and percentage change from 2001 onwards. From 2015 to 2020 is forecasted. It is expected for global production to stabilise and there to be limited growth [1].

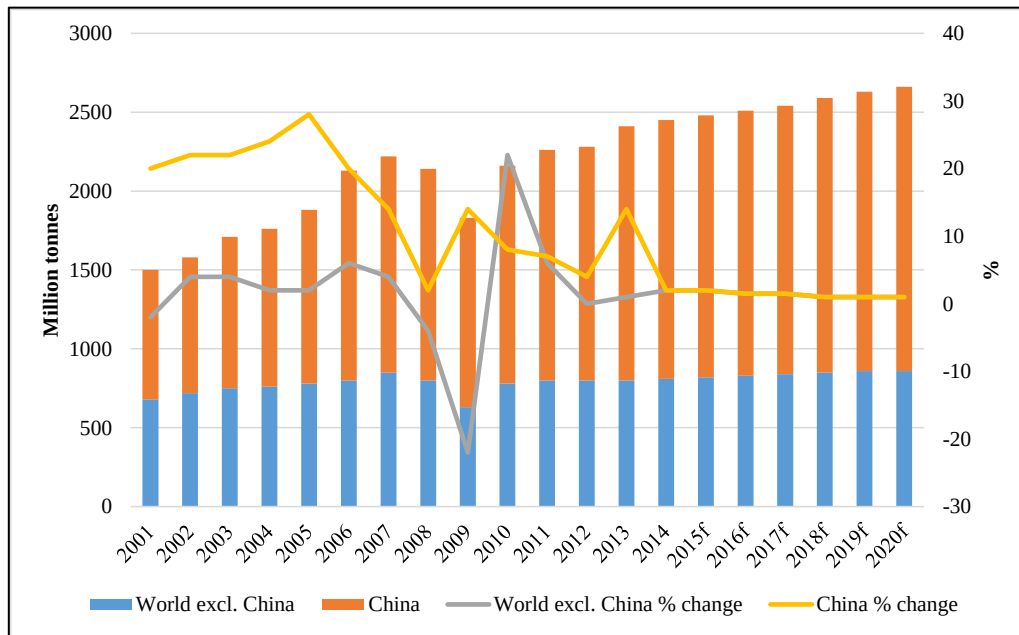


Figure 2: Global steel production³

The study done by Ernest & Young Advisory Services [1] estimates that due to the impact of high energy prices and the European Union's planned reduction in the carbon dioxide (CO₂) emissions allowance, the European steel industry will face additional costs of €58 billion between 2020 and 2030 [1].

The Ernest & Young Advisory Services [1] study showed the trends in the global steel and iron industry, namely, steel production and demand. It can be derived from the Ernest & Young report that the global steel industry needs to reduce costs to grow in an economically struggling industry.

1.2.2 South Africa steel economy

South Africa is not exempt from the economic growth strain as discussed in the Section 1.1. The South African steel industry is struggling due to various factors. An article from

³ Adapted from [1]

Business Day Live (BDLive) [2] and statistics released by the World Steel Association [3] show that the South African steel production was down 4.5% year-on-year in May 2016. Although there was growth in production during the whole of 2015, the first half saw a decline of 7.6% year-to-year from 6.7 mt to 3.2 mt. This major decline is mainly due to the battle with electricity supply disruptions [2].

Some of the electricity supply problems may have been improved, but the first five months of 2016 saw South Africa steel production down by 12.3% year-on-year. This downward trend in steel production is mainly due to large multibillion rand state investments in steel-intensive projects, such as railway lines, that have not been implemented. National Treasury has outlined in their budget speech of 2016 that R291.6 billion would be invested in the steel-intensive logistic and transport sector [2].

Figure 3 represents the decline in South African crude steel production from 2005 to 2015 [4]. In Figure 4, the upward trend of the world crude steel production can be seen. This is a concern to the South African steel economy. It is clearly visible that in 2008 there was an abnormal dip in production. This was mainly caused by a worldwide recession [2].

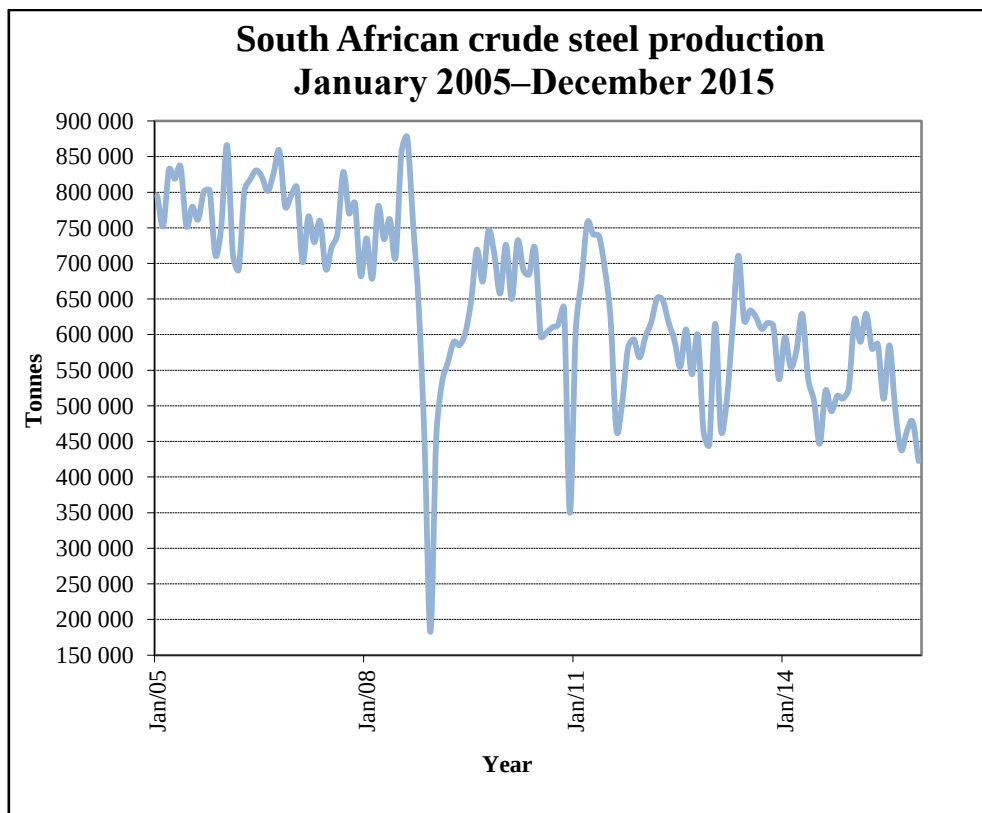


Figure 3: South African crude steel production downward trend [4]

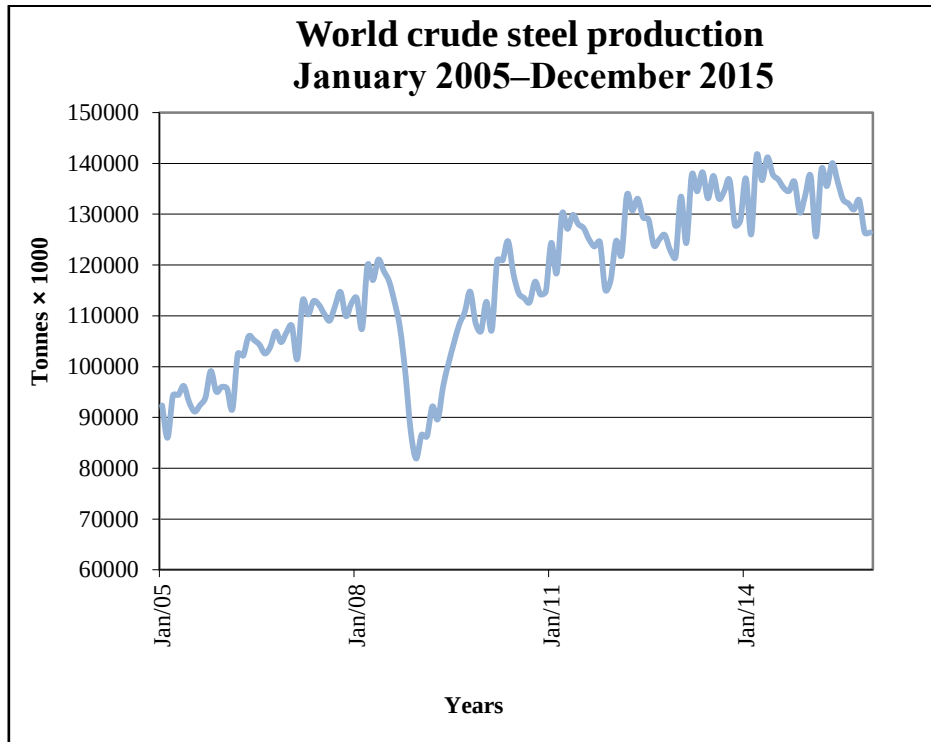


Figure 4: World steel production's upward trend [4]

The steel industry and labour unions are in trouble. Trade authorities need to protect the domestic steel market. Marius Croucamp, the deputy general of Solidarity – a South African trade union, estimates that the South African steel industry could lose all capacity by the end of 2016. It might take 10 years to get it back to where it needs to be. This comment was made in a Mail & Guardian article published on 8 April 2016 [5].

Croucamp warns that ArcelorMittal South Africa (AMSA), South Africa's largest steel producer, can follow the same path as Evraz Highveld Steel and Vanadium that closed their South African operations after a failed business rescue attempt in February 2016. Close to 2 200 employees lost their jobs. AMSA is in a large economic difficulty and needs to take drastic steps to save approximately 7 000 direct jobs. The company's share prices dropped to by 62.5% in 2015 and recorded losses of R8.5 billion [5].

In 2015, the South African government met a 10% import tariff on some steel products to protect the local steel industry. The government also implemented a safeguarding duty, which can only be implemented for three years and must be reduced from implementation onwards. However, the local demand needs to increase to bring local production costs down [5].

The biggest concern is the Chinese market, where the cost of steel production is extremely low, dumping steel. Figure 5 shows the South African steel consumption graph with the

percentage imports. Imports drastically increased since 2010. In 2013 and 2014, imports have increased even though the consumption trend decreased [5].

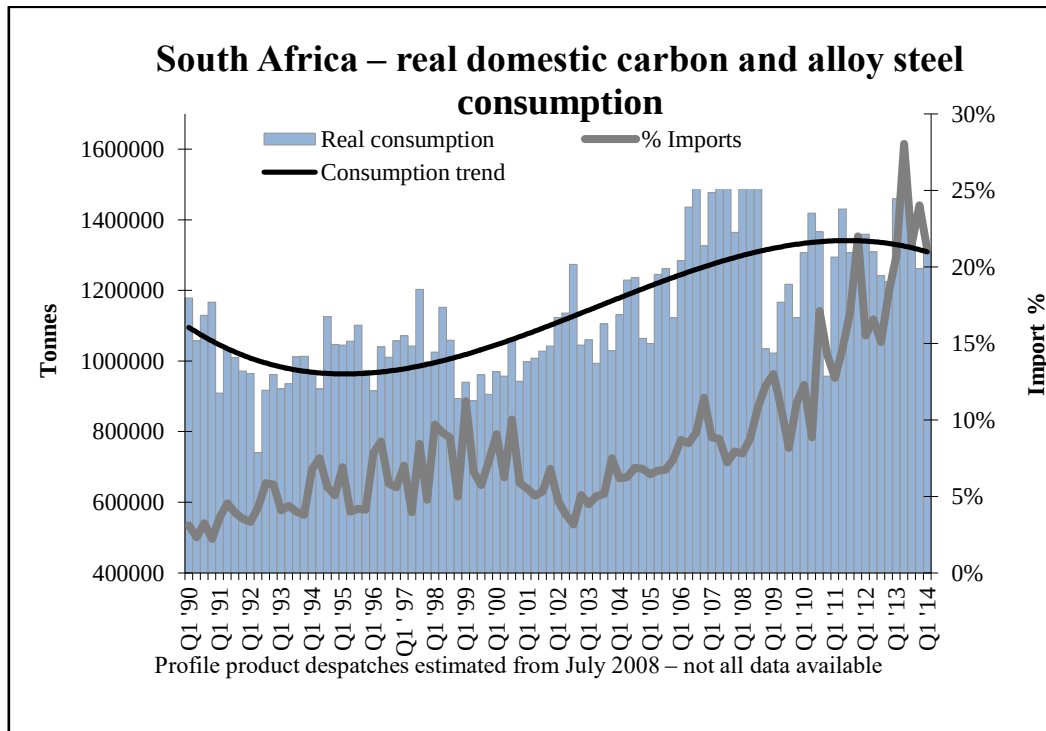


Figure 5: South African steel consumption graph [4]

Figure 6 shows the percentage change in the production of crude steel in South Africa versus the rest of the world.

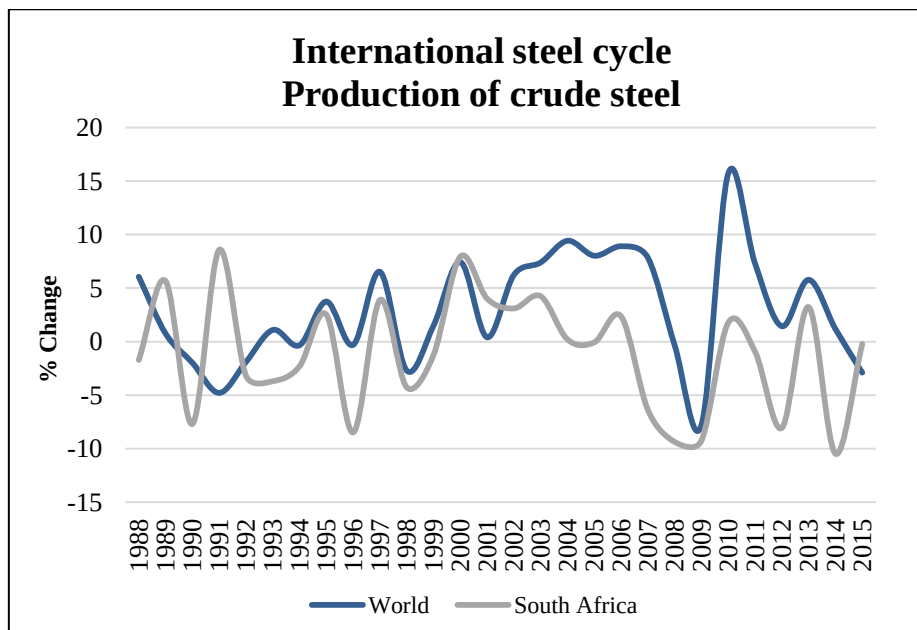


Figure 6: Production of crude steel in South Africa versus the world [4]

From 2008, South Africa's negative growth rate was larger than that of the rest of the world. The positive change percentage is lower than the rest of the world while the negative change percentage is larger. As discussed previously, there was a total positive gain in 2015, but quick decline during the first semester in 2016 [4].

Figure 7 shows the labour cost increase over the past five years. This also contributed to the increase in the production cost of steel [6].

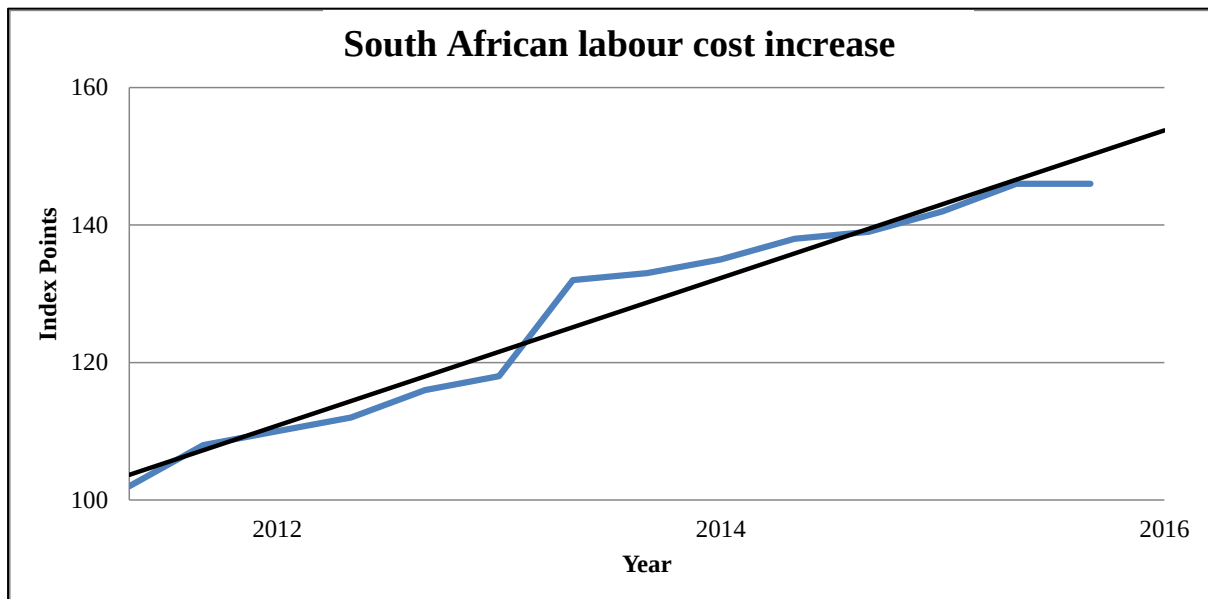


Figure 7: South African labour cost increase⁴

On 16 June 2015, Adam Wakefield from News24 published an article after Eskom proposed an electricity price hike of 25% [7]. In the article, the Steel and Engineering Industries Federation of South Africa (Seifsa) said, “Eskom’s electricity hike will further cripple the already bleeding South African economy”. Seifsa went further in stating that the metal sector has already been struggling for five years due to import competition from the Asian market, industrial action, increasing production costs and Eskom power outages [7].

The chief economist of Seifsa, Henk Langenhoven, made it clear that the stability of electricity supply and the cost thereof were as crucial as the availability of electricity. The steel sector needs to stay competitive globally since most of its products are exported [7].

⁴ Adapted from [6]

1.2.3 Electricity demand in South Africa

Electrical energy is an important and integrated part of the economic cycle in South Africa. Eskom is the largest supplier of electricity in South Africa with a generation capacity of 240 300 GWh per annum. Of the electricity generated by Eskom, 85% is generated using coal-fired power stations. This implies a large carbon footprint on the environment [8].

The actual electricity consumption in South Africa increased by 1.2% year-on-year until 2013/2014 [8]. In 2015, South Africa experienced a shortage in supply and Eskom was forced to implement load shedding. The international standard for electricity reserve margins is 15%, but almost no capacity was available in 2013 (as discussed in Appendix A under electricity cost risks) [9]. It is therefore clear that South Africa has experienced an electricity shortage in the past and can experience similar situations in the future [8].

Eskom started constructing two major power stations, namely, Kusile and Medupi. These power stations will provide an additional electricity generation capacity of 4800 MW each, which can be delivered to the national grid. These projects are behind schedule and the energy gap decreases steadily [9]. Figure 8 shows the supply shortage up to 2016 that continues to grow.

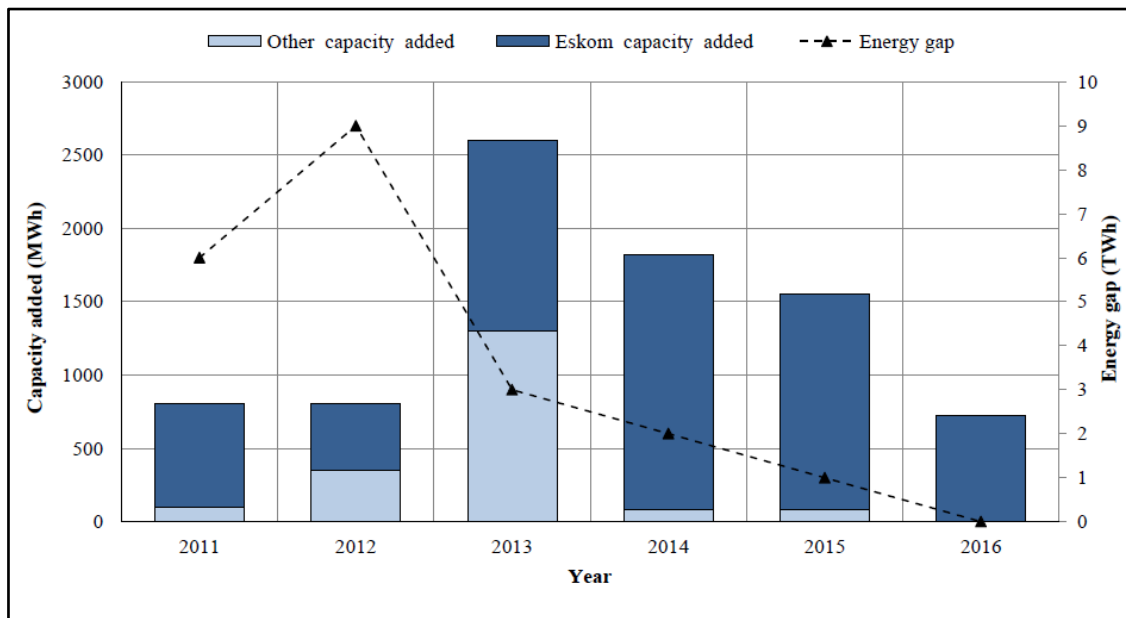


Figure 8: Added capacity and energy gap [9]

South Africa has lower electricity costs than other African countries, which can be seen in Figure 9. However, in the last decade the increase in electricity prices has grown at a rapid rate [10].

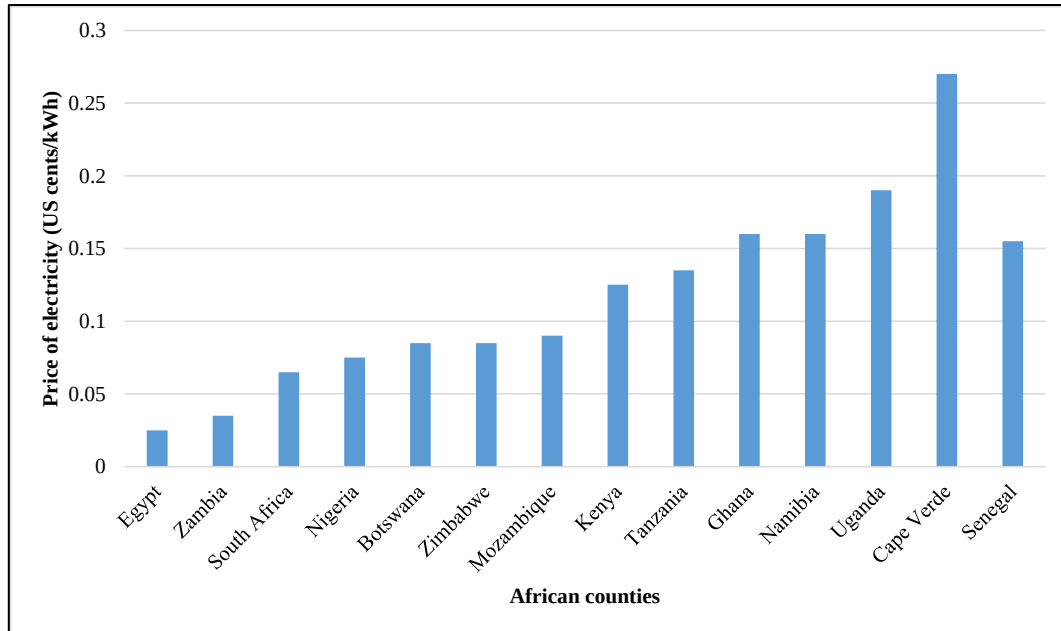


Figure 9: Average electricity price in African countries (US cents/kWh) [10]

Figure 10 shows the increase in electricity against the inflation rate in terms of the consumer price index [11]. Up to 2007, it was below the inflation rate before it increased in 2008 as indicated on the graph. Without additional increases requested, electricity tariff will increase by 300.7%, which is 255.6% higher than the inflation rate increase.

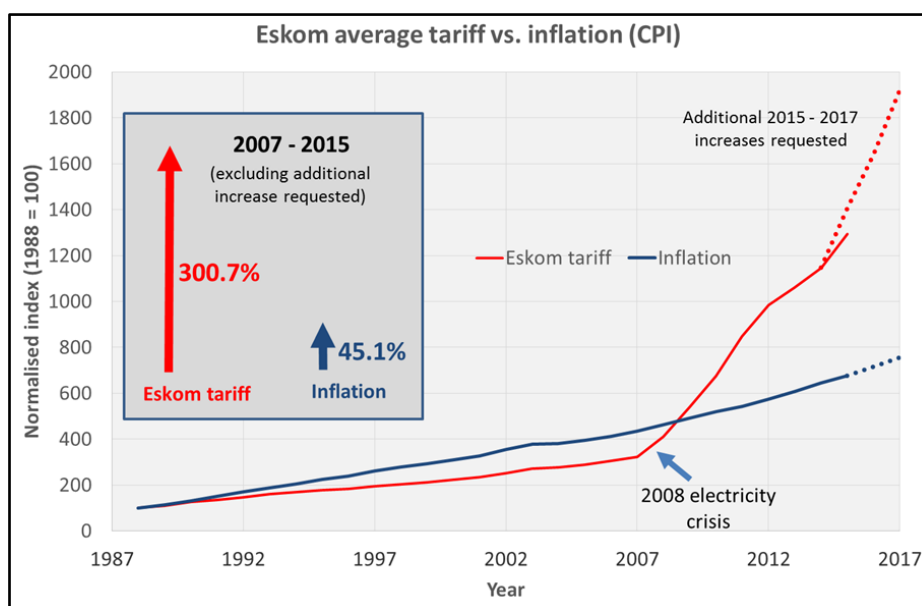


Figure 10: Eskom average tariff increase versus inflation (consumer price index) [11]

1.2.4 Basic iron and steelmaking overview

The South African steel industry is in a crisis amidst a global economic growth strain period for the steel industry. To develop a solution for a problem of this magnitude, the basics surrounding steelmaking need to be understood. This section provides basic knowledge of iron- and steelmaking processes to understand the steel industry and its associated cost risks.

Steel is typically produced using a primary and a secondary process. It is divided into ironmaking and steelmaking. Steel is produced using two main methods that are used separately or in combination, namely, [3], [12]:

- Integrated steel mill method using the blast furnace–basic oxygen furnace (BF-BOF) route;
- Electric arc furnace (EAF) method.

Integrated steel mills

The integrated steel mill method uses blast furnaces to produce molten iron/pig iron from iron ore, coal, coke and fluxing agents. The basic oxygen furnace (BOF) uses the molten iron received from the blast furnace and converts it to refined steel by adding 30% steel scraps and alloys [13]. After the BOF process, the steel is cast before it is rolled or/and coated. The final product is normally delivered in the form of coils, plate, sections or bars. Of the steel produced in the world, 70% thereof is made using the BF-BOF steelmaking route [3].

EAF

EAF steel mills use recycled steel scrap and a percentage of other iron-containing material to produce steel, depending on the availability of steel scrap. The products from EAF steel plants are mostly carbon steels, alloy as well as speciality steels [3], [13]. The EAF method uses electricity as an energy source to melt the recycled steel input [14]. Electrical energy can be supplemented with oxygen that is injected into the EAF. The downstream processes from the EAF such as casting, reheating and rolling are identical to the processes that can be found with the integrated steel mill process. Of the steel produced in the world, 29% thereof is produced using the EAF method [3].

Open hearth furnace

There is a third method that is used to produce steel, namely, open hearth furnace. This only makes up approximately 1% of the world's steel production. This method is not environmentally friendly and is energy intensive. It is therefore not economically feasible to use [3]. The study focuses only on the integrated steel mill and EAF methods since they are the two largest steel-producing methods. Figure 11 shows the basic ironmaking and steelmaking process flow with both methods displayed.

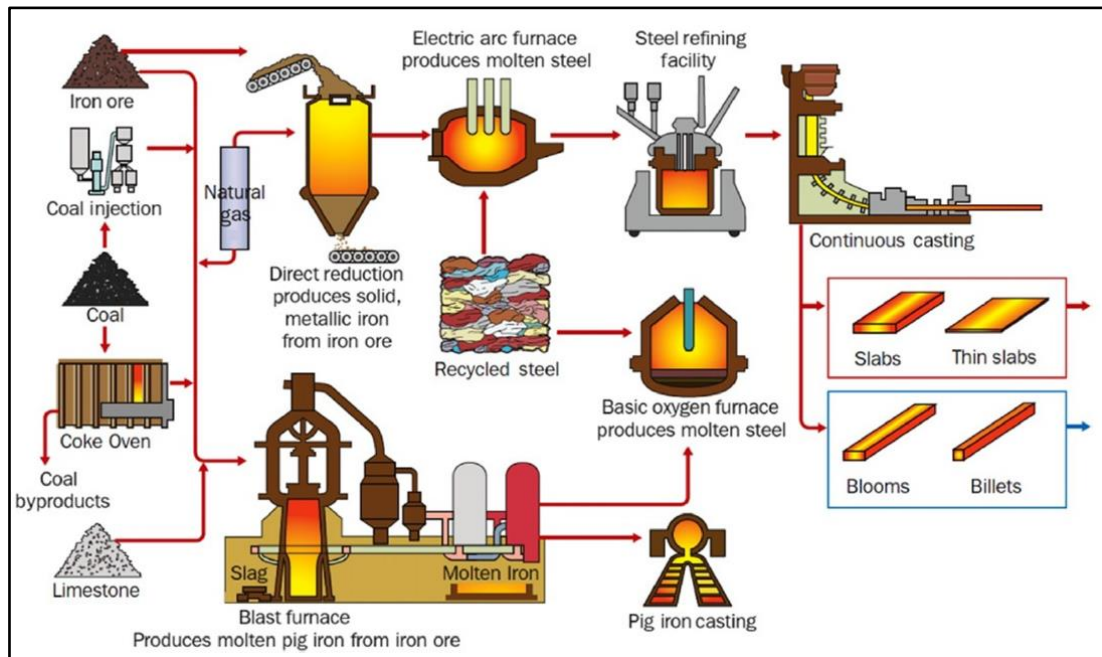


Figure 11: Iron and steelmaking flow sheet [15]

1.2.5 Use of energy in steelmaking

The use of the EAF method has increased from 2001. The continued growth of this type of steel plants is limited to the availability of cost-effective and adequate supplies of scrap. With a combination of alternate steelmaking processes, the EAF capacity can be expanded [13]. Steel production is ultimately an energy-intensive process [3].

Improvements in the energy efficiency of the processes have led to a reduction of about 60% in energy required to produce one tonne of crude steel. This reduction in required energy can be seen over a period of 53 years from 1960 to 2013 as recorded and published by the World Steel Association [3]. Figure 12 shows the indexed global energy consumption per tonne of crude steel produced. There was a steep descend from 1960 to 2013.

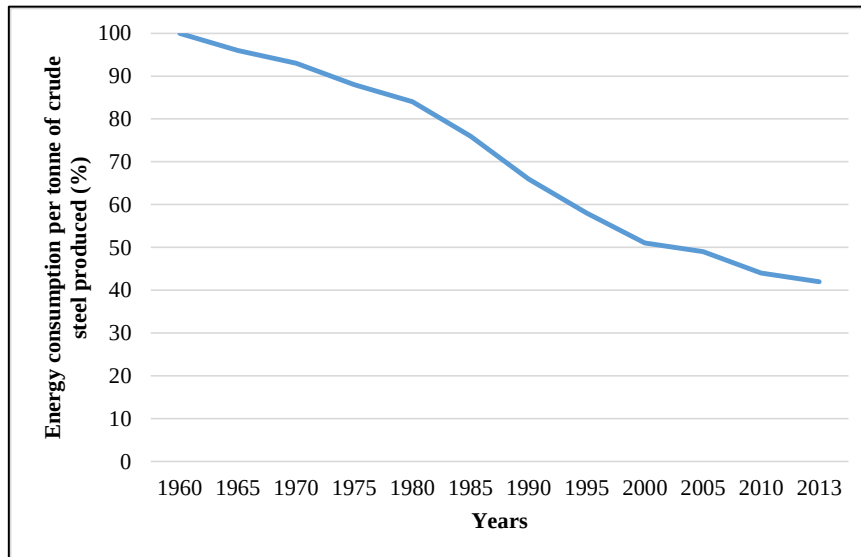


Figure 12: Global energy consumption per tonne of crude steel produced⁵

Energy inputs mean associated costs. A significant portion of the cost to produce crude steel is the required energy inputs. Improving energy efficiency can result in reduced production cost. With reduced production cost, a steel producer can become more competitive in the steel industry [3].

Mining, preparing and transporting raw materials can take up to 8% of the total energy required to produce steel. Each steelmaking facility's energy efficiency varies, which is dependent on the production process, types of iron and coal used, required steel product mix, material efficiency and operational control. The World Steel Association states that an integrated steel facility's main energy sources are divided as such [3]:

- 55% coal;
- 35% electricity;
- 5% natural gas; and
- 5% from other gases.

The blast furnace uses coke as the major source of energy. In the process, coke has the role of reductant, burden support and fuel. In the global production of molten iron (pig iron), coke is partially replaced by pulverised coal injection (PCI) and injection of secondary fuels such as biomass and plastics. There is a global increase in the use of alternative fuels and reductants for blast furnace ironmaking, thus replacing expensive metallurgical coke [15].

⁵ Adapted from [3]

Electrical energy is a significant requirement for numerous large processes in steelmaking as well as subprocesses such as:

- EAF;
- Rotary drive mechanism for a direct reduction iron (DRI) kiln, conveyors and feeders;
- Casting; and
- Rolling;

From Section 1.2.5, it has become evident that electricity is a significant role player in the total energy cost of a steelmaking facility.

1.3 Previous research applicable to this study

1.3.1 Steel industry value chain

Anglo American, through their Kumba Iron Ore operations in South Africa, published a study on creating a sustainable iron and steel value chain. The study has recognised that a sustainable value chain requires effort from all participants in the value chain. The main participants in the value chain were identified as [16]:

- Government – focusing on the impact of state interventions;
- Exploration, extraction and mining beneficiation – focusing on iron ore mining;
- Metallurgic beneficiation and shaping – focusing on the steelmaking process; and
- Conversion/fabrication and manufacturing – focusing on the downstream end-users.

Figure 13 shows the different role players in the iron and steel value chain starting with metallurgical beneficiation and shaping, steelmaking, rolling mills, converters and fabricators.

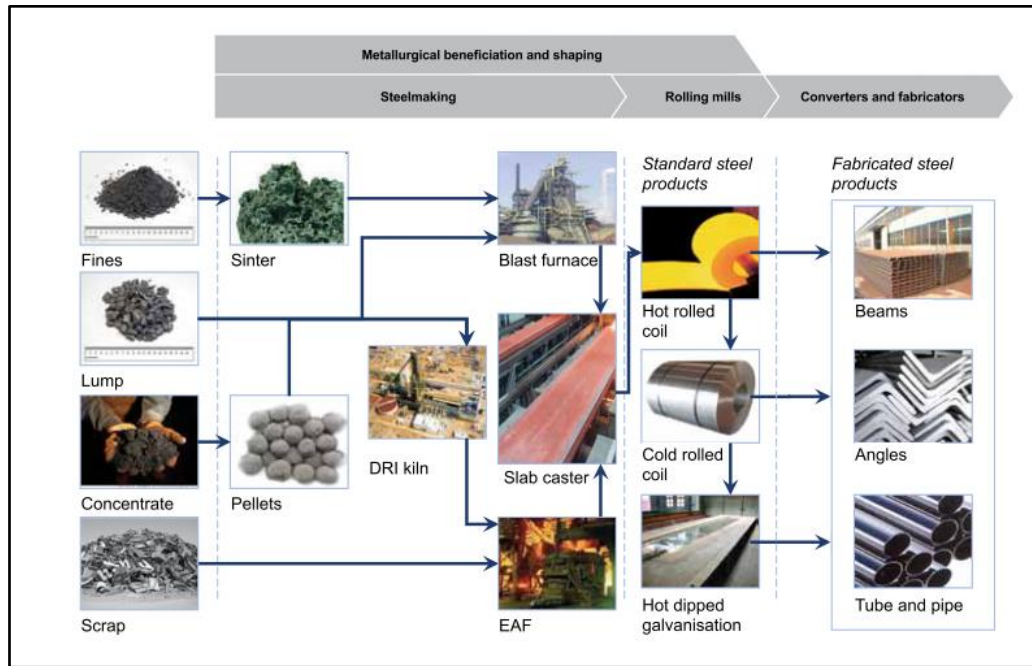


Figure 13: Different role players in the steel value chain [16]

The study found that South Africa's iron ore and steel value chain has large and significant growth potential. However, if the infrastructure is not in place and market prices not reached, growth will not take place [16].

The prospect of growth in South African steelmaking is limited. This is due to global and local overcapacity. South Africa has a poor cost position estimated at 30–35% greater cost in major markets versus low-cost competitors such as China, Brazil and Japan [16]. Thus, it costs 30–35% more to produce steel in South Africa than in similar steel-producing markets.

The study continues that there is no clear economic case for new steelmaking capacities in South Africa. Even though two potential growth opportunities have been identified, these will only be implemented if government policy makes it attractive to invest in the iron- and steelmaking industry. These two opportunities are [16]:

- Researching and developing new steelmaking technologies. These technologies need to reposition the cost competitiveness. It can be done by using thermal coal, which are locally available, as well as low-quality iron ore fines.
- Constructing a large export facility at the coast with an Asian partner dedicated to iron and steel. This will require major investment and at best result in a marginal economic benefit.

South Africa has structural advantages and disadvantages compared with the global steel market. The advantages include [16]:

- High-quality iron ore reserves;
- Sufficient global demand and logistic advantages to countries such as Australia and Brazil; and
- Well-developed rail and port infrastructure.

The disadvantages include [16]:

- South African production facilities do not have the scale of global facilities;
- Compared with the end price of steel, South Africa has high logistical costs;
- Most of the steel mills are located inland and steel exports need to be transported over long distances;
- South Africa has higher input costs than low-quality exporters such as Ukraine and Russia; and
- South Africa has a large domestic market, but it is too small to warrant large investments for modern plant facilities.

This study by Anglo American [16] explains the value chain and the role players in the iron and steel industry. The study specifically refers to the South African environment, and the disadvantages and advantages of steelmaking in South Africa as part of the larger value chain. The study emphasises the need for government contributions and new more efficient technologies for the industry to become competitive.

Large investments are required to grow the iron and steel industry successfully. Large investment into research and new technology will take a significant time and use human resource time. Quick solutions are required. In this thesis, the focus will be on investigating quick opportunities to reduce the cost of steelmaking by identifying electricity cost saving projects. Also, to obtain electricity cost reduction through operational changes.

1.3.2 Energy cost reduction in the South African steel industry

The National Cleaner Production Centre of South Africa (NCPC-SA) initiated a world-class manufacturing programme at one of South Africa's leading steelworks. The plant supplied a suitable platform to engage with the Industrial Energy Efficiency (IEE) Project. The IEE Project introduced an energy management system (EnMS) and energy system optimisation

measures to be implemented on the plant. This was done in alignment with ISO 50001, which is the international energy management standard [17].

The case study reported by the NCPC-SA showed that the IEE Project supported a large South African steel works in solving challenges that included [17]:

- Rising energy prices;
- Reliability of operations;
- Plant competitiveness;
- Plant efficiency; and
- Generating financial, economic and environmental returns.

Table 1 shows the results achieved in the case study implemented by the NCPC-SA on the South African steel works. Without significant capital investment, significant savings were realised [17]. It can be seen in Table 1 that the payback period was less than one year.

Table 1: NCPC-SA case study energy efficiency achievement [17]

South African steel works plant energy efficiency achievements (2011)	
Total number of projects	12
Total investment	R500 000
Gross financial savings for 2011	R89.7 million
Overall payback period (in days)	4
Energy savings for 2011 (GWh)	80
Greenhouse gas emission reduction (tonnes CO₂)	77.2

To implement the IEE strategy, an energy manager was appointed in May 2010. The job description was to develop and implement an energy strategy for the plant. The first step was to conduct an energy audit on the steelworks. A list was compiled with all the existing initiatives and new opportunities identified. The energy manager was accompanied by three energy engineers to form an ‘energy team’. The focus of this team was identifying potential energy saving opportunities as well as developing and implementing energy saving projects [17].

The energy management personnel had to undergo technical training to implement the EnMS. The EnMS was implemented on three departments regarded as the significant energy users (SEUs). The EnMS was based on the plan-do-check-act (PDCA) cycle [17].

The study published by NCPC-SA [17] is important to this thesis. It provides more information to energy cost saving initiatives already implemented in the iron and steel industry in South Africa. It showed that large savings are possible with relatively low investment costs of R500 000. The report, however, lacks a generic step-by-step framework for implementing energy cost saving projects. The study only focused on the SEUs. The question remains if identifying SEUs is necessarily the best place to start investigating energy saving measures.

This thesis fills the gap for a tool to identify and prioritise energy cost saving opportunities in the steel industry. It focuses on the possible opportunities that can be identified on different plants. The focus will be on operational changes rather than new technologies with large capital requirements.

1.3.3 Energy cost reduction in the global iron and steel industry

Energy management and energy cost reduction are important in a steel plant. It is the largest energy consumer of all the industrial sectors. For the steel industry to stay competitive, sustainable and have minimal environmental impact, energy conservation is of the utmost importance. The objective of energy management is to reduce energy usage. The following opportunities are present in a steel plant [18]:

- Adopt best practices for the use of energy sources;
- Adopt best practices for recovery of heat and gas energy;
- Decrease energy intensity per tonne of crude steel produced;
- Enable plants to develop energy reduction plans; and
- Prioritise biggest impact investments for energy efficiency.

For the steel industry, a twin approach for energy management is proposed in industry, namely [18]:

- System-based approach; and
- Technical approach.

The system-based approach is a management approach that optimises the systems connected to energy use and energy conservation. The technical approach is focused on the information obtained from process monitoring and control systems as well as production planning. The technical approach is real-time for decision-making purposes [18]. This thesis will use

technical data to apply a system-based approach for electricity cost reduction in the steel industry.

ENERGY STAR

The United States (US) Environmental Protection Agency funded a programme called ENERGY STAR® that helps businesses protect the environment through extensive energy efficiency. The research brought about a report by Worrell et al. [19] that focuses on energy efficiency improvements and cost saving opportunities for the US iron and steel industry.

It is important to note that the ENERGY STAR® report states that to realise major energy efficiency savings, large capital investment may be needed. It is summarised that capital investment may not be supported by the cost savings achieved alone [19].

The ENERGY STAR® report serves as a guide for energy managers. It provides an overview of energy efficiency opportunities and their specific application. This helps energy managers to select the correct areas for energy efficiency opportunities. The study emphasises that a good energy management programme is required to enforce positive change. Energy efficiency typically only occurs where strong organisational commitment exists [19].

The ENERGY STAR programme works with large industrial manufacturers to make sure that they have a good energy management programme in place [19]. The report focuses on the US iron and steel industry. Although most steel plants use the same processes, there are differences throughout steelmaking in the world. The ENERGY STAR report is valuable, because it lays the foundation for the important case of energy management and a framework in the steel industry. The report, however, is vague in the sense that the importance of energy management is stated and then the opportunities on the different processes are covered.

No mention is made of how to identify the electricity cost savings or to prioritise the savings. The emphasis is on the management after implementation. There are also no implementation results. The results and guidelines were obtained from previously published research. It is a summary of the possible energy efficiency measures for the iron and steel industry focusing on the US iron and steel industry.

In this thesis, a practical model for energy managers is developed to implement on different plants. Because the thesis focuses on the South African environment, the following measures become inevitable to ignore:

- Eskom time-of-use (TOU) tariff structures;
- 12L tax incentives for plantwide energy efficiency; and
- 12I capital investment from the government for proposed energy efficiency savings.

Best Available Techniques iron and steel production

The European Commission produced a report on the best available techniques for iron and steel industries. The report compares the iron and steel industry in Europe to the rest of the world. The report identifies items that are important for integrated steelworks to improve their energy efficiency, including [20]:

- Optimising energy consumption;
- Monitoring energy flow;
- Reporting and analysis;
- Defining energy consumption levels and comparing them year-on-year; and
- Doing energy audits to identify energy opportunities.

The report continues to describe process-integrated techniques used for energy efficiency improvement such as [20]:

- Recovering heat by insulating steam pipes and hot water pipes;
- Optimising energy flows by heating fire furnaces with process gas; and
- Reducing electrical costs using power management systems.

The report forecasts what the future of primary ironmaking and steelmaking will look like considering the past and the present situations. Figure 14 shows these comparisons. The report by the European Commission predicts that future steelmaking will be less energy intensive than past and present [20].

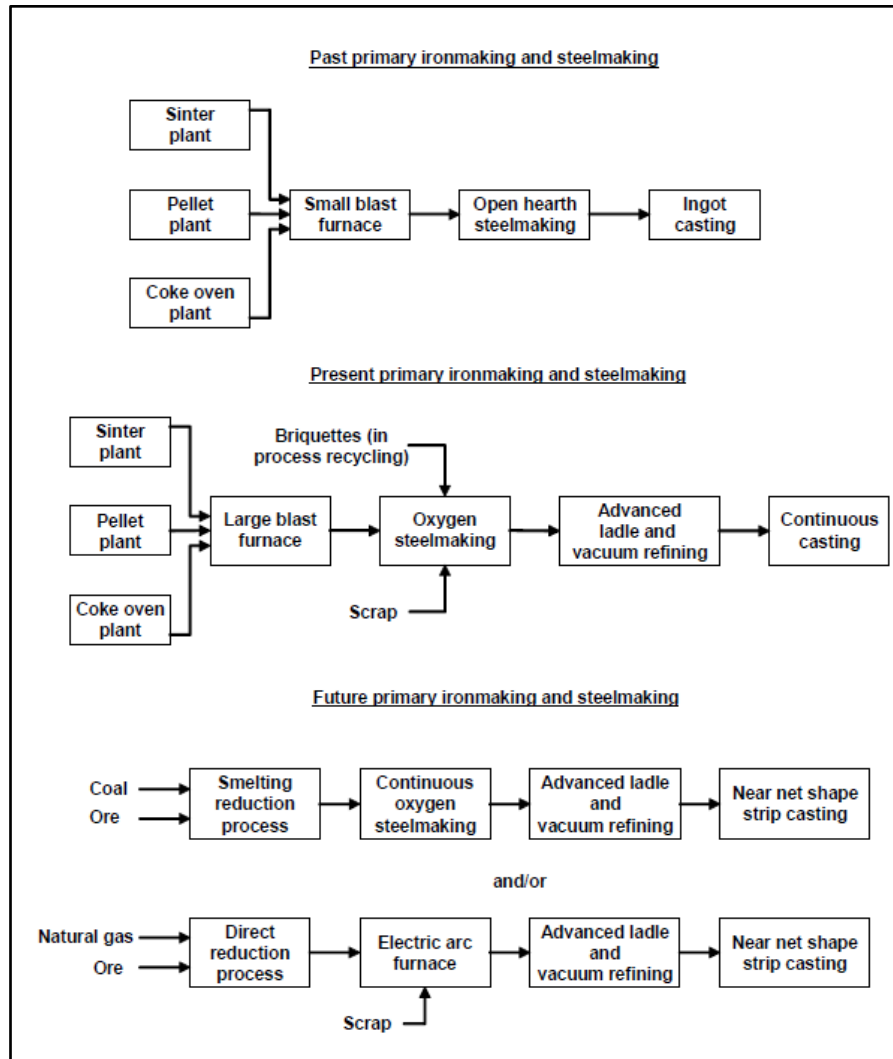


Figure 14: Different routes for alternative iron and steelmaking processes [20]

As was the case with the previous study discussed, this report focuses on the European ironmaking and steelmaking industry and on large changes in infrastructure and technology used. It is a valuable study because it describes the best available techniques. This report is valuable to energy managers in the industry for benchmarking their process techniques and energy saving measures to that of the European Union. This report, however, lacks practical implementation results and it is still to be found if all the techniques are viable.

This thesis will incorporate best techniques to develop a framework for energy managers to identify, prioritise and implement energy cost saving measures.

Northeastern University, Shenyang, China

Setting up important indices of energy consumption is essential for the sustainable development of steelworks. Useful tools for analysing energy consumption are [21]:

- Specific energy consumption; and
- Energy medium consumption of per tonne crude steel.

The study by Qi et al. [21] stipulates the major energy mediums in steelworks, namely:

- Blast furnace gas (BFG);
- Coke oven gas (COG);
- Linz Donawitz gas; and
- Oxygen.

The study focuses on the important specific energy consumption per tonne crude steel, which is an important index used by energy managers to evaluate the energy use level in iron- and steelworks [21].

In the published work of Qi et al. [21], the $e-p$ analysis method is presented that is based on various influencing factors of energy consumption. The $e-p$ analysis shows the process intensity (e) and the steel ratio of the process (p). The equation is given in Equation 1 [21]:

$$E = \sum_i p_i \cdot e_i \quad \text{Equation 1}$$

Where

E = specific energy consumption per tonne crude steel of the steelworks (kgCE/t)

e_i = process intensity of the i process, such as ironmaking or coke-making

p_i = steel ration of the i process i.e. iron/steel ration or coke/steel ration

The study by Qi et al. [21] presents an analysis index to be used by energy managers when analysing the energy use of steel plant processes. It, however, lacks practical tools to identify and implement energy cost saving interventions and prioritise facilities if the energy use of the steel plant process is below the required set point.

This thesis will focus on the opportunities that arise in economic growth strain periods for the iron and steel industry such as electricity cost reduction through operational changes.

Fazeli et al.

It is beneficial to be able to realistically compare a plant against best practice technologies. It is important to distinguish and diagnose where energy efficiency improvements are possible.

One of the most common tools for energy benchmarking is the energy benchmark curve. This curve plots plant efficiency as a function of the total production volume from similar plants [22].

Fazeli et al. [22] reviewed the energy benchmark curve. The iron and steel industry of China and the US were compared. Figure 15 illustrates a typical energy benchmark curve for the manufacturing industry [22]. The figure indicates the best practice technology (BPT) and best available technology (BAT).

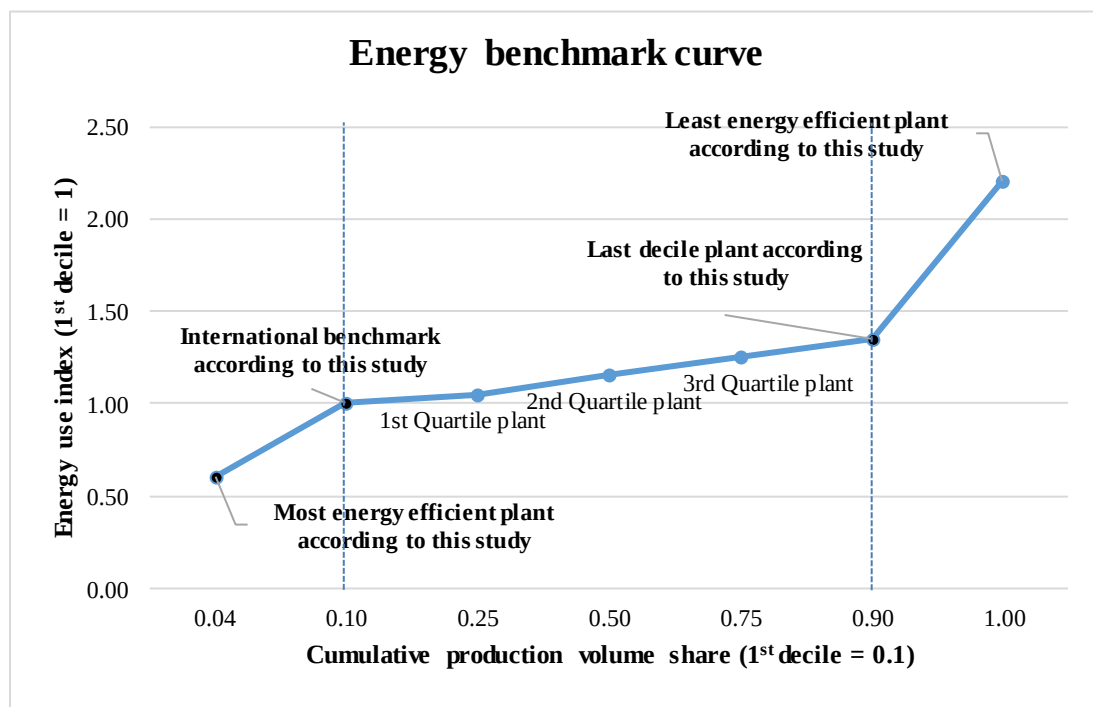


Figure 15: Illustrative energy benchmark curve for the manufacturing industry⁶

Fazeli et al. [22] propose the Sankey diagram to show flow and consumption for energy management. With a Sankey diagram, it is possible to see the magnitude of one energy stream relative to the magnitude of another. With this tool, interpretation is simple for the energy manager to identify the source, destination and consumption of energy flow [22].

Fazeli et al. [22] discuss the best tool to use as an energy manager when it comes to analysing and interpreting energy flow. They suggest using a Sankey diagram in conjunction with an energy benchmark curve to not only compare the energy flow for a plant, but to also to measure it against other plants with similar production volumes [22].

⁶ Adapted from [22]

This study discussed by Fazeli et al. [22] stops at identifying energy intensity and the problem of large energy intensity for the iron and steel industry. This thesis will fill the gap with an approach to use an identification tool and link it with energy saving opportunities with the goal of reducing the electricity cost of a steel plant.

1.3.4 Energy management as a framework

In recent times, research was done by the US government to develop systematic frameworks to assist organisations in improving their energy management practices. Several programmes such as the US Department of Energy Industrial Technologies Program, the Environmental Protection Agency programme and the ENERGY STAR programme have been completed [23].

The Environmental Protection Agency developed a lean energy management toolkit integrating energy reductions into a lean manufacturing framework. Six Sigma techniques were recommended to eliminate energy waste [23]. ENERGY STAR developed assessment guidelines that apply to energy management and the improvement thereof. It is a step-by-step process for achieving superior energy savings. The steps include [23]:

1. Make a commitment;
2. Assess performance;
3. Set goals;
4. Create an action plan;
5. Implement the action plan;
6. Evaluate progress; and
7. Recognise achievements.

This methodology is ongoing and aimed at continuous performance. The US Department of Energy's Industrial Technologies Program focused on improving technologies such as compressors and boilers. The work done was technology-focused and suggested upgrading technologies. In recent times, the Industrial Technologies Program expanded to the Superior Energy Performance Program focusing on incorporating ISO 50001 standards [23].

Stoddard [23] developed a methodology for energy cost savings. The general methodology consisted of four main points with subdivisions. The methodology can be summarised as follows [23]:

1. Historical trends:
 - a. Gather historical data.
2. Assess the current energy uses:
 - a. Develop a plant equipment list.
 - b. Assign trends to the users.
 - c. Use plant production data.
 - d. Chart consumption and cost.
3. Identify and recommend energy saving opportunities:
 - a. Use the output from (1) and (2) to determine SEUs.
4. Develop a process map for energy savings currently implemented:
 - a. Understand the process.
 - b. Obtain relevant data.
 - c. Create current process map.
 - d. Develop new process map.

This study shows the methodology of a framework for successfully implementing energy efficient projects in industry. It also backs the objective of cost savings through operational changes rather than large capital investments. The study, however, lacks the aspect of funding models for projects and the role players involved.

This thesis will incorporate the role players that play a significant role in electricity cost reduction. Funding models are important for the feasible identification and implementation of electricity cost reductions.

1.4 Research objectives

Identifying, prioritising and implementing electricity cost saving opportunities are important to the steel industry in South Africa especially considering the economic growth strain the industry is finding itself in.

Previous research was discussed regarding energy management in South Africa, energy management in the global industry, electricity cost reduction and the implications thereof for the steel industry. A summary of some of the limitations of the previous studies is shown Table 2.

Table 2: Summary of previous studies with their limitations

Main focuses of study	Limitations	Publisher/writer
- Focuses only on large investments. - Requirements for growing the iron and steel industry in South Africa.	No indication of possible energy cost saving opportunities from process optimisation in the current economic situation.	Anglo American [16]
Provides more information to energy cost saving initiatives already implemented in the iron and steel industry in South Africa.	Only discusses the implementation of an EnMS with no elaborate discussion on identifying savings with an EnMS.	NCPC [17]
Lays the foundation for the important case of energy management and cost savings in the iron and steel industry.	- Relevant case study results and identification methods were not covered. - Focuses only on US iron and steel industry.	Worell et al. [19]
Describes the best available techniques for energy managers.	- Large capex requirements and no connection made with economic growth strain. - Focuses on the European iron and steel industry.	Remus et al. [20]
Analysis index to be used by energy managers to analyse the energy use of the steel plant processes.	- No identification tool for energy cost saving interventions. - Focuses on accurately calculating energy intensity without discussing improvement opportunities.	Qi et al. [21]
Lays the foundation for benchmarking and project feasibility identification in the iron and steel industry.	No identification tool for energy cost saving opportunities.	OECD [24]
- Describes the energy benchmark curve as well as the Sankey energy flow diagram. - Compares the Chinese and US iron and steel industries energy intensities.	- No evidence was found for an energy managing tool to identify energy cost saving opportunities under economic growth strain periods. - No mention is made of the iron and steel industry in South Africa.	Fazeli et al. [22]

The main objective of this study is to develop a framework to implement operational changes to reduce electricity costs. A framework is developed and implemented on a steelworks in South Africa.

The objective is further developed to focus on an approach to aid energy managers on steelworks to implement electricity cost saving projects. To achieve this, the framework will be implemented and validated on a real-life South African steel plant.

This approach will select the most suitable electricity cost saving opportunities for a specific steel plant focusing on low to no capital input. Through this approach, energy managers will be aware of the possible opportunities and be equipped to prioritise and implement these electricity cost saving opportunities in the steel industry.

1.5 Original contributions of this study

1. An operational framework for electricity cost reduction in the South African steelmaking environment

How is it currently done?

Currently, steel plants are mostly considering large capex projects, which improve their efficiency, to lower their costs.

Why are the current methods insufficient?

Many steel plants are marginal. Large capex projects, however feasible for long-term cost savings, are not an option in the current economic situation.

What needs to be done?

Steel plant electricity costs must be reduced for these plants to stay competitive in the harsh production environment of South Africa.

How does this study solve the problem?

A framework is developed for steel plants in South Africa to identify, prioritise and implement electricity cost reduction opportunities.

This framework focuses on operational changes rather than capex that steel plant management can implement to reduce electricity costs.

2. Identification methodology of operational electricity cost reductions in the South Africa steel industry

How is the identification currently done?

Currently, steel plants follow global trends and focus on large capex projects. The focus shift in industry is towards energy management as a holistic plant approach. Electricity is not the main contributor to energy cost on a steel plant and is neglected as a major area for cost savings. There is no guidance or framework for identifying facilities on steel plants where operational changes for electricity cost reduction can be implemented successfully.

Why are the current methods insufficient?

Precious time and costs are wasted on investigating and implementing major capex projects with medium return on investment (ROI). Not knowing how and where to identify operational changes for electricity cost reduction leads to inefficient decision-making and electricity cost reductions.

What needs to be done?

An identification methodology is required as part of the framework for operational change to reduce electricity cost.

How does this study solve the problem?

The new framework must include an identification methodology to identify facilities on a steelmaking plant where operational changes can be implemented. It guides the user to streamline the drive for cost reduction of electricity.

3. Facility prioritisation model for the implementation of operational changes to reduce electricity costs

How is the prioritisation currently done?

Steel plant facilities are not prioritised according to a specific method. In many cases, the plant with the biggest drive towards energy savings is prioritised.

Why are the current methods insufficient?

The facility that is prioritised is not always the best facility for implementing operational changes. There are other factors influencing the prioritisation of facilities.

What needs to be done?

The facilities on the steel plant need to be prioritised to implement the identified operational changes on the best possible facility.

How does this study solve the problem?

The framework includes a model for prioritising facilities best suited for operational changes to obtain electricity cost savings.

4. Operational analysis method for the implementation of operational changes**How is the analysis currently done?**

Responsible personnel neglect operational changes since they add to their current responsibilities and workload. The main objective for plant personnel is currently to improve operations and optimise production. Time is limited for focusing on energy-related projects.

Why are the current methods insufficient?

Electricity cost reduction is not obtained efficiently and the time for implementing operational changes is delayed.

What needs to be done?

A method is needed for responsible personnel on steelmaking plants to handle the process of implementing operational changes.

How does this study solve the problem?

The new framework includes a method for analysing operational changes to be implemented. This streamlines the analysis time and the implementation for electricity cost reduction.

1.6 Thesis layout**Chapter 1**

Chapter 1 focused on the background and the objective of this study. It also included the original contributions of this study. Chapter 1 presented a few important studies relevant to this study that was critically reviewed.

Chapter 2

Chapter 2 presents the literature review for the thesis. The literature includes a review on several topics:

- Electrical energy in the steel industry.
- Existing frameworks for electricity cost reduction: Including a conceptual framework, standards, energy saving project identification, system characterisation, system analysis, funding models and the energy roadmap.
- Energy management in the steel industry: Including system-based approach, identification and prioritisation of projects, efficient technologies and operational interventions.
- Energy efficient technologies in the steel industry.
- Available funding models.
- Finally, the chapter is concluded and summarised.

Chapter 3

Chapter 3 focuses on developing the framework for operational changes to obtain electricity cost savings. This chapter is divided into subsections focusing on the following aspects:

- Facility engagement to obtaining electricity cost savings;
- The tasks of a facility-specific energy champion;
- The role players that have interested in the electricity cost savings and the framework;
- The operational flow of the framework; and
- The implementation of the framework for the South African steel industry.

Chapter 4

Chapter 4 discusses the implementation of the framework for operational changes to obtain electricity cost savings in the South African steelmaking environment. Two case studies have been chosen. The two plants, on which the framework was implemented, are the two largest producing plants of crude steel in South Africa.

The two plants are ideal for implementing the framework. Both plants are integrated in terms of iron, steel and finishing production. The verification of the methods developed as well as the validation of the new framework are done in Chapter 4.

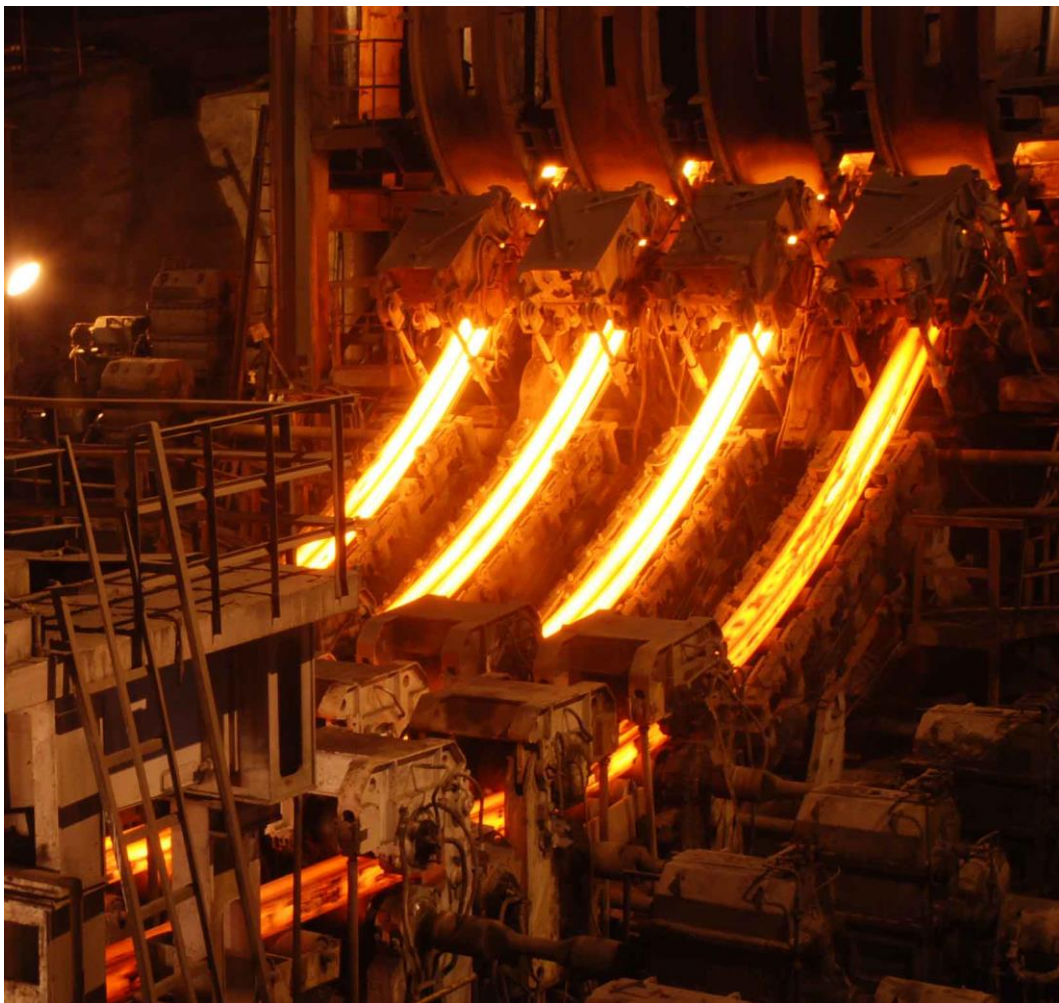
Chapter 5

Chapter 5 is the concluding chapter and includes a summary of the results obtained in this study. The conclusion chapter also recommends additional work to be done on the developed framework. It discusses the expansion of the developed framework for more application in the industry.

1.7 Conclusion

Chapter 1 summarised background information about the steel industry in the current economic turmoil of South Africa and the global market. Different studies on cost reduction and frameworks in the steel industry were discussed. By reviewing the previous research and information, the need for this specific study was discussed and the novel contributions explained.

Chapter 2: Operational changes and electricity cost reduction



Continuous casting of molten steel⁷

⁷ Vizag Steel, “Infrastructure,” Vizag Steel, [Online]. Available: <https://www.vizagsteel.com/code/Infrastr/sms.asp>. [Accessed 5 November 2016].

2.1 Introduction

Chapter 1 outlined the background for this study, stated the original contributions and concluded with the thesis layout. Chapter 2 focuses on the critical reviews of studies, focusing on cost savings for the steel industry. In Chapter 2, the focus is specifically on existing frameworks used in industry to obtain energy savings in general.

Electricity cost reduction initiatives will be reviewed for this study. Chapter 2 covers the literature required to develop a framework in Chapter 3. Added electricity cost-related risks not discussed in Chapter 2, are included in Appendix A.

2.2 Electrical energy in the steel industry

2.2.1 Electricity intensity of the steelmaking industry

Since 1980, the direct sale of electricity from Eskom to the manufacturing industry increased significantly. This sharp increase was mainly driven by growth and the increased consumption of electricity by the non-ferrous metal, and iron and steel subsectors. Figure 16 shows the increase in direct Eskom sales from 1980 to 2008. It is clear that the iron and steel industry was a big consumer [25].

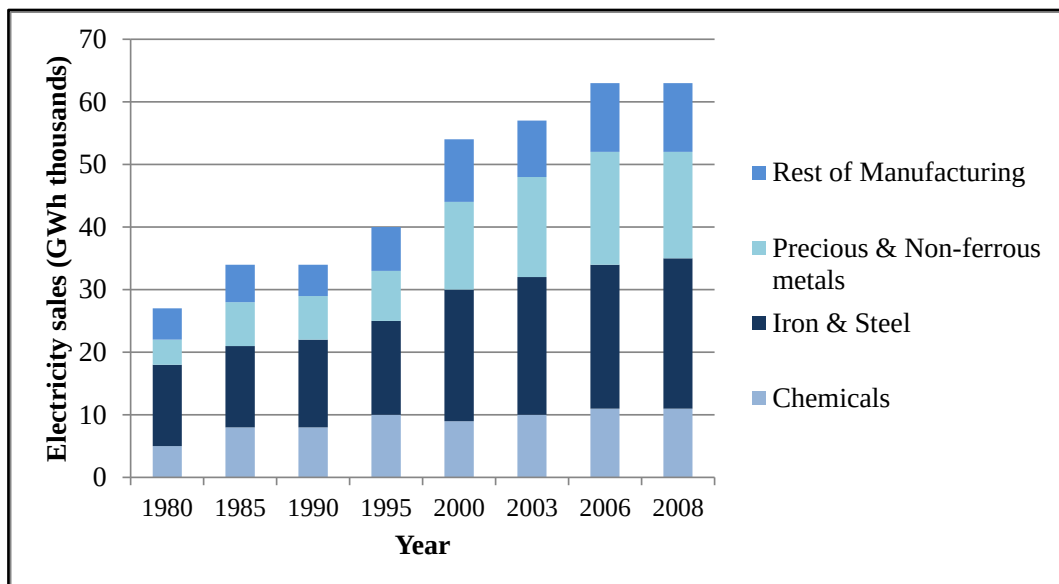


Figure 16: Direct electricity sales from Eskom to the manufacturing sectors⁸

⁸ Adapted from [25]

It was found that from 1993 to 2006, the iron and steel industry was the second-largest contributor to the national electricity consumption with 13 027 GWh consumed [25], [26].

Electricity intensity is a measure of how reliant an industry is on electricity based on its actual consumption. The basic metals industry, which includes iron, steel and non-ferrous metals, is the most electricity-intensive industry. Figure 17 shows the cost of electricity as a percentage of the operational expenditure (opex). ArcelorMittal, Evraz Highveld Steel and Cisco are iron and steel producers, but Evraz Highveld Steel has since closed their operations. From this graph, it is possible to see that up to one fifth of the total operational cost of a typical steel plant in South Africa is allocated to the cost of electricity [25].

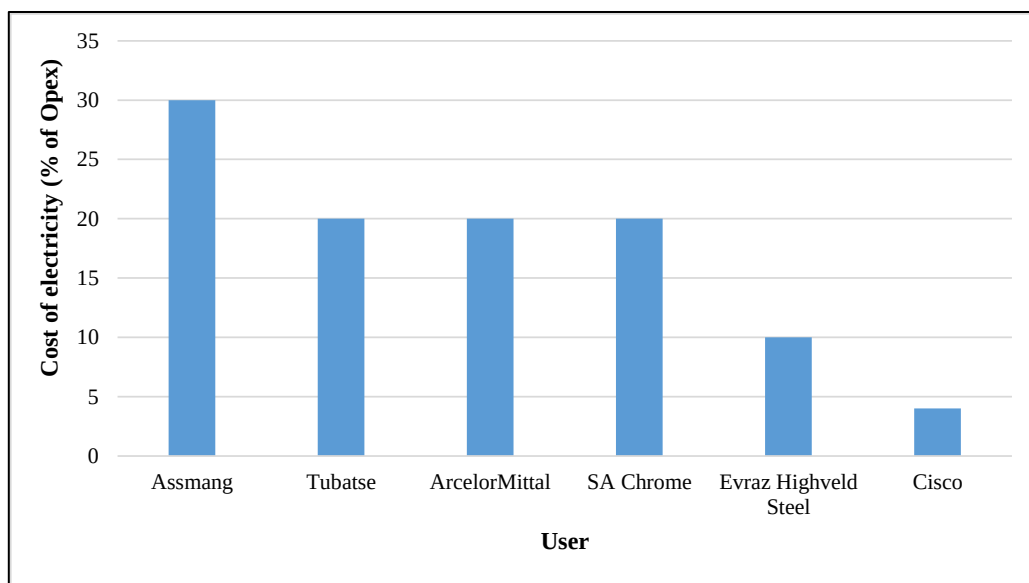


Figure 17: Cost of electricity as a percentage of the total operational costs⁹

The electricity cost risks associated with the South African industrial sector are discussed in Appendix A.

Electricity-intensive systems

A variety of products can be produced by a steelmaking facility, ranging from slabs to flat products such as steel sheets. For all the different products, there are only two main methods used in crude steel production [19], [27]:

- Primary: BF-BOF process using primarily iron ore; and
- Secondary: EAF process using primarily steel scraps.

⁹ Adapted from [25]

The two processes differ in energy usage, but the industry as a whole is a large energy-consuming industry. Figure 18 shows the breakdown of fuels used for energy in the US steelmaking industry. ‘Other’ includes steam and energy. Electricity consumption was only 13%, but accounted for 33% of primary energy use cost. It depends on the amount of electricity generated [19].

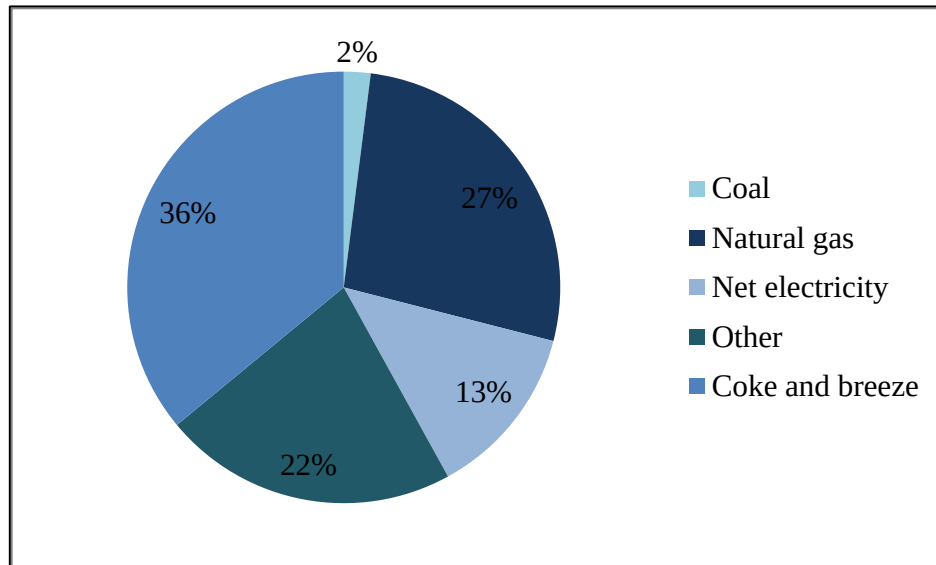


Figure 18: Fuels used for energy¹⁰

Table 3 shows the energy used by the different processes due to fuel consumption, electricity consumption and the net primary energy usage. Table 3 shows that the primary process is more energy intensive than the secondary process. This is since EAF uses scrap metal and does not need coke and sinter. It is, however, evident that the primary process is less electricity-intensive. The EAF has an energy intensity of 304–525 kWh/t of product produced while the total average for all the processes in the primary process adds up to 85 kWh/t [19].

Table 3: Energy usage by process [19]

	Fuel (kWh/t product)	Electricity (final) (kWh/t product)	Primary (net) (kWh/t product)
Sinter	0.41–0.47 (0.41)	28–20 (26)	0.41–0.47 (0.41)
Coke	0.82–0.88 (0.82)	33–38 (36)	0.91–1.29
Hot stove	0.41–0.50 (0.44)	–	0.41–0.50 (0.44)
Blast furnace	2.90–3.05 (2.93)	–	2.90–3.05 (2.93)
BOF	0.21–0.29 (0.23)	13–38 (23)	0.02–0.15 (0.09)
EAF	0.06–0.23 (0.12)	304–525 (401)	0.94–1.52 (1.14)

¹⁰ Adapted from [19]

	Fuel (kWh/t product)	Electricity (final) (kWh/t product)	Primary (net) (kWh/t product)
Continuous casting	0.02–0.06 (0.04)	5.4–13 (8)	0.10–0.15 (0.12)
Reheating furnace	0.7–1.4 (1.1)	2–10 (6)	0.7–1.4 (1.1)
Hot strip mill	0.01	90–152 (121)	0.6–1.2 (0.8)

Mitigation and interventions for reducing electricity costs

There are a vast variety of opportunities in the iron and steel industry to reduce energy consumption while keeping up the productivity of plants. Industry experience shows that projects for improved energy efficiency can be identified with modest investment. This includes best practices and techniques. However, significant energy efficiency projects require larger investment and major capex [28]. These projects include amongst others blast furnace or BOF gas recovery turbines [19].

There is a large need to implement energy efficiency projects due to the struggling economy. The need to develop efficient and effective corporate and plant energy management programmes have to be addressed. Worrel et al. [19] state there are currently energy efficiency measures, but that each plant is different and needs decision makers to realise mitigation strategies on different plants within the iron and steel sector [19].

To fill the gap in the industry as stated [19]: “for decision makers to realise the mitigation strategies on different plants”, the following two novel contributions are justified:

1. An operational framework for electricity cost reduction in the South African steelmaking environment.
2. Identification methodology of operational electricity cost reductions in the South Africa steel industry.

2.2.2 Electricity input for process output

When the potential for energy savings are investigated, electricity rationing approaches can be divided into two aspects, namely [29]:

- Reducing demand; and
- Reducing overall consumption.

For South Africa, electricity rationing is important to supply sufficient electricity to its consumers. There is a definite difference between electricity demand and electricity usage. This is important when a utility needs to explore the responses to electricity shortage, as has been the case in South Africa since 2008 [29] [30].

Energy use is the amount of kWh consumed by the user during a period such as a week, month or year. Electricity demand is instantaneous and is the amount of kVA or kW connected to the national grid at any given time. Eskom, the utility provider, needs to have a 15% reserve margin above the operational capacity at any given time. If the demand from electricity users exceeds the operational capacity of the grid, it could shut down. The level of consumption, especially during certain times of the day, needs to be reduced to secure electricity supply [29].

If electricity consumers can shift or clip their use at peak electricity usage times of the load curve it can be sustainable, which reduces the risk for the grid on the demand side [31]. Figure 19 shows the relationship between electricity and process output. Initially in Phase 1 there might be no impact if electricity is reduced. If the electricity is reduced further such as in Phase 2 and 3, the output decreases to a point where the process shuts down. The iron and steel industry falls in Phase 2 because most of the processes are influenced if electricity is reduced. A reduction in electricity can lead to a loss in batches [29].

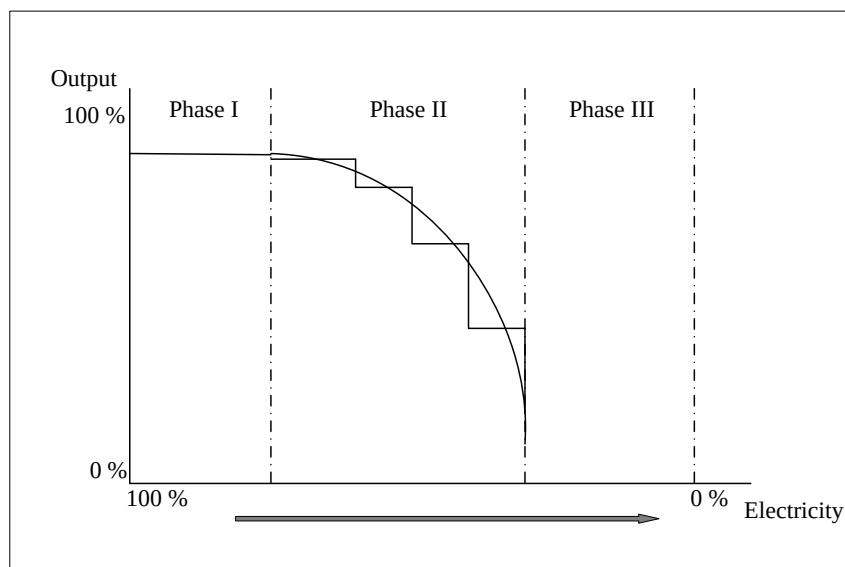


Figure 19: Phases of electricity reduction¹¹

¹¹ Adapted from [29]

The amount of potential power savings on the processes in the manufacturing industry depends on the following aspects [29]:

- The extent of already implemented demand side management (DSM) initiatives;
- If processes are batch or continuous processes;
- If processes are energy intensive; and
- The possibility and sustainability for cogeneration projects.

The aim of DSM projects is to reduce the power consumption without affecting process production outputs. A decrease in production will have a negative influence on the economy [32]. A few of the well-known opportunities for power savings include [29]:

- Installing metering;
- Installing energy efficient lighting;
- Changing the process load profile; and
- Implementing cogeneration opportunities.

When focusing specifically on the iron and steel industry, the plant electricity usage distribution is vastly different from other industries in terms of process heating. After steel is cast, it is reheated in different process sections to make a series of final products according to the customer's specification [29].

Table 4 shows the percentage distribution of electricity usage by industry. It is clear that process heating, compressed air and other machine drives are the largest electricity consumers in the iron and steel industry [29].

Table 4: Percentage usage of electricity by industrial user [29]

	Food and beverages (%)	Textiles (%)	Wood and wood products (%)	Chemicals (%)	Iron and steel (%)	Non-ferrous metals (%)	Basic metals (%)	Manufacturing (%)
Indirect uses boiler fuel	2	1	3	1	0	0	0	1
Process heating	4	5	6	3	39	1	17	10
Process cooling	24	7	0	6	1	0	0	5
Compressed air	8	10	38	10	8	0	11	9
Other machine drives	44	50	38	53	40	2	56	47
Electrochemical processes	0	0	0	18	2	95	17	11

	Food and beverages (%)	Textiles (%)	Wood and wood products (%)	Chemicals (%)	Iron and steel (%)	Non-ferrous metals (%)	Basic metals (%)	Manufacturing (%)
Other process uses	0	1	1	0	1	0	0	1
HVAC	8	15	4	4	3	1	0	8
Lighting	7	10	7	3	4	1	0	7
Facility support	2	2	1	1	1	0	0	2
Transportation	0	0	0	0	0	0	0	0

Table 5 shows the DSM interventions. If compared with Table 4, it can be seen that for the iron and steel industry there is potential on the compressed air in terms of the motors, variable speed drives (VSDs), compressed air savings and refrigeration. Regarding the process heating, thermal measures needs to be investigated [29].

Table 5: DSM interventions and their potential savings by end user [29]

	Steam system (%)	Thermal measures (%)	Efficient motors (%)	VSDs (%)	Efficient lighting (%)	Compressed air savings (%)	HVAC (%)	Refrigeration (%)	Load shifting (%)
Indirect uses boiler fuel	15	5							
Process heating		5							
Process cooling				10					20
Compressed air			5	5		15		15	
Other machine drive									
Electrochemical processes									
Other process uses									
HVAC			5	10			30		20
Lighting									
Facility support					40				
Transportation									

If all the potential DSM initiatives are implemented, Table 6 shows that a 2 289 GWh saving can be achieved with a payback period of 2.3 years [29].

Table 6: Energy saving DSM potential [29]

Sector	Potential saving in GWh	Typical payback period in years
Iron and steel	2 289	2.3
Wood and wood products	1 458	2.2
Chemicals	1 370	2.7
Food and beverages	605	2.4
Rest of manufacture	542	2.6
Textiles	67	2.6

It is clear that by changing the load profile of the process, electricity cost savings can be achieved. The payback period of 2.3 years is above the threshold for currently allowed capex projects with a maximum allowed payback period of 1 year. “If electricity consumers can shift or clip their use at peak electricity usage times of the load curve it can be sustainable, which reduces the risk to the grid on the demand side [29].” This statement justifies the following contributions with this study:

1. An operational framework for electricity cost reduction in the South African steelmaking environment.
2. Identification methodology of operational electricity cost reductions in the South Africa steel industry.

2.3 Existing energy management solution and frameworks

2.3.1 Integrative conceptual framework for energy efficiency

There has been an increase in energy efficiency in the past decade across a wide spectrum of industrial sectors. However, there is still a large share of the potential energy efficiency to be implemented. Schulze et al. [33] state that more than half of the savings remain untapped. There is a definite gap between the theoretical calculated energy efficiency that can be obtained and the actual level of energy efficiency. If all the cost-effective technologies are hypothetically implemented, the remaining gap is called the energy efficiency gap [33].

In the research done by Schulze et al. [33], it is stated that if energy management is included over and above cost-effective technologies, the potential for improved energy efficiency is higher [33]. Schulze et al. [33] identify non-technical improvements such as enhanced operations to the inclusion of energy management [33]. It is therefore necessary to include

operational non-technical changes in the energy efficiency drive to increase the potential for cost reductions. Schulze et al. [33] list reasons from research why energy efficient technologies are not implemented [33]:

- Various barriers existing for energy efficient technology;
- Implementation challenges due to technology characteristics; and
- High complexity of industrial energy systems.

Schulze et al. [33] state that given the complexity of improving energy efficiency, there is a need for a systematic approach to industrial energy management. In the research, the author developed a framework for integrative energy management. The framework is illustrated in Figure 20.

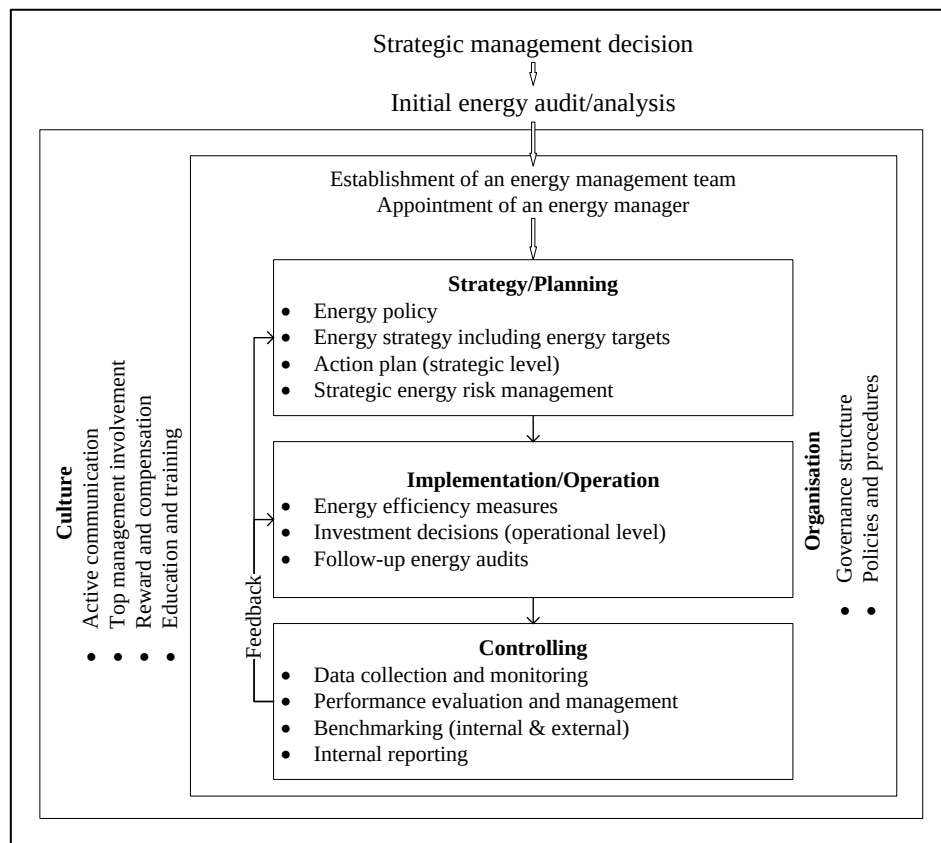


Figure 20: Framework for integrative energy management¹²

The developed framework shows a continuous improvement cycle that needs to be repeated. The framework starts with a strategic management decision. This is important since it forms the basis for implementing energy management and cost saving initiatives [33].

¹² Adapted from [32]

After a team of personnel is appointed to form the energy committee, an energy coordinator is appointed, who reports directly to top management of the company. The responsibility of this energy committee is to perform an initial energy audit. This is a systematic procedure that analyses the status of the current energy flows of the company [33].

Based on the results of the energy audit, an energy policy needs to be developed with long- and short-term energy targets. The energy targets then need to be operationalised. This needs to happen from an overall company perspective. The implementation step focuses on operational level of energy management. Based on an action plan developed in the planning phase, energy management strategies can be implemented on a technical or operational level [33].

The controlling step is the final step in the framework. This step ensures that energy-related data is collected on a regular basis. It also defines key performance indicators (KPIs), and measures and monitors the energy performance of the company [33].

Schulze et al. [33] conclude that the framework developed shows a comprehensive approach to energy management. For personnel in industrial plants, this research assists with decision-making to approach and obtain energy efficiency and cost savings [33].

Review

The research done by Schulze et al. [33] is valuable for this study. A framework for energy management is developed. In the framework, which will be developed in Chapter 3 of this study, the focus is on facility level to develop a framework that only focuses on the operational changes for electricity cost savings. Schulze et al. [33] specifically focus on a holistic energy management framework that is not structured specifically for the steel industry. The author states that operational changes should form part of the bigger energy management strategy. The following novel contributions are justified:

- 1. An operational framework for electricity cost reduction in the South African steelmaking environment.**
- 2. Identification methodology of operational electricity cost reductions in the South Africa steel industry.**

2.3.2 International Organization for Standardisation

The International Organization for Standardization (ISO) is a non-governmental, independent international organisation with membership of national bodies around the globe. The organisation develops market-relevant international standards that support and provide innovative solutions to global challenges. The organisation has published more than 21 000 international standards since its beginning in 1946 [34].

International standards can be used as strategic tools and guidelines to help end-users with demanding challenges that arise in the modern-day business environment. To ensure that companies operate as efficiently as possible, the ISO standards can be a valuable tool [34].

The benefits for implementing the international standards are [34]:

- Cost savings: Optimise operations and improve bottom line.
- Enhanced customer satisfaction: Improved quality has a direct effect on client satisfaction and sales.
- Access to new markets: International standards help prevent trade barriers.
- Increased market share: Increase competitive advantage through increased productivity.
- Environmental benefits: Reduce negative impacts and effects on the environment.

The framework developed in this study can be seen as a tool to mitigate electricity costs through the reduction thereof. ISO 50001 is an energy management standard that is based on a combination of the ISO 9001 and ISO 14001 standards that form part of the management system model [34]. The ISO 50001 standard provides the framework for companies to [34]:

- Develop a policy for using energy efficiently.
- Use data to understand and make informed decisions about using energy.
- Set up targets and objectives to meet policy.
- Review the effectiveness of the policy.
- Measure results.
- Improve energy management on a continual basis.

2.3.3 ISO 50001 as framework

ISO 50001 is an energy management system standard that gives organisations the requirements for an EnMS. It is estimated that the ISO 50001 energy management standard has the potential to influence 60% of the energy use in the world [35]. ISO 50001 follows the well-known PDCA cycle process for the continual improvement of EnMSs. Only one case study is discussed in this chapter. For more case studies please read Appendix B and Appendix C. The standard can be implemented into everyday company standards. The approach can be summarised as follows [35] and is visually displayed in Figure 21:

- Plan: Establish the facility baseline and conduct an energy review.
- Do: Implement an energy management action plan.
- Check: Monitor and measure the implementation process and KPIs.
- Act: Continual action to improve the energy performance and the EnMS as a whole.

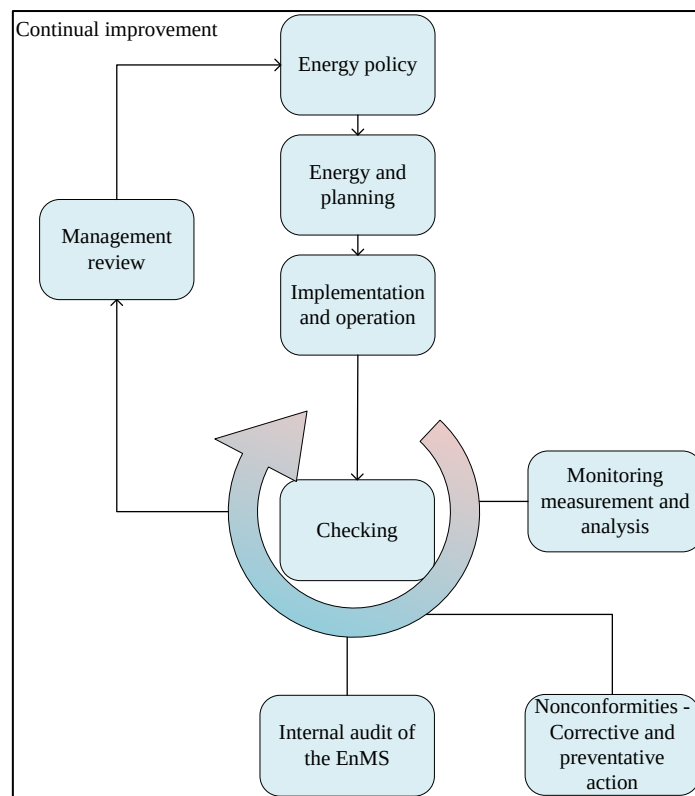


Figure 21: EnMS system model based on the PDCA cycle [35]

ISO 50001 framework – Case Study 1

Gopalakrishnan et al. [36] developed an ISO 50001 analyser tool incorporating the ISO 50001 standardised methodology. Gopalakrishnan et al. state that by providing a

framework for energy management in the industry, plants will enhance their energy efficiency, reduce greenhouse gas emissions and minimise energy costs [37]. These aspects can give plants a competitive advantage [36].

The ISO standard specifies mandatory requirements for an EnMS. These include energy policy, target, objectives and action plans on SEUs. Gopalakrishnan et al. [36] developed a structured methodology together with an ISO 50001 software analyser tool. The purpose of the project was to aid companies in implementing ISO 50001-compliant EnMS systems [36].

The software was developed by Gopalakrishnan et al. [36] with a step-by-step algorithm using flow charts to form a final standardised methodology. Their work describes an approach to facilitate, with the aid of a tool, the successful implementation of a robust EnMS.

Gopalakrishnan et al. [36] list the key elements in EnMS development as:

- Performance indicators – ISO 50001: Energy performance indicators (EnPIs);
- Energy measuring – ISO 50001: Require demonstration of energy performance improvement;
- Framework for implementation – A task-centred computer-aided framework; and
- Financial considerations – Use of an energy balance spreadsheet recommended.

The ISO 50001 analyser software developed by Gopalakrishnan et al. [36] is intended mainly for use by small- and medium-sized industries to implement ISO 50001. The software can be used by both energy managers and energy consultants. The software takes manual inputs from the user to check if standard requirements are met [36].

The analyser tool developed by Gopalakrishnan et al. [36] has been applied and tested at several manufacturing facilities. The software was used by plant engineers on plants that wanted to become ISO 50001-compliant but needed assistance. According to Gopalakrishnan et al. [36], the plants where the tool was implemented received assistance in determining the scope of work required for certification. The tool developed the correct timelines and lines of responsibilities for the relevant personnel [36].

The ISO 50001 analyser software, however, was only designed to provide guidance. It does not include significant data processing and error-checking features. It is recommended by Gopalakrishnan et al. [36] that in the future development of such tools, there needs to be an error-checking feature [36].

The software cannot check if the required documents were entered into the software analyser tool. However, there is a general checklist. The user has to manually record actions at each step. The tool does not require the user to use the EnPIs to develop an energy baseline [36].

Review

The study done by Gopalakrishnan et al. [36] provides valuable information on a framework to implement energy savings using an ISO 50001 analyser tool. The study is limited to the input of energy managers or energy consultants. The inputs required are well-structured documentation. The framework developed in Chapter 3 of this study firstly focuses specifically on the steel industry in South Africa and provides the step-by-step framework to obtain the necessary information and to use it efficiently to reduce electricity costs.

The author states: “framework for energy management in the industry is required” [36]. This phrase justifies the following novel contributions:

- 1. An operational framework for electricity cost reduction in the South African steelmaking environment.**
- 2. Identification methodology of operational electricity cost reductions in the South Africa steel industry.**

More case studies can be viewed in Appendix B.

2.3.4 System-based approach as framework

The system-based energy management approach enables steel plants to identify the systems and processes that need energy performance improvement. This energy performance includes energy consumption and efficiency. Successful implementation of systems depends on commitment from all levels of management. The EnMS requirements are specified by the energy management system standard ISO 50001-2011. Upon these requirements, a plant can implement an energy policy and establish the following [18]:

- Energy objectives;
- Energy targets; and
- Energy action plan.

These established objectives, targets and action plan consider legal requirements and information related to significant energy use. The ISO 50001 standard specifies requirements for establishing, implementing, maintaining and improving an EnMS. The end goal is to enable a steel plant to follow a systematic approach to improve energy performance [18].

The standard also provides guidelines for requirements applicable to energy usage and consumption, including [18]:

- Measurement and verification (M&V);
- Documentation and reporting;
- Design and procurement practices for systems and processes; and
- Energy personnel requirements.

ISO 50001 is based on the PDCA continual improvement process. The PDCA approach incorporates energy management into the everyday practices on a steel plant. If placed in the context of energy management, the PDCA approach can be outlined as follows [18]:

- Plan: Conducting an energy review and establishing the baseline, EnPIs, targets, objectives and action plans that deliver energy performance results with the steel plant's energy policy.
- Do: Implementing the energy management action plan.
- Check: Monitoring and measuring the processes and characteristics key to determining energy performance against the policy and objectives.
- Act: Taking actions to continually improve energy performance on the steel plant.

The systems approach for energy management is important on a steel plant since it contributes to using energy resources efficiently, reducing greenhouse gas emissions and adding to the competitiveness of the plant [18].

The technical approach based on energy management consists of an energy management information system which provides system information. The information enables the identification and detection of energy saving opportunities. It also contributes to energy performance as well as operational improvements [18].

On a steel plant, the following are some of the benefits from an implemented energy management information system [18]:

- Better handling of abnormal operations;
- Accurate measuring and analysis of energy consumption;
- Plantwide control of energy supply and demand;
- Correlate energy consumption to its measured output;
- Optimise the purchase and consumption of all fuels; and
- Optimise the use of by-products.

To summarise: It operates as an effective system for operating a comprehensive energy management flow [18].

Review

This report justifies the framework developed in this study. The report under discussion uses the ISO 50001 as a framework to implement energy management in the steel industry. The benefits of a systematic approach are given, but the actual procedure to implement a systematic approach such as a framework is lacking. The framework developed in Chapter 3 of this study will focus on a systematic approach to obtain electricity cost savings through operational changes. Two case studies are discussed in Chapter 2. Please refer to Appendix B for more case studies on energy management.

System-based approach – Case Study 2

Price et al. [38] conducted a study and published a paper titled “Energy assessments under the Top 10 000 Program – a case study for a steel mill in China”. The Top 10 000 program was a follow-up to the successful Top 1 000 Program. The Chinese government’s responsibilities for the project included [38]:

- Training energy managers;
- Promoting energy efficient technologies for different industries;
- Providing financial incentives; and
- Providing financial support for energy efficient technical retrofits.

The case study is based on a steel mill located in China that has been operational since 1998. It is a steel rolling plant that mainly produces 12–40 mm diameter deformed steel bars and steel rods. The mill produced 850 000 t steel rebar in 2010. The mill has one reheating furnace which uses coal as energy source input. The plant also has one steel rolling production line and a water-cooling system [38].

Price et al. [38] published a Sankey diagram that shows the furnace heat balance as can be seen in Figure 22.

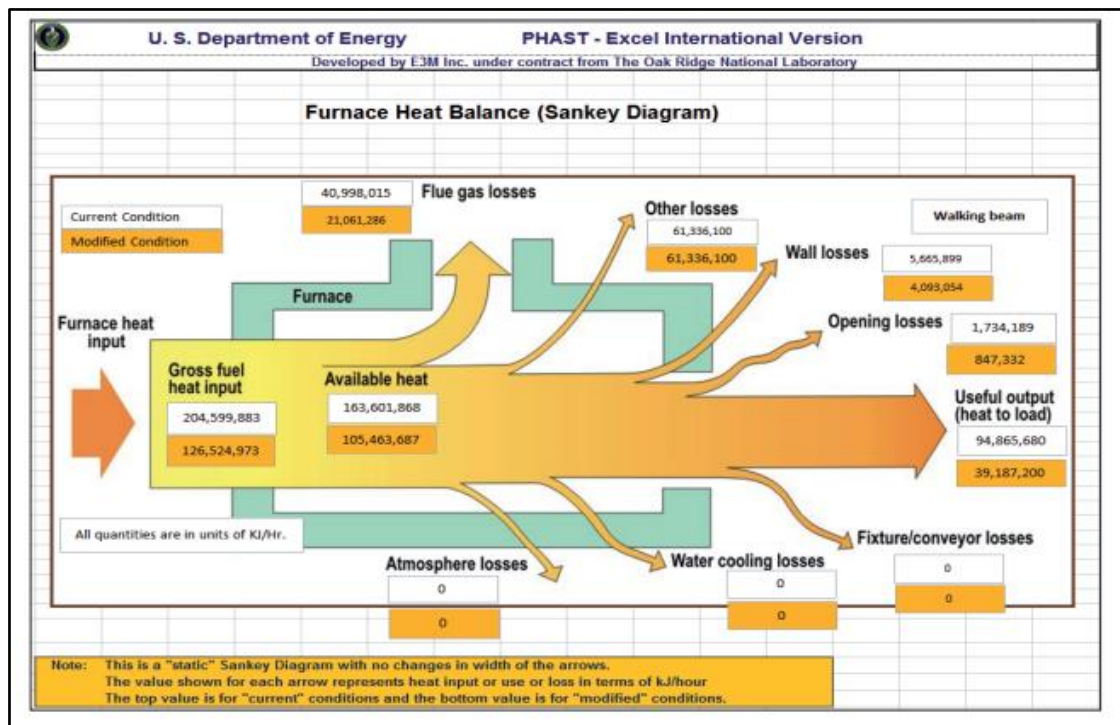


Figure 22: Furnace heat balance (Sankey diagram) [38]

The plant reported that they use 52 kWh of electricity per tonne of steel produced. The project team first analysed the data using a PHASTExcel (PHASTEx) tool. They collected and analysed production data, fuel data and furnace measurements. During the data collection period, the project team received assistance from the plant manager and engineers [38].

The project team used the Sankey diagram to simplify the energy efficiency analysis. The plant's main heat loss was due to openings in the furnace wall where heat escaped. The key energy efficiency analysis was conducted on the exhaust gas analysis [38]. The project team identified opportunities and used the PHASTEx tool to analyse modification results to energy savings [38]. Table 7 shows the energy savings achieved.

Table 7: Energy savings on the steel mill by area [38]

Energy use or loss category	Energy use – loss (Current)		Energy use – loss (Modified)		Energy savings (Current – Modified)			Coal reduction t	Cost savings	
	kJ/h	kgCE/h	kJ/h	kgCE/h	kJ/h	GJ/yr	TCE/yr	% savings	Ren	Min Bi
Charge material	94 865 680	3 238	39 187 200	1 337	55 678 480	467 699	15 962	71	18 618	9 308 925
Fixtures, trays, conveyors etc.	0	0	0	0	0	0	0	0	0	0
Wall surface heat losses	5 665 899	193	4 093 054	140	1 572 845	13 212	451	2	526	262 967
Water or air cooling (internal)	0	0	0	0	0	0	0	0	0	0
Atmosphere or makeup air	0	0	0	0	0	0	0	0	0	0
Radiation losses from opening	1 734 189	59	847 332	29	886 857	7 450	254	1	297	148 282
Other heat loss or heat addition	61 336 100	2 093	61 336 100	2 093	0	0	0	0	0	0
Flue gas loss	40 998 015	1 399	21 061 286	719	19 936 729	167 469	5 716	26	6 666	3 333 247
Exothermic heat from process	0	0	0	0	0	0	0	0	0	0
Total gross heat input required	204 599 883	6 983	126 524 973	4 318	78 074 911	480 461	22 383	100	26 107	13 053 421
					(38.2%)	(38.2%)	(38.2%)			

The case study at the steel mill in China showed the significant energy savings opportunities and potential that exist on plant level. There was 38% technical energy savings potential. The energy savings initiative was triggered by the Chinese government. The author concluded with what could be done to improve the Top 10 000 program and energy assessment activities. Price et al. [38] state that a standardisation tool and standard need to be adopted on similar plants [38].

Review

The importance of this study by Price et al. [38] is that it showed that there is definite energy savings potential on plant level. Although this study does not focus on electricity as an energy source, it is shown that there is 38% technical savings potential. Price et al. [38] justify the framework developed in Chapter 3 of this study with the statement: “standardisation tool and standards need to be adopted on similar plants”. The study, however, does not focus on the whole facility and how to identify projects and prioritise facilities to implement operational changes. This gap will be filled with the developed framework.

System-based approach – Case Study 3

Matteini [39] gave feedback on the United Nations Industrial Development Organization (UNIDO) energy efficiency activities in the steel industry at the 78th session of the Organisation of Eastern Caribbean States steel committee. UNIDO is part of the United Nations system and is a specialised agency [40]. The agency promotes and supports inclusive and sustainable industrial development. The focus is on developing countries and the transition in economies [39].

UNIDO is involved with technical cooperation projects around the globe. One of the focus areas is implementing an EnMS in industry with ISO 50001 as guideline. The standards included in the UNIDO programme are [39]:

- ISO 50001 EnMS;
- Minimum energy performance;
- Conformity assessment;
- Energy/ISO – energy audits; and
- Energy benchmarking.

In the presentation by Matteini [39], the number of steel industry projects in the UNIDO IEE portfolio was listed. Summarised in Table 8 is the UNIDO steel industry portfolio. It is important to note that for some plant, data are not currently available. It is indicated with N/A in the table.

Table 8: UNIDO steel industry portfolio [39]

Plant	Product	Capacity (t/yr)	Production (t/yr)
Al Ezz Dekheila (EZDK)	Long and flat steel	5 800 000	3 000 000
Novacero	Bars, rods and solid sections of iron and steel	N/A	100 000
UMMC-Steel	Rolled steel	N/A	1 000 000
AMSA Saldanha Works	Hot rolled coils	1 200 000	1 200 000
SteelAsia	Steel reinforcing bar	N/A	1 000 000
CSC Steel	N/A	N/A	N/A
Sabah Steel	N/A	N/A	N/A
Amsteel Mills	N/A	N/A	N/A
Antara Steel Mills	N/A	N/A	N/A
Pag-asa Steel Works	Steel reinforcing bar	N/A	N/A
AMSA Vanderbijlpark	Hot rolled coil, cold rolled and coated products	N/A	N/A
Oxin Steel	N/A	N/A	N/A
Esfahan Steel	N/A	N/A	N/A

The UNIDO model includes training and seminars from international and national industry and process experts in the field of energy savings. The project implemented on the AMSA Saldanha Works included ladle heating station system optimisation, compressed air system optimisation and increased energy efficiency awareness. By implementing an EnMS and an energy efficiency project, the plant obtained 460 GWh energy savings. The plant achieved \$9.1 million gross financial savings in 2011 [39].

At the EZDK steel company in Egypt, energy performance opportunities were identified and implemented. An annual energy saving of 176 GWh was achieved. This resulted in financial savings of \$7.6 million per annum [39].

Review

There are global energy saving activities focusing on the steel industry and significant funding from organisations such as UNIDO is available. However, this funding is limited to

specific case studies important to these organisations. In South Africa, the work of UNIDO mostly includes doing energy audits and writing reports with suggestions. Training is limited and suggestions are not always implemented. The funding from UNIDO is limited towards implementation. The framework developed in Chapter 3 of this study will therefore serve as an easy-to-use guide that will streamline identification, prioritisation and implementation of electricity cost saving opportunities. The framework also incorporates all the role players such as available funding sources. The following contributions are justified:

- 1. An operational framework for electricity cost reduction in the South African steelmaking environment.**
- 2. Identification methodology of operational electricity cost reductions in the South Africa steel industry.**
- 3. Facility prioritisation model for the implementation of operational changes to reduce electricity costs.**

2.3.5 Identification and prioritisation of energy efficient projects

Identification and prioritisation – Case Study 4

ABB South Africa conducted an energy efficiency case study in the steel industry. What makes this study valuable is the methodology for implementing an energy efficiency programme to obtain electricity cost savings. To identify a project opportunity, the following process is followed as shown in Figure 23. [41]

Firstly, information such as utility consumption data, process flow diagrams (PFD) and other necessary documentation are required. After the information is gathered, an initial data review can take place. This is done before a site visit is conducted by the contracting company. It is important to do the review to compile a site agenda for the site assessment [41].

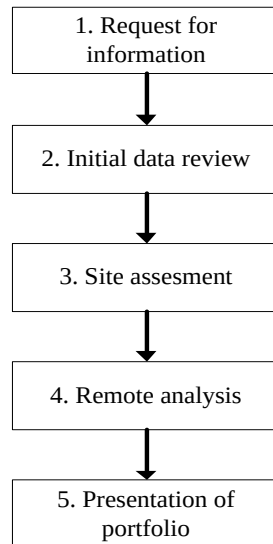


Figure 23: Project identification process [41]

Finally, a study team will visit the site to review the physical condition of the assets and to validate the data and other information obtained [41]. With the site visit, practical opportunities for energy efficiency and energy management need to be identified. After the site visit, the team needs to continue with analysing and confirming the identified opportunities. The output of the opportunity identification phase is to produce a portfolio or list with possible project opportunities for energy efficiency on plant systems [41].

After the initial identification phase, the implementation or master plan comes into effect. The master plan is a continuous process and the methodology is summarised in Figure 24.

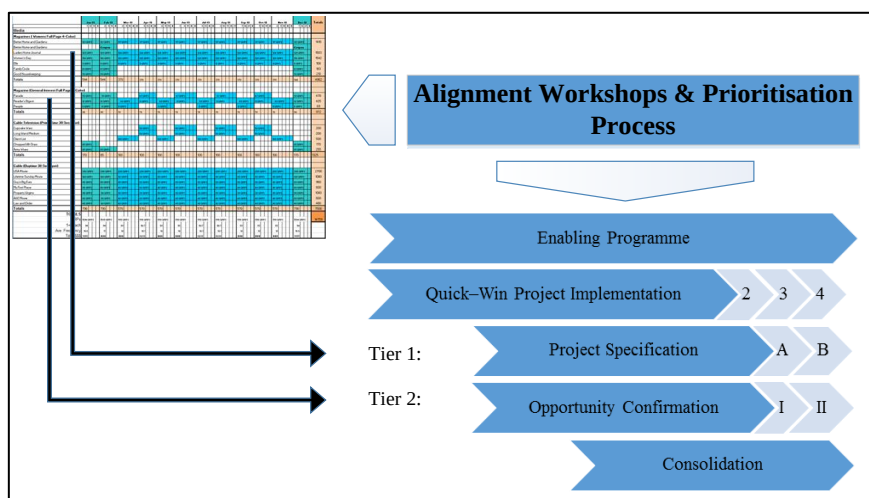


Figure 24: Master plan methodology ¹³

¹³ Adapted from [40]

The main elements of the master plan are [41]:

- Alignment workshops;
- Prioritisation process;
- Deliverables;
- Enabling programme; and
- Consolidation.

The focus of this thesis is specifically on the prioritisation step. In the case study report, the author gives limited information on the prioritisation process. The prioritisation process is conducted while the alignment workshops are held. The objective is to prioritise the energy savings opportunities per evaluation criteria. The projects are scored on feasibility and ease of implementation. The criteria include payback period and the impact on the business. [41]

The energy savings programme was implemented on an integrated steel mill. Opportunities were identified and low-capital investment opportunities were implemented first. These low-capital projects achieved the expected estimated savings for the energy savings programme. The quickly implemented projects were used to accumulate investments for more capital-intensive projects. [41]

The study was concluded and it was found that quick payback opportunities are still available in the steel industry. To identify these projects, it is important to understand technologies, operations and specific constraints. Energy savings of R1.2 million per annum were achieved for this specific integrated steel mill [41].

Review

What makes this study valuable is the methodology for implementing an energy efficiency programme to obtain electricity cost savings. It is important to have a step-by-step methodology. It is also important to note that quick payback period opportunities are still available in the industry. The report by ABB South Africa, however, does not focus on prioritisation.

This study will fill the gap and prioritise the cost savings opportunities using the developed framework. The following novel contribution is justified:

3. Facility prioritisation model for the implementation of operational changes to reduce electricity costs.

2.3.6 Operational interventions for electricity cost savings

Operational changes to achieve cost savings – Case Study 5

The European Steel Technology Platform published a report for the European Union on energy transition. According to the report, demand side load management is not receiving as much as attention as, for example, energy storage. DSM has real potential as a cost savings initiative. The report shows that there is significant potential in the steel industry to contribute to DSM [42].

Shutting down part of a plant's power during the short times of daily peak demand can result in electricity savings. If the load has to be regained, it will result in cost savings. The steel industry in France consumes 8 600 GWh/yr of energy. The specific energy intensity is 581 kWh/t with a combination of integrated BF-BOF and EAF mills [42].

It was found that for the EAF steelmaking process, which is a batch process, the power can be switched off easily for short periods of time. An integrated steel mill process consumes 20 GJ/t of energy, 10% of which is electrical energy. Figure 25 indicates the electricity consumption of different users on an integrated steel mill facility. It is evident that steelmaking uses the largest portion of electricity, followed by hot rolling. Hot rolling is where steel slabs are shaped [42].

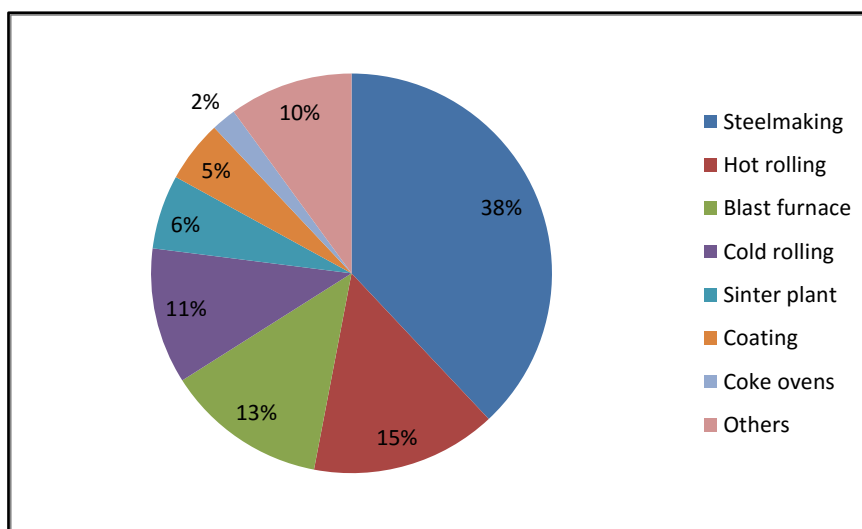


Figure 25: Electricity consumption in an integrated steel mill by production plant [42]

In the report, it is assumed that the slab yard can act as a buffer for hot rolling. With this assumption, it is estimated that the power, which can be switched off during the peak period, can accumulate to 142 MW, which is half of the potential estimated for the EAF process, which is a full batch process [42].

A less conservative measure indicated in the report is using the torpedo ladles as buffer for upstream hot metal. This measure will further reduce power consumption by 38% during peak demand periods. It is estimated that the French steel sector has the potential to switch off between 442 MW and 710 MW power during peak demand periods [42].

This is a significant amount and the authors of the report state that the estimated potentials shown are very rough. The objective is to see the potential and to investigate this. The author suggests more work be done in analysing grid details and actual steel mill scenarios. The technical potential needs to be converted to business case potential [42].

Operational changes to achieve cost savings – Case Study 6

In a study done by Esmailnadjad and Sundquist [43], two case studies are discussed. Case Study 6.1 and Case Study 6.2. In the first case study, the electricity consumption was approximately 500 GWh. The electricity consumption is due to furnaces used for melting and moulding of steel scrap. An EAF is used to melt steel scrap. The plant consists of an EAF, six ovens and two electric boilers of 15 MW each [43].

Esmailnadjad and Sundquist [43] state that DSM becomes complicated with interconnected processes such as melting and moulding. If load is shifted or shed, it influences multiple processes. The EAF process is a batch process. When the furnace is charged, a downscale in power supply can damage the furnace. It is therefore only possible to do load shifting by changing the start time of charging to a desired time. Furnaces used for the heating of components for reshaping can be ideal for load flexibility [43].

If planning is done properly in advance, the furnaces can be scheduled. The production value needs to be considered. Figure 26 shows the shifting of load for the steel industry looking at an EAF and boilers [43].

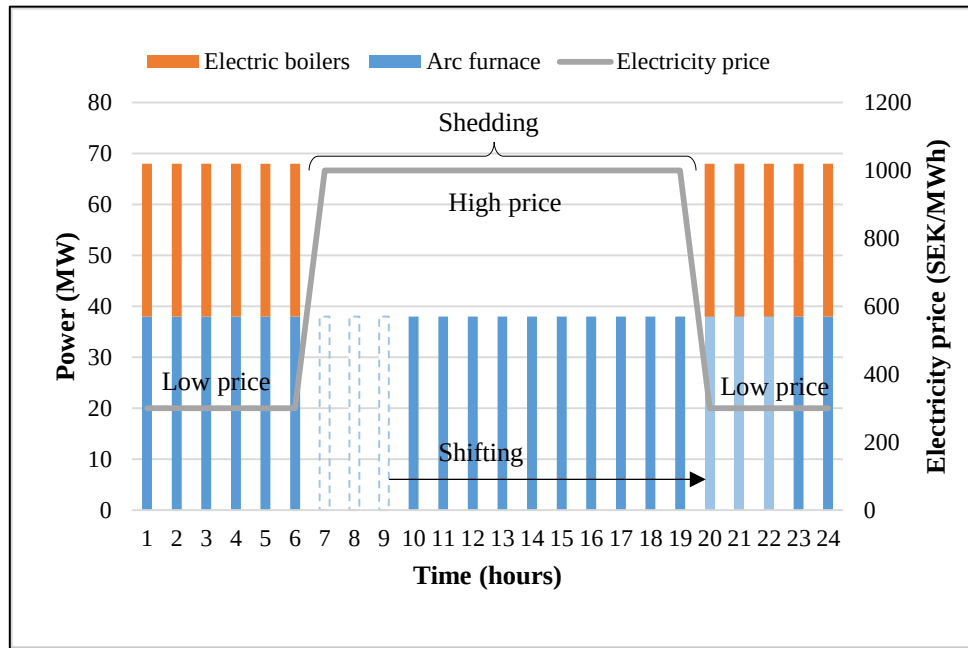


Figure 26: Arc furnace and boiler theoretical response to electricity prices¹⁴

It was found that even if the economic benefit for the peak demand periods is considered, it would not be feasible to implement. It is concluded that the company in Case Study 6.1 needs a compensation of 150 to 200 times the electricity price for every MWh of furnace downtime. It is therefore possible to implement a load management initiative, but it is not financially feasible due to the production value [43].

Case Study 6.2 also considers an EAF. The difference between the two furnaces is mainly the charge time. Case Study 6.2 furnace can also be shut down during early phases of operation. The EAF is also much smaller than the EAF in the first case study. Figure 27 shows the load shifting possibility [43].

¹⁴ Adapted from [42]

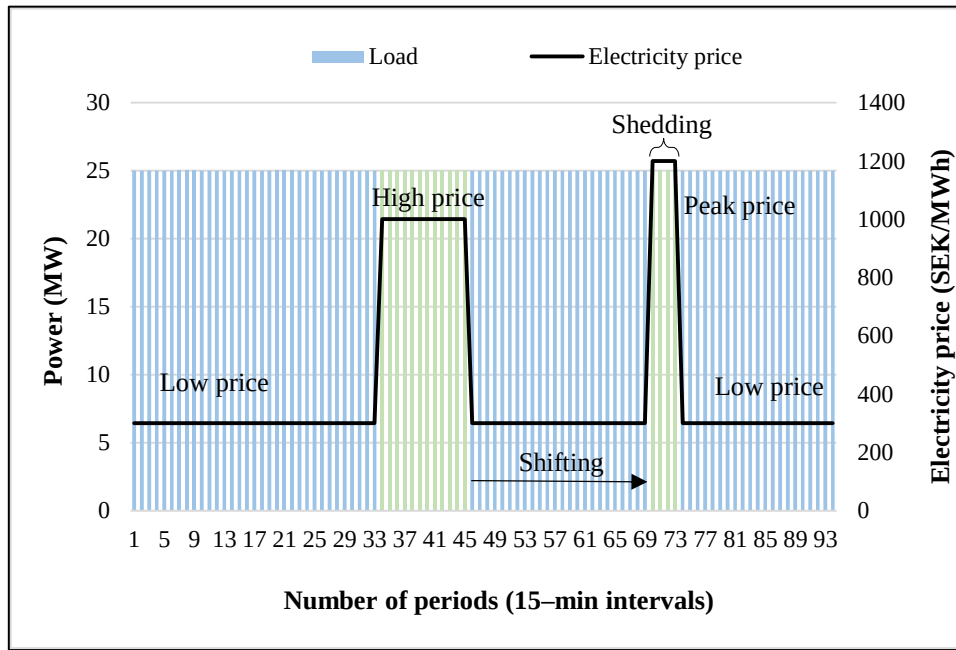


Figure 27: Flexibility of electricity load of the EAF¹⁵

Once a simulation was done, it was found that it would be possible to implement a load shifting initiative. A compensation of 300 000–600 000 SEK/period of regulation is needed to make the implementation financially feasible. This is equivalent to 4000–8000 SEK/MWh [43].

Operational changes to achieve cost savings – Case Study 7

Ashkok [44] studied load management based on programmable logic controllers, specifically in steel rolling mills. The author used an integer programming technique to minimise electricity costs. The electricity costs are minimised by scheduling the loads while still satisfying the process, maximum demand and production constraints [44].

The model developed can determine industry response under different tariff structures. The case study used by the author was a steel mill in India. In India, most of the industries are not aware of the potential posed by load scheduling by optimising processes [44].

The results from the case study on steel mills showed that it is possible to reduce total electricity cost by optimal process scheduling. Optimal scheduling under the TOU tariff structure resulted in electricity savings of 5.21% compared with a baseline calculated from current working conditions. A significant peak demand reduction can also be achieved

¹⁵ Adapted from [42]

through optimal load scheduling. The tool developed by Ashkok [44] assists industries with optimal response [44].

Review

The studies under discussion are important since DSM is proposed as a measure for operational changes to reduce electricity costs. It is important to note that a process can either be a batch or a continuous process. This can make a large difference in the possible amount of cost savings. The author also conducted simulations before any project was implemented. However, these studies lack a step-by-step methodology or framework for an energy management team to use when DSM projects are identified, prioritised and implemented. Therefore, the following novel contributions are justified:

- 1. An operational framework for electricity cost reduction in the South African steelmaking environment.**
- 2. Identification methodology of operational electricity cost reductions in the South Africa steel industry.**
- 3. Facility prioritisation model for the implementation of operational changes to reduce electricity costs.**

2.3.7 Energy roadmaps

A roadmap is a strategic plan to describe the steps that a company or organisation needs to take to achieve a certain outcome or goal [45]. The roadmap clearly needs to outline the links between the actions and priorities for short-, medium- and long-term goals. An effective roadmap generally includes milestones to allow tracking towards obtaining the ultimate goal [46].

Within a roadmap, there are five important definitions that need to be understood [46]:

- Roadmap: Strategic plan that outlines activities to undertake to achieve a goal.
- Roadmapping: The evolving process in which the roadmap is created, prioritised, implemented, monitored and updated if necessary.
- Setting a vision: This is the process where future scenarios are analysed and the objectives defined.

- **Stakeholders:** These are the relevant individuals or organisations who share interests in seeing the roadmap developed and implemented. These can include government, industry, academia as well as non-governmental organisations.
- **Implementation:** This is the process of putting the roadmap into action. It is done by carrying out identified and prioritised projects and initiatives. This also includes monitoring progress using a tracking system.

A successful roadmap can be divided into five subsections as shown in Figure 28 [46]:

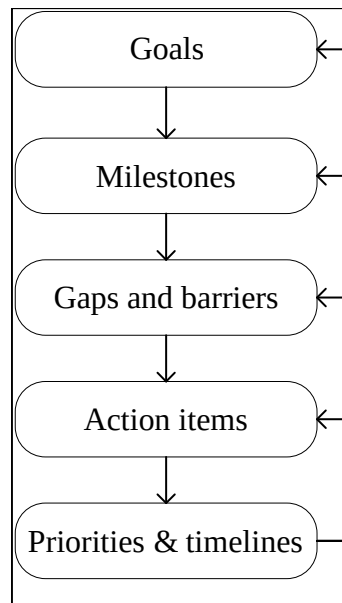


Figure 28: A typical roadmap [46]

Roadmaps can be used for many different aspects of which energy is one.

Review

It is important to make an energy roadmap part of the framework. The discussed energy roadmap is an example of the terminology and the layout of a typical energy roadmap from literature. The framework developed in Chapter 3 of this study will be summarised in a roadmap for the framework to see the start and end goals.

2.4 Efficient technologies

2.4.1 Emerging ironmaking technologies

Hasanbeigi, Arens and Price [47] did a study to consolidate all information available on emerging energy efficient technologies. The paper covers the main emerging ironmaking

technologies of which only a summary of the commercially available technologies will be discussed in the subsections that follow. The remaining processes in the paper are still in design, demonstration or pilot stage. [47] For energy management on a steel plant, it is good to know what the emerging technologies are.

COREX® process

The COREX process is a two-stage direct smelting process. It consists of melter-gasifier and direct reduction furnace that reduces lump ore using reducing gas from the melter-gasifier [48]. The baseline is the traditional BF-BOF ironmaking process. There are some limitations to the technology, but the advantages of this technology regarding energy and operational cost savings are the following [47]:

- Fuel savings of about 18% and oxygen reduction of about 13%;
- An approximated 20% lower CO₂ emission level; and
- Reduced investment and operation cost.

The technology has not been implemented widely in industry [47].

FINEX® process

The FINEX process is in principle the same as the COREX process except that the FINEX process can directly use sinter feed, which is fine ore [49]. A FINEX plant consists of a melter-gasifier and fluidised beds in series in which the fine ore is reduced in multiple stages. The advantages of the technology towards this study are the following [47]:

- Capital cost 20% lower than a traditional blast furnace;
- Production cost 15% lower;
- Lower energy use; and
- High value export gas.

The process is commercial, but has not been adopted by many plants [47].

Coal-based HYL process – a syngas-based DRI plant

With this technology, iron ore is reduced directly using reducing gases. The reduction takes place in a solid-gas moving bed reactor. Reducing gas is produced in a type of coal gasifier that can gasify basically any carbon-bearing material. The main advantages towards energy savings and operational cost reductions are that [47]:

- Low-quality coals can be used; and
- Hot DRI is produced that could in turn be charged to an EAF that can result in large energy cost savings.

This technology is available, but has a low adoption rate across the industry [47].

Coal-based MIDREX® process

This technology uses a natural gas-based furnace to convert iron oxides into DRI. The Jindal steel plant in India has contracts to use the MIDREX technology. AMSA Saldanha Works also uses this technology to produce DRI. Figure 29 shows a schematic of this process [47].

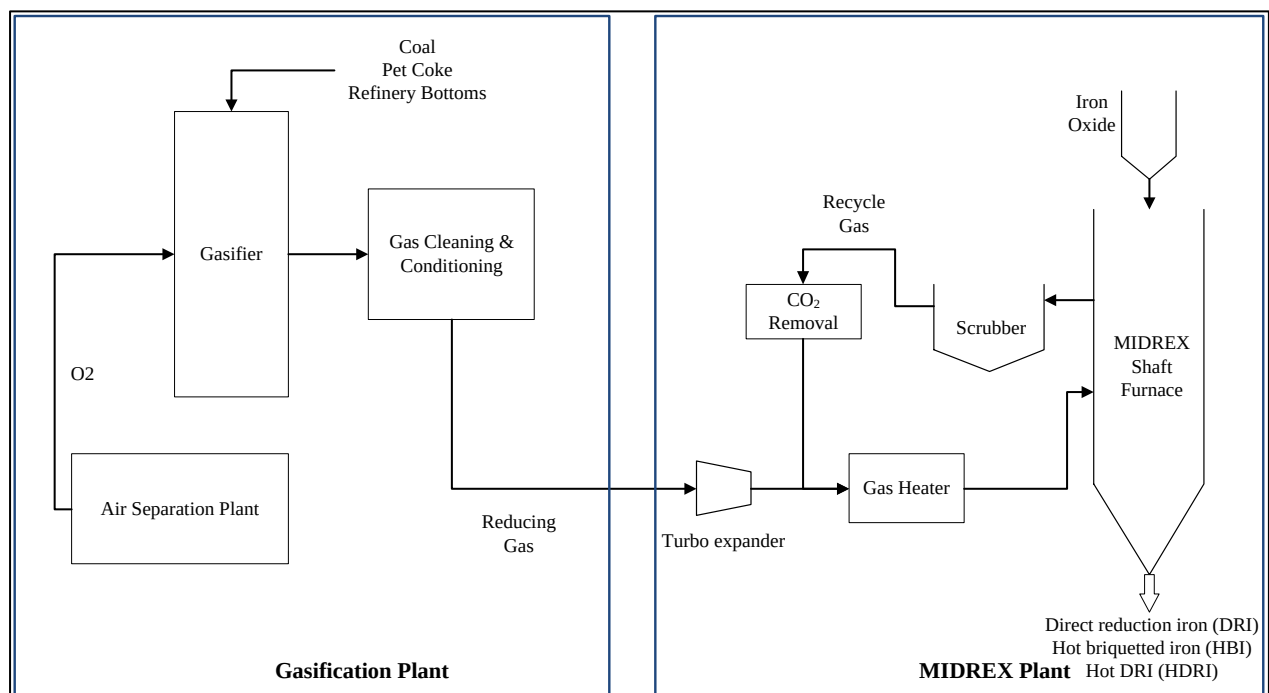


Figure 29: Coal-based MIDREX process¹⁶

Advantages of this technology towards energy efficiency and cost savings are that [47]:

- DRI can be hot-charged into the EAF for steelmaking;
- The specific capital cost is lower than for an integrated steelworks; and
- Air emissions are less.

¹⁶ Adapted from [46]

Low CO₂ emission technologies for the iron and steel industry

XU and Da-qiang [50] conducted a study on low CO₂ emissions. The author states that is important to employ energy savings/recovering technologies in industry. The technologies are categorised in two sections, namely [50]:

- Short-term approaches; and
- Long-term approaches.

In this specific paper, the short-term CO₂ reduction approaches include the following [50]:

- Coke dry quenching approach; and
- Top-pressure recovery turbine (TRT) approach.

The TRT technology is widely adopted due to its excellent operational reliability. Power is generated with this technology. In Japan and Korea, from 40 kWh to 60 kWh of electricity per tonne of pig iron can be produced. In Japan, around 8% of all electricity consumed on steelworks is generated using TRTs [50].

In South Africa, none of the steelworks use TRTs and the off-gases are used for less effective processes. The reason for this is the capital needed to install a TRT. With the current economic constraints, the payback period is too long.

The other technologies discussed in the study by Hasanbeigi et al. [47] are CO₂ capture and storage. However, these technologies are not important for this thesis topic, which is reducing specific plant electricity costs with operational changes.

Current situation in China for measures taken to save energy in the iron and steel industry

The study conducted by Guo and Fu [51] focuses on the measures taken for energy savings in the Chinese iron and steel industry. The authors list several measures and they will be discussed shortly in the subsections that follow [51].

Expanding dry quenching technology

When adopting coke dry quenching technology, up to 80% of the sensible heat from hot coke can be recovered. It is estimated that 1 t of hot coke can generate from 0.45–0.6 t of steam.

The steam can be generated at a pressure of about 3.9 MPa. The technology is therefore environmentally friendly, energy efficient and pollution-free [51].

Expanding TRT technology

A turbine generator group can be used to generate power with the energy of pressure at the top of a blast furnace. The power normally generated equals the power energy consumed when coal gas pressure at the top of the furnace is around 80 kPa. The economic return from using this technology can increase when the pressure of the coal reaches 100 kPa or even 120 kPa. It is estimated that up to 30% of the energy can be recovered from blast air. In China, this technology is widely used and adopted at steelworks [51].

Expanding the technology of PCI for the blast furnace

The use of PCI for blast furnaces is an innovation that is very important to the steel industry. It is an incentive to prompt more energy structure optimisation, energy saving and reducing costs. With PCI, coal can replace coking, which is expensive and not always easily available in many countries [51].

Eliminate low-level equipment and introduce new technology

In the study conducted by Guo and Fu [51] it is noted that the energy consumption of small iron and steel producers was 1.5 times higher than for medium- to large-scale plants. This is mostly due to old equipment. In China, the COREX process is motivated and adopted at many steelmaking facilities [51].

All the opportunities listed in this study focus on new technologies that need to be implemented. This is important in a country where the steel industry has been growing for the past decade. In a country such as South Africa, where there is little to no capital available for new equipment, alternative ways need to be researched and adopted.

Review

This technology is commercially available at the current stage. These technologies listed summarise the important commercially available technologies as replacement for the very energy-intensive blast furnace. However, these technologies can be used when a new plant is developed or an existing facility expanded. The cost of a new plant is immense and the capital needed to buy these technologies is expensive.

There is definite operational cost efficiency as well as energy efficiency when using alternative technologies. For the purpose of this study, it is important to understand that there are other technologies available and that when a plant is designed, these technologies can be considered.

Reduction in energy consumption in the Indian steel industry

Energy efficiency in steelmaking has three main aspects, namely [52]:

- Minimising energy requirements for the process;
- Minimising energy losses; and
- Maximising energy use.

Samajdar [53] states that for energy efficiency in current steelmaking facilities, the focus should be on better operational management towards maintaining uninterrupted process flow. The author also includes the incorporation of continual technological innovation. According to Samajdar [53], the future of energy efficiency in the steelmaking industry must be focused on adopting new energy efficient technologies and shifting towards more continuous operations.

Review

Operations management will briefly be discussed in this thesis. To improve productivity, yield and energy consumption, incremental changes to operation management are critical. Samajdar [53] states:

“The future of energy efficiency in the steelmaking industry must be focused towards the adoption of new energy efficient technologies and shifting towards more continuous operations.”

This statement justifies the study for operational changes rather than new technology, which is expensive and has long payback periods.

2.5 Available funding models

2.5.1 12L

As already discussed in previous sections, South Africa has energy-intensive industries. Several measures have been developed to decrease the energy intensity. These measures can be called incentives and are managed by organisations such as [54], [55]:

- Eskom,
- The Department of Trade and Industry; and
- The South African Revenue Services (SARS).

There are several incentives that can be implemented in the industry in South Africa, of which the steel industry forms part. One of these incentives is the 12L tax incentive. Section 12L of the Income Tax Act, 1962 (Act No. 58 of 1962) allows for achievable cost savings. These cost savings are in the form of a tax reduction. This incentive came into operation on 1 November 2013. To claim this incentive, a baseline and an assessment period need to be established. The data sources need to be compliant. The results need to be calculated and reported by a South African National Standards Association accredited M&V team [54].

The South African National Energy Development Institute (SANEDI) has to ensure that this incentive is effective and credible. The only exclusions and limitations to this incentive are the following [54]:

- Captive power plants with efficiencies less than 35%; and
- Concurrent benefits, such as an Integrated Demand Management (IDM) funded project.

2.5.2 12I

12I is a tax allowance incentive that offers support for capital investment and training. The goal of this incentive is to improve labour and manufacturing productivity in the South African environment. The incentive allows for both greenfield and brownfield investments. Greenfield investments are in new plants with no limitations from previous investments. Brownfield investments are made on existing plants and can include mergers and upgrades [54].

The funds for this incentive are received from the Department of Trade and Industry. The assistance in capital is obtained via a tax deductible as a percentage of the total qualifying asset. These capital investment allowances are summarised in Table 9 [54].

Table 9: 12I capital investment [54]

Type of project	Qualifying assets (%)	Maximum (R)	Criteria status
Greenfield	55%	R900 million	Preferred
Greenfield	35%	R550 million	Qualifying
Brownfield	55%	R550 million	Preferred
Brownfield	35%	R350 million	Qualifying

To qualify for this incentive, several requirements need to be met in South Africa such as creating direct employment and providing skills development. [54]

2.5.3 Manufacturing Competitiveness Enhancement Programme

The Manufacturing Competitiveness Enhancement Programme offers cash grants to the manufacturing industry [56]. The objectives of the programme are [54]:

- Promoting enterprise competitiveness;
- Sustaining employment;
- Investing in process and equipment;
- Maximising value addition;
- Stabilising and increasing productivity; and
- Reducing the environmental impact.

For the purpose of this thesis, only the general guidelines are discussed. The Department of Trade and Industry funds this programme and it can be divided into two sections [54]:

- A production incentive; and
- An industrial loan facility.

To qualify for this programme, a company needs to adhere to a list of requirements [54]:

- It must meet the minimum investment criteria;
- It must be at least a Level 4 B-BBEE company;
- It must only have applied for funding once in a two-year period;

- It must maintain average employment levels throughout the company; and
- It must have been a legally registered South African company for at least 12 months.

2.5.4 IDM

IDM is an Eskom initiative that offers financial incentives for offsetting electricity consumption from the network [57]. The objective of this initiative is to improve the electricity crisis in South Africa.

The IDM model works with a R/MW energy savings benchmark. Standard offer and performance contracting are no longer available as part of IDM [54].

Two further funding models that are available are the NCPC-SA and the Green Energy Efficiency Fund. The NCPC-SA programme promotes the implementation of resource efficiency and cleaner production. The programme funds energy efficiency projects and presents case studies. The Green Energy Efficiency Fund is a loan facility with R500 million in available funds for energy efficiency investments. They lend money at prime less 2% over a period of 15 years [54].

It is important to understand and be aware of the available funding models in South Africa. When electricity cost saving projects are identified, an application can be done to obtain funding. Budge, Booysen and Vosloo [54] developed a process diagram to assist with choosing a funding model for a specific application or project. The process diagram is displayed in Figure 30.

Review

These funding models are important; however, for the framework developed in this study, only IDM and 12L funding will be used. The value of the study by Budge et al. [54] is the fact that a model has been developed to identify the type of funding model that has to be chosen for specific projects. The study does not incorporate the selection model into a framework for the steel industry specifically.

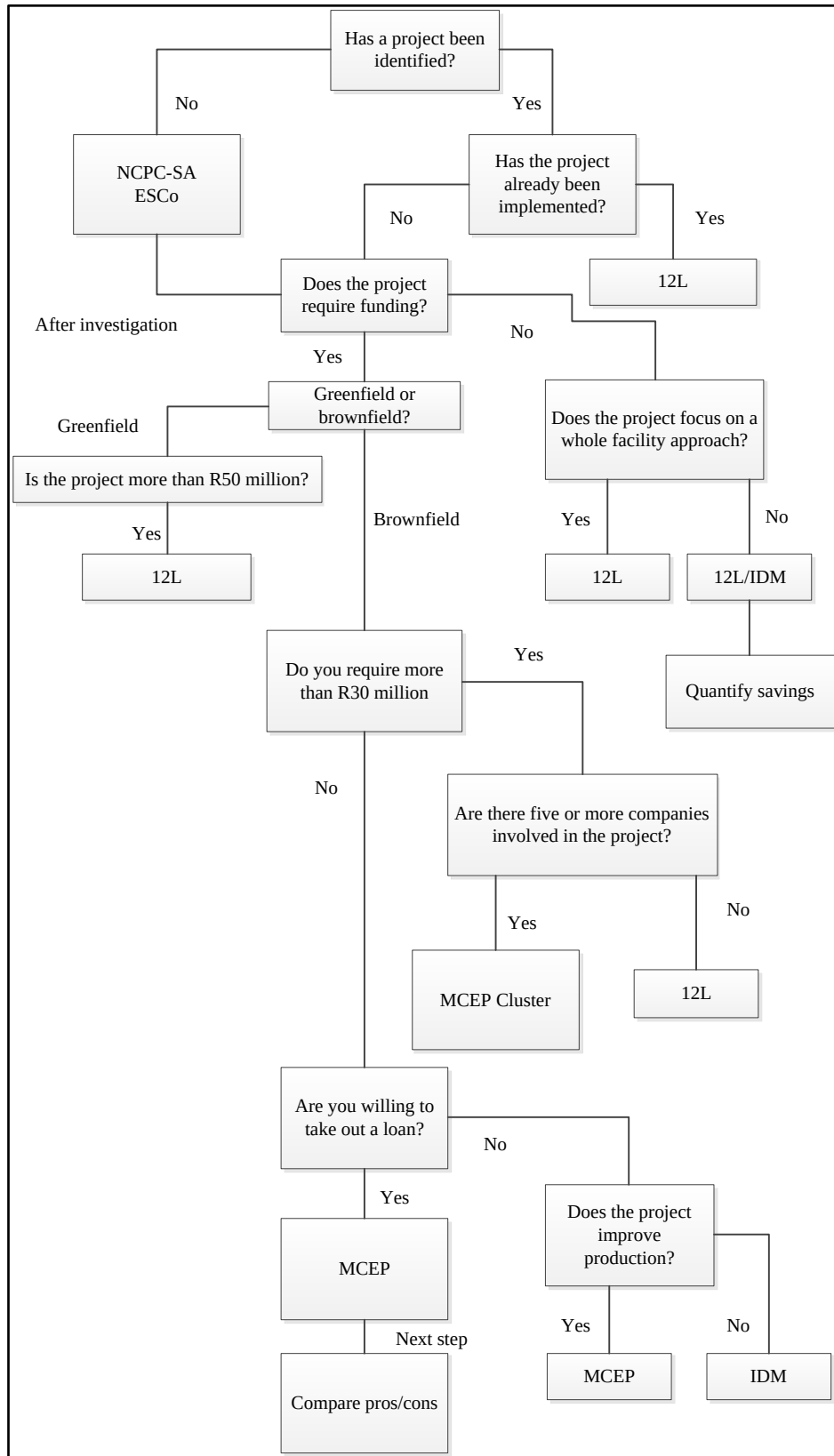


Figure 30: Funding model selection diagram [54]

2.6 Benchmarking in the steel industry

The Canadian Steel Producers Association conducted a study on energy benchmarking in the steel industry. The study focused on a methodology for benchmarking and the results thereof.

Intensity indicator

Energy intensity benchmarking needs an indicator that is dependent only on the energy which is consumed by the process or plant being evaluated. It is important that the indicator is only reacting to technology and practice changes within the boundary specified for the specific process [58].

External differences such as the way that the electricity purchased is generated will not change the efficiency in which energy is consumed. The energy intensity indicator must also factor out sales and purchases. All material to be produced and processed must be considered at the same energy intensity as that of the plant being evaluated [58].

An energy indicator is conveyed in energy per unit of product. It is usually expressed in MJ/t. It is important to note that the energy intensity indicator is based on the lower heating values for the fuels consumed. The energy intensity indicator must not be confused with actual plant energy consumption. Using the indicator is solely for comparative purposes for relative performance of similar processes [58].

Energy efficient technology is an important part of plant energy efficiency. However, in some instances, other factors can also have a large influence such as [58]:

- Climate;
- Maintenance of equipment and process technologies;
- Product mix; and
- Better use of equipment.

The study focuses on Ecotech technologies, which are energy efficient technologies in the Canadian steel industry, or technologies which have been recommended. Different plants and plant configurations were investigated to determine how applicable the energy intensive indicators are [58].

Data collection

The data required for calculating energy intensive indicators requires [58]:

- Actual energy consumption data; and
- Production data.

Both these data sets need to be for the same period. The data in this study was obtained from the plants in the form of reporting spreadsheets. These spreadsheets calculate the energy intensity indicators for each of the processes as the data is entered. This enables the plant energy champion to identify results that seem out of the expected range [58].

For energy benchmarking, plants need to be defined by the processes used to produce a specific product. For the results in the report, the energy intensity indicator is expressed in unit of energy (MJ) per tonne of plant product. Figure 31 is an example of a graph comparing electricity intensity indicators for different plants [58].

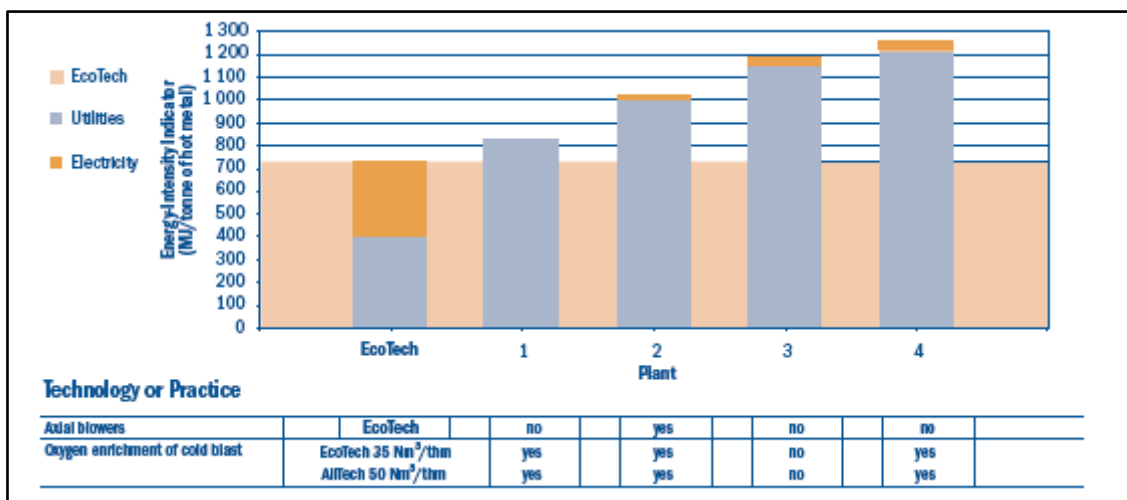


Figure 31: Energy intensity for the blowers supplying the air for the blast furnaces [58]

Review

In this study, most of the processes found in the South African steelmaking industry are discussed. However, it is only necessary to understand the methodology followed to benchmark energy usage in the Canadian steel industry. Furthermore, this is a case study where electricity intensive indicators comprise the benchmarking methodology.

2.7 Conclusion

Throughout this chapter, the existing framework and energy management strategies were reviewed. The energy cost towards the steel industry in South Africa was also reviewed. The shortcomings were identified in existing research and Chapter 3 can continue with the development of the newly developed framework.

Chapter 3: Developing a novel framework for reducing electricity costs



Rolling of casted steel¹⁷

¹⁷ Feingold Research, “Allianz und Salzgitter vor Hürden,” Feingold-research, 5 August 2016. [Online]. Available: <http://www.feingold-research.com/2016/08/allianz-und-salzgitter-vor-huerden/>. [Accessed 25 October 2016].

3.1 Introduction

The objective of the study is to develop an operational framework for the South African steel industry to obtain electricity cost savings. Chapter 3 focuses on developing the framework. The framework is structured from different sections to satisfy the objective. These sections are made up off the main subsections developed in the framework, namely:

- Facility engagement;
- Role players;
- Operational flow; and
- An operational framework roadmap using the ISO 50001 methodology.

These subsections are incorporated into one framework to satisfy the objective of this study. The novel contributions that need to be satisfied are:

- **An operational framework for electricity cost reduction in the South African steelmaking environment.**
- **Identification methodology of operational electricity cost reductions in the South Africa steel industry.**
- **Facility prioritisation model for the implementation of operational changes to reduce electricity costs.**
- **Operational analysis method for the implementation of operational changes.**

The framework for operational changes to reduce electricity will from now on only be referred to as the framework. The framework consists of several building blocks. Figure 32 shows the main overview of the framework, which will be discussed in the subsections that follow. The framework consists of six aspects, namely:

- Facility engagement and planning;
- Role players;
- Operational identification;
- System characterisation;
- System analysis; and
- Operational framework roadmap.

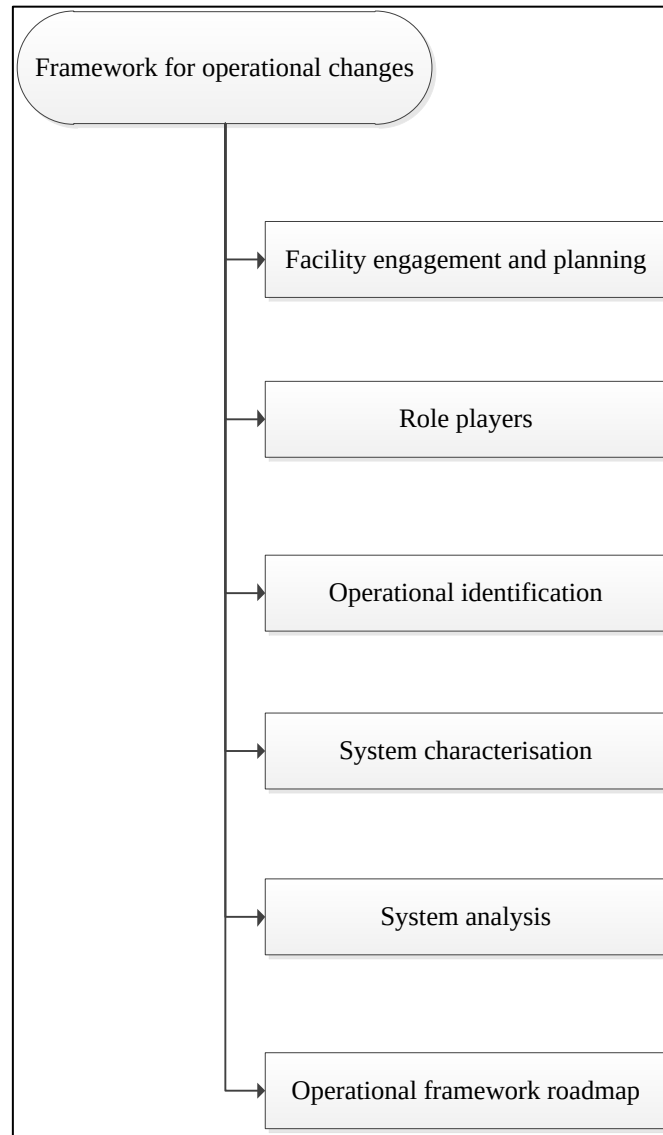


Figure 32: Overview of the framework for operational changes

Chapter 3 discusses the framework in detail to show the development thereof.

3.2 Facility engagement and planning

3.2.1 Top plant management commitment

The steelmaking facility needs to be fully engaged in the objective of saving costs by making operational changes. This part of the framework lays the foundation for the success of the framework. In all energy management structures and frameworks, it is important to have top management commitment. For the development of the framework, it is assumed that top management is committed to achieving energy savings and supports electricity cost savings specifically. Both case study plants discussed in Chapter 4 form part of a steelmaking group

under economic growth strain. The plants have a big drive toward cost savings and thus have a commitment from top management.

Top management needs to promote the set targets and support the initiatives to obtain these targets. The energy leader or energy manager form part of the plant's top management team. In many cases, this energy leader is part of the business improvement department and reports to the executive committee of the plant.

In South Africa specifically, the energy leader/manager does not form its own department in most cases. (In this study, the energy leader will only be referred to as the energy manager.) This makes it difficult for an energy manager who has limited access to resources that can identify, manage and implement projects. Figure 33 shows the flow of command from the energy manager down to the implementation of the project. This is the typical scenario for energy management in South African steel plants.

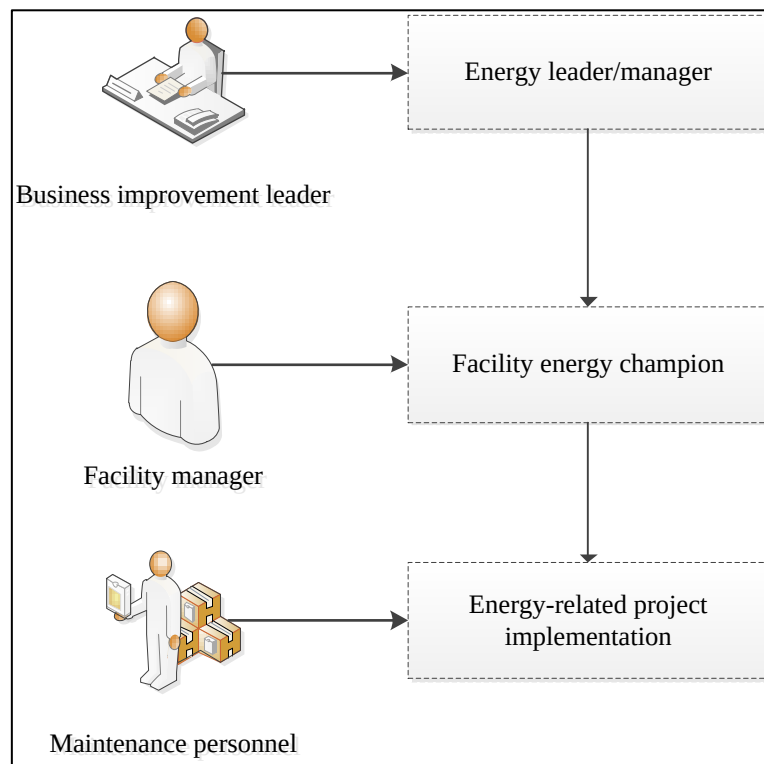


Figure 33: Current energy management operation in South Africa steelmaking plants

For instance, the energy champion on a specific facility can also be the manager of the facility. This means that his main objective is to meet production targets. The person to implement the energy-related projects is also responsible for the maintenance thereof. Therefore, that person's main goal will be to keep the facility operational.

Resources are needed who only focus on energy efficiency improvement and related cost savings such as optimising operations for electricity cost savings. This will, however, result in additional labour costs. It is therefore important to use available resources effectively and cut on time-consuming tasks. This framework will improve the efficiency of available resources and streamline the energy improvement task on steelmaking plants.

3.2.2 Facility-specific energy champion

This study specifically focuses on promoting an effective framework for facility energy champions to obtain electricity cost savings through operational changes. Appointing an energy champion is critical. It is important that the energy champion should be competent with the following aspects:

- Have a strong drive to promote energy savings;
- Be familiar with the plant regarding production and energy use;
- Have good support from staff on the facility; and
- Be in good standing with top management to receive support.

On steel plants in South Africa, it happens that the person appointed as the energy champion is also the facility manager (as shown in Figure 33 and discussed in the previous section). The facility manager is first and foremost responsible for production as a KPI to improve and report on. Therefore, energy KPIs are neglected and do not receive adequate attention.

Operational changes are an aspect that a facility manager, who focuses on production, may be hesitant and reluctant to focus on. As discussed in Section 2.3.5, operational changes may result in quick savings without requiring large capex. However, these opportunities need to be identified and the facilities prioritised to implement them.

Appointing an energy champion is therefore a critical process. It is included in the framework to assist in the appointment process. For this study focusing on the steelmaking industry, the tasks and responsibilities as summarised in Table 10 are important for a facility-specific energy champion.

Table 10: Energy champion tasks and responsibilities

Responsibility and tasks	Description
Interface	Contact between energy committee of the plant's top management and the specific facility
Information	Coordinate all the information regarding energy to the facility
Energy best practices	Promote energy best practices
Energy roadmap	Implement the plant energy roadmap
KPIs	Coordinate the facility-specific energy KPIs
Identify	Identify potential energy savings
Prioritise	Prioritise economically feasible projects
Contracts	Understand energy contracts
Funding	Monitor funding for potential energy saving projects
Changes	Monitor changes for energy savings

The ten tasks and responsibilities listed in the table are important to consider when appointing a facility-specific energy champion. This person will be the user of the framework to obtain electricity cost savings. This study will incorporate these tasks listed to form a framework focusing on electricity cost savings through operational changes.

3.2.3 Scope and boundaries of the framework

After top management has committed to electricity cost savings through process changes, the scope and boundaries of the framework need to be identified. The scope of the framework is to continually reduce electricity consumption of facilities through operational changes and optimisation.

The framework is focused on electricity consumption of steel plants and reducing electricity costs. The reason being the large cost contribution electricity has as part of the total energy cost. The contribution of electricity is usually larger than that of gas for South African steel plants. Although coal is the largest contributor to energy costs, a large portion of the coal is directly used in the process of making steel.

Electricity intensity and consumption are major concerns in the South African steelmaking environment. Electricity is expensive and a cost risk for large steelmaking plants. It is used as energy source in most facility processes. Figure 34 summarises the scope and boundary of the study as discussed in this section.

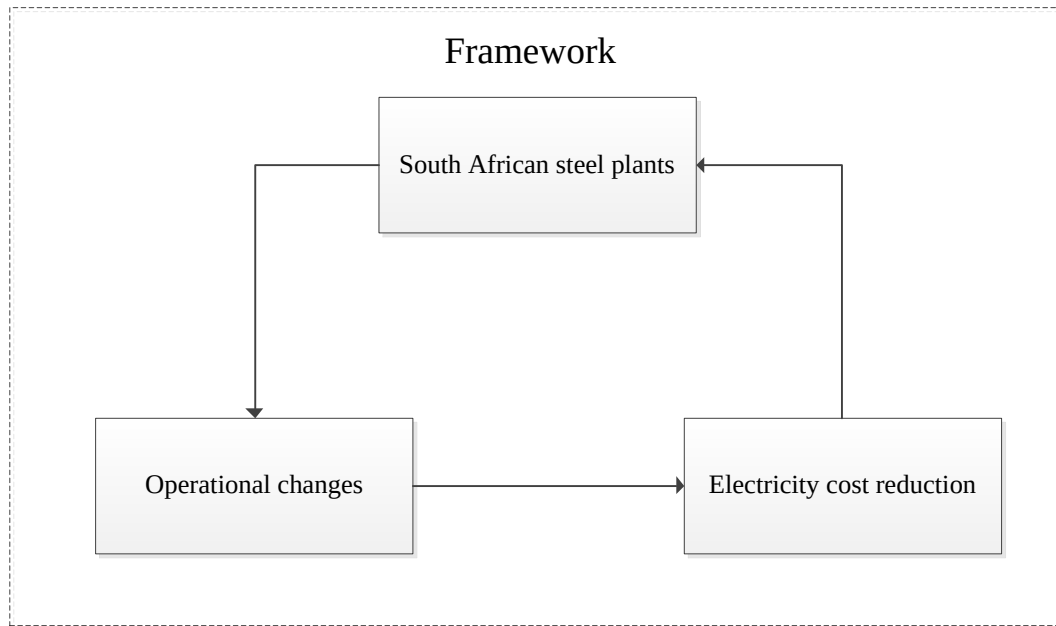


Figure 34: Scope and boundary of the framework

3.3 Evaluate the role player's involvement and requirements

3.3.1 Typical role players

The role players are the institutes involved in the framework to obtain electricity cost savings. In this section, all the role players will be discussed. The role players included in this section of the framework is:

- The steelmaking facility;
- Government rules and regulations;
- Eskom;
- Section 12L tax incentive; and
- M&V.

Figure 35 shows the process flow for the role players involved in obtaining electricity cost savings through operational changes. The tasks of the role players will be discussed further in Section 3.3.

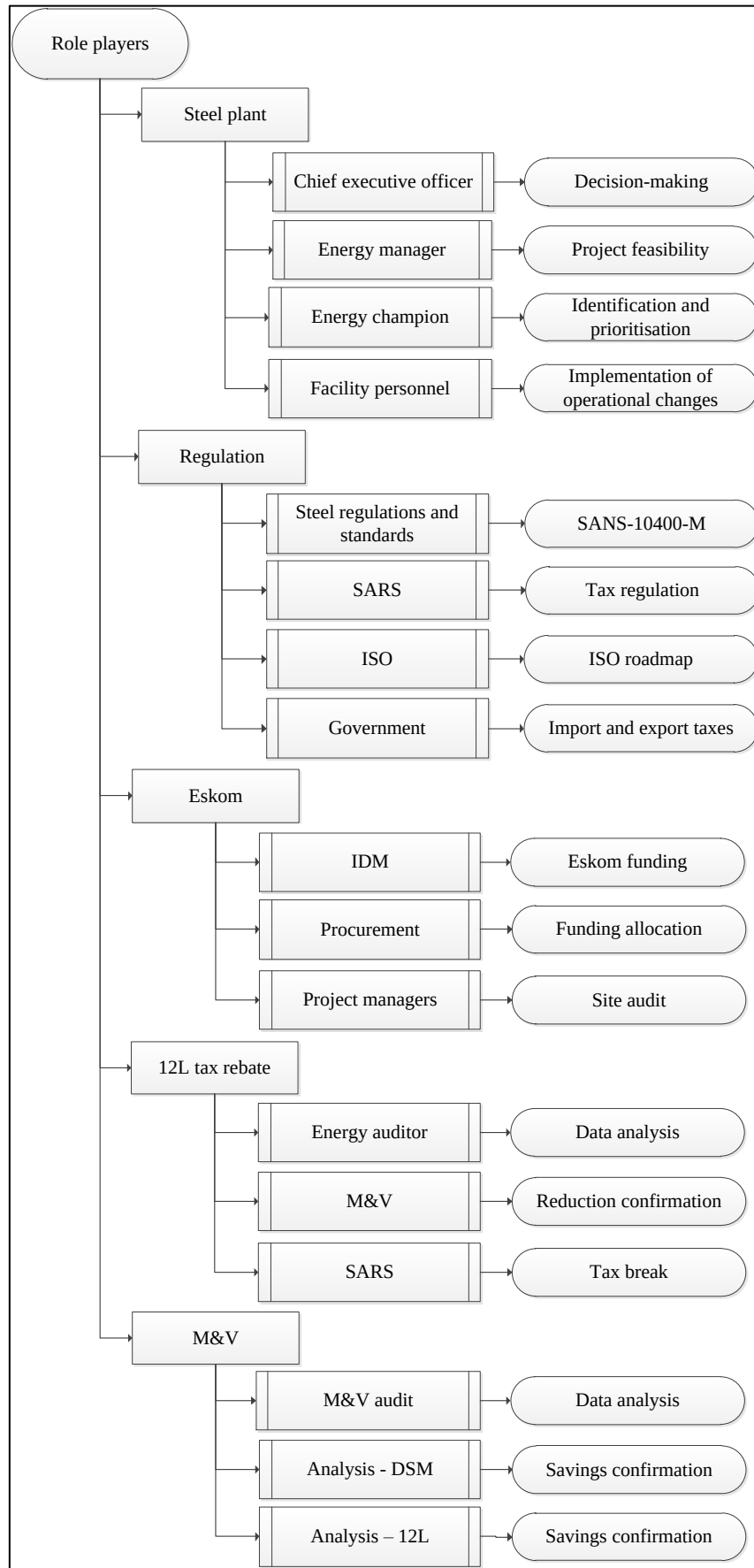


Figure 35: The role players related to electricity cost savings through operational changes

3.3.2 Steel plant

The role and engagement of the steelmaking facility have already been discussed in Section 3.2. Plant management needs to be committed to realise operational electricity cost savings. Management is responsible for approving the feasibility of projects from a financial perspective. In this section, the requirements to understand the framework and evaluate the results from the plant perspective will be discussed.

Energy purchasing

The energy purchasing contracts need to be understood by all relevant stakeholders, which include the contracting committee and the energy champion. It is necessary for the energy champion to engage with the contracting committee and both parties should:

- Understand the contract;
- Know the flexibilities in the contract; and
- Be aware of forecasts such as electricity price increases.

With the appropriate knowledge, the energy champion can align the production planning for operational optimisation and make changes to achieve reduction electricity costs. When developing a framework for operational cost savings, the following points of a typical contract need to be understood:

- Maximum and minimum limit of the energy demand such as maximum demand on the Eskom electricity purchase contract.
- Regulated or deregulated market. A regulated market has steady prices while a deregulated market is subject to spot prices.
- Power factor and reactive power. If a plant has no protective equipment to mitigate the charge, it might increase the penalty charge on the bill.
- Tariff structure. The TOU tariff structure allows for different costs of electricity at different periods of the day. The purchased electricity is more expensive during the peak times of the day.
- Marginal energy cost. The amount of fixed energy cost for a facility, even if the plant is switched off for a certain period.

Project evaluation

It is important for each facility-specific energy champion to be able to evaluate a project's feasibility in terms of technical impact and economical profitability. These aspects are particularly important for prioritising electricity cost saving initiatives and understanding the real impact thereof. Each steelmaking plant will have thresholds for specific financial parameters for a project to be considered economically feasible. It is also important to understand the plant cost benchmark and the marginal effect of a project.

As previously discussed, the energy champion needs to understand the energy purchasing contract. It is important to know the pricing mechanisms since they will affect the profitability of the project. The increase in energy prices also needs to be understood. If the project has a long implementation period, the savings can be absorbed by the increase in energy costs.

For an electricity cost saving project, the energy balance of the total plant needs to be understood. If a saving is achieved on one facility, the effect on the other facilities needs to be known. It has no advantage when saving in one place and overspending on another. The profitability for an electricity cost saving project can be evaluated using the following parameters:

- ROI in percentage;
- Simple payback period in years; and
- Net present value (NPV) in rand.

ROI

The ROI can be calculated using different methods. Normally it is calculated by dividing the gain year-on-year by the total investment amount to give a percentage per year. The ROI equation is shown below with Equation 2.

$$ROI = \frac{\text{Yearly projected gain}}{\text{Total investment amount}} \quad \text{Equation 2}$$

Simple payback period

This parameter is a simplified estimate of the profitability of a project. It is calculated using the total amount to be invested divided by the gain year-on-year. It is important to know that this calculation does not incorporate taxes, inflation and depreciation. The simple payback period equation is shown in Equation 3.

$$\text{Simple payback period} = \frac{\text{Total investment amount (R)}}{\text{Yearly projected gain (R/year)}} \quad \text{Equation 3}$$

NPV

The NPV value estimates the net value a particular project entitles for a company. The value is calculated by considering the free cash flow and the cost of capital. NPV is a measurement of the profitability of an undertaking. It is calculated by subtracting the present value of cash outflows from the present values of cash inflows over a period.

It is important for the energy champion to understand the economic feasibility of a project. The energy champion needs to apply for funding, whether it is capex or opex. The appointed person will need to know if an initiative for electricity cost savings is feasible or not.

Potential funding and subsidies

The role players who can fund projects will be discussed in more detail in Section 3.3.4. Many steel plants have access to private as well as public funds, which can include incentive loans or national government grants. In Chapter 3, a systematic way to use funding specifically for the South African steel industry is developed. This forms an important part of identifying and prioritising electricity cost saving projects.

For the energy champion, it is important to understand the sources of funding. In general, there are three sources to investigate and approach:

- Governmental banks;
- The National Department of Energy; and
- Utilities providing the plant with services.

In South Africa, it is important to apply well in advance for any available funding since it may take a considerable amount of time to process and consider the application. The funding discussed in this thesis is focused on government-owned funding available in South Africa.

Performance monitoring

Establishing KPIs

Energy-related KPIs is an indicative factor that the plant acknowledges energy as a manageable cost driver. Establishing KPIs differs from one facility to another and depends on various factors such as:

- Internal power generation;
- Electricity grid stability; and
- The type of facility.

It is the responsibility of the energy champion to identify facility-specific KPIs. The energy champion, together with the energy manager, needs to decide on the frequency of reporting on KPIs. A facility might have more than one set of KPIs that may differ on the goal of reporting. The top management of the plant may require a different set of KPIs than the facility manager and engineers.

An easy-to-use guide is developed to assist the energy champion on which facility-specific KPIs to measure and report on:

1. Identify a possible KPI.
2. Identify the unit for the KPI such as kWh/t.
3. Rate the importance of the KPI.
4. Determine how the KPI is measured.
5. Determine the frequency of reporting.
6. Identify responsible person for KPI tracking.

Table 11 shows the critical KPI evaluation and selection question set. One of the finishing mills, namely the hot strip mill, is used as example.

Table 11: KPI critical selection table

What is the KPI?	Which unit will it be measured in?	Why is it important?	How is it measured?	Frequency to be reported? And how?	Who is responsible?
Specific electric energy consumption at blast furnace.	kWh/t	Electricity is an important cost driver for the blast furnace.	There is specific appropriate metering.	Weekly, to be discussed by hot strip mill management. and Monthly, during plant energy team meeting.	Hot strip mill energy steering committee member.

A rating matrix is developed to rank the identified KPIs from most important to least important. The ranking is based on the influence that the KPI has on electricity cost savings. The easy-to-use COWS method is used:

- C – Criteria;
- O – Options;
- W – Weights; and
- S – Score.

Table 12 show an example developed for the COWS method. The different options for KPIs are shown in the top row. Each option has a rating and a score. All the KPIs are measured against the criteria as shown in the far-left column. Each criterion has a weight next to the criteria. This means that each option has a rating of how relevant the KPI is to the criteria. The score is then calculated using Equation 4.

$$Score = Rating \times Weight \quad \text{Equation 4}$$

Table 12: COWS method for easily prioritising between different KPIs

Criteria	Weight	Electricity consumption versus production		Temperature versus production		Compressed air consumption versus production	
		Rating	Score	Rating	Score	Rating	Score
Electricity	3	3	9	1	3	2	6
Performance	2	2	4	2	4	2	4
Maintenance	1	1	1	3	3	3	3
Total			14		10		13

From Table 12 and Equation 4 it is identified that ‘electricity consumption versus production’ is the most important KPI. ‘Air consumption versus production’ follows, and finally ‘temperature versus production’. This example is for a specific facility and will change with the type of facility managed.

KPI and data tracking

It is important to track your KPIs and the data used for the KPIs. The tracking of the KPIs must include the following:

- Needs to cover all energy users and producers on the facility;
- Needs to include all the relevant data;
- Is available for reporting; and
- Ensures safe usage and storage of data.

The ideal tracking system collects and calculates KPIs, and generates reports automatically. An easy-to-use KPI tracking system is developed for the energy champion to use. The KPI tracking system flow consists of several steps, namely:

1. Ensure that electricity-consuming equipment measures correctly.
2. Collect meter readings on the local supervisory control and data acquisition (SCADA) for real-time monitoring.
3. Record all the relevant data to calculate the KPIs.
4. Analyse the KPIs daily and flag deviations from the target.
5. Monitor the KPIs on a continuous basis against the set target.
6. Investigate deviations in the KPIs against the set target.

The KPI tracking flow is indicated in Figure 36. It is important to understand the sequence of the procedure when tracking KPIs.

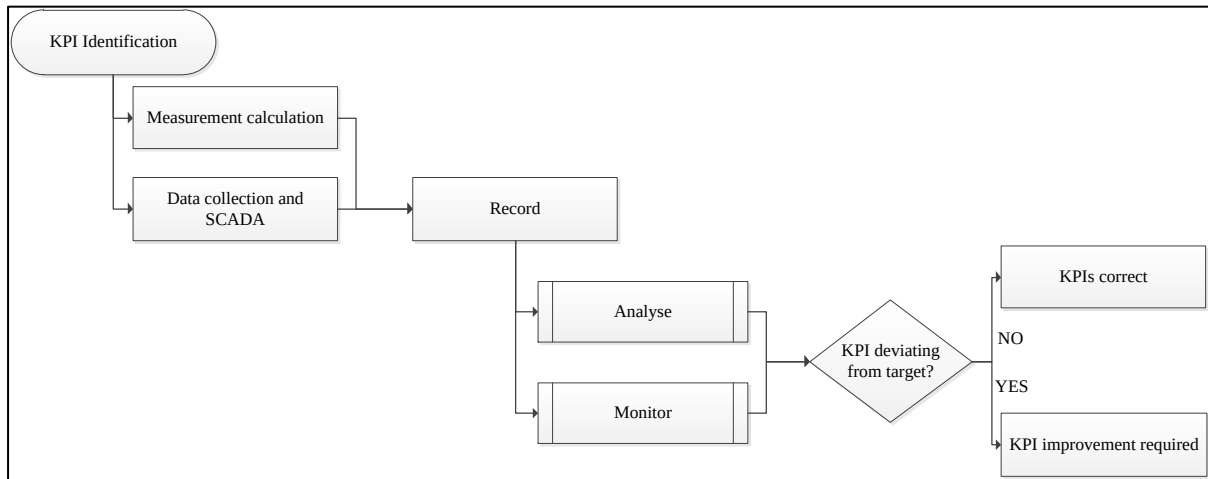


Figure 36: KPI tracking flow diagram

3.3.3 Regulations

Local and international regulations, and legislation can affect the steel industry drastically. As discussed in Chapter 2, there are several state-owned role players involved in funding energy efficiency projects and cost saving opportunities. These initiatives came to light because of:

- Company tax; and
- Eskom's electricity shortage.

One of the major apprehensions in the steel industry in 2016 is the possibility of the implementation of carbon tax in 2017. Carbon tax liability will greatly influence industries such as the iron and steel industry in South Africa. This tax liability for carbon emissions has not yet been implemented, but implementation is planned for 1 January 2017.

A plant with CO₂ emissions will be liable to pay R120/t for carbon emissions. One way to reduce carbon emissions is to improve energy efficiency. Therefore, there will be an increased awareness and effort to reduce energy consumption in the steel industry specifically.

3.3.4 Eskom

Eskom IDM funding can be used for identified DSM projects. There are three scenarios in which the DSM funding can be applied for (as shown in Table 13):

- Electrical energy efficiency;
- Electrical peak clipping; and

- Electrical load shifting.

Table 13: Scenarios for Eskom IDM funding

No.	Scenario	Type	Funding available
1	Electrical energy baseline is lowered for a 24-hour profile	Energy efficiency (EE)	IDM
2	Electricity use reduced in the Eskom peak periods by reducing the load	Peak clipping (PC)	IDM
3	Electricity use reduced in the Eskom peak periods and increased in the other time periods	Load shifting (LS)	IDM

Electrical energy efficiency is the ideal scenario. The total amount of electricity usage is reduced. Peak clipping is also a way to reduce electricity usage, but only for short periods. A peak clipping initiative depends on the willingness of the facility to compromise on production. The best initiative depends on the amount of savings that can be achieved from each of the scenarios.

For production-driven facilities, the load shifting initiative is feasible and an industry-preferred solution. Production needs to be scheduled to minimise the load in Eskom peak periods and to increase the load in the other periods, namely, standard time and off-peak time.

Load shifting is possible on plants where production processes are not limited to batch processes. With the current cost of electricity, implementing this initiative can result in large cost savings. Table 14 shows the cost (c/kWh) for electricity usage in South Africa for 2016 during different TOU periods.

Table 14: Tariff for electricity in South Africa in 2016

Cent/kWh (excl. VAT)	Winter	Summer
Peak	201.33	65.68
Standard	60.99	45.20
Off-peak	33.12	28.68

3.3.5 12L tax rebate

As discussed in Section 2.5.1, the 12L tax rebate incentive is applicable to large energy efficiency improvements. This initiative is recommended when large capital-intensive projects have been implemented, such as the refurbishment of a facility for more efficient

production with lower energy input. However, the rebate is not limited to large capital projects only. SANEDI focuses on funding smaller projects as well.

A 12L tax certificate allows the deduction of 95c/kWh from a company's taxable income. The effective rate is 37c/kWh. Applying for the tax incentive can only be done after the project has been identified, implemented and energy efficiency savings have been obtained. It is incorporated in the framework as a funding option since the benefit of claiming 12L may be substantial. The benefit of 12L is obtained in the next financial year after implementing the project.

There are three major requirements when deciding if a project can benefit from a 12L tax rebate claim, namely:

- Can the energy efficiency savings be conservatively quantified?
- Can compliance with the relevant regulations and standards be proved?
- Can the proposal pass auditors and a panel of experts from SANEDI?

If the plant energy manager is confident with these requirements, the steps for a 12L claim can be followed, which are summarised in Figure 37.

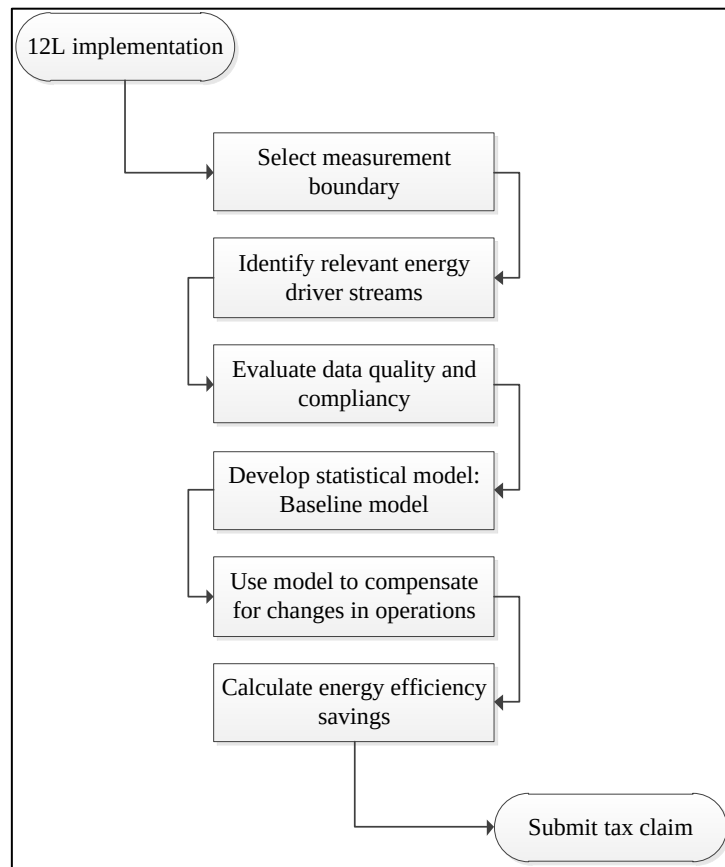


Figure 37: 12L implementation process flow

Although this initiative normally accompanies large investments for energy efficiency projects, it can also be applied for if process changes resulted in large energy efficiency savings. The application is a lengthy process, but has a large possible benefit. The benefit needs to be calculated and weighed against the investment and the possible gain. For this thesis, the 12L tax rebate forms part of the framework.

3.3.6 M&V

All the savings obtained need to be verified by an independent M&V team. These teams are third-party companies who authenticate the claimed savings. The baseline for each of the facilities needs to be signed off by the M&V team.

To measure and track the savings obtained, intensity KPI graphs can be used (as seen in Figure 38). It shows the lower intensity for the same amount of production between two different periods. This analysis will be done before and after the operational changes were implemented to understand if an electricity cost reduction was obtained. In Figure 38, the

trend lines are polynomial (Poly) for the period of data. The production tonnes used are tonne liquid steel equivalent (tLSE).

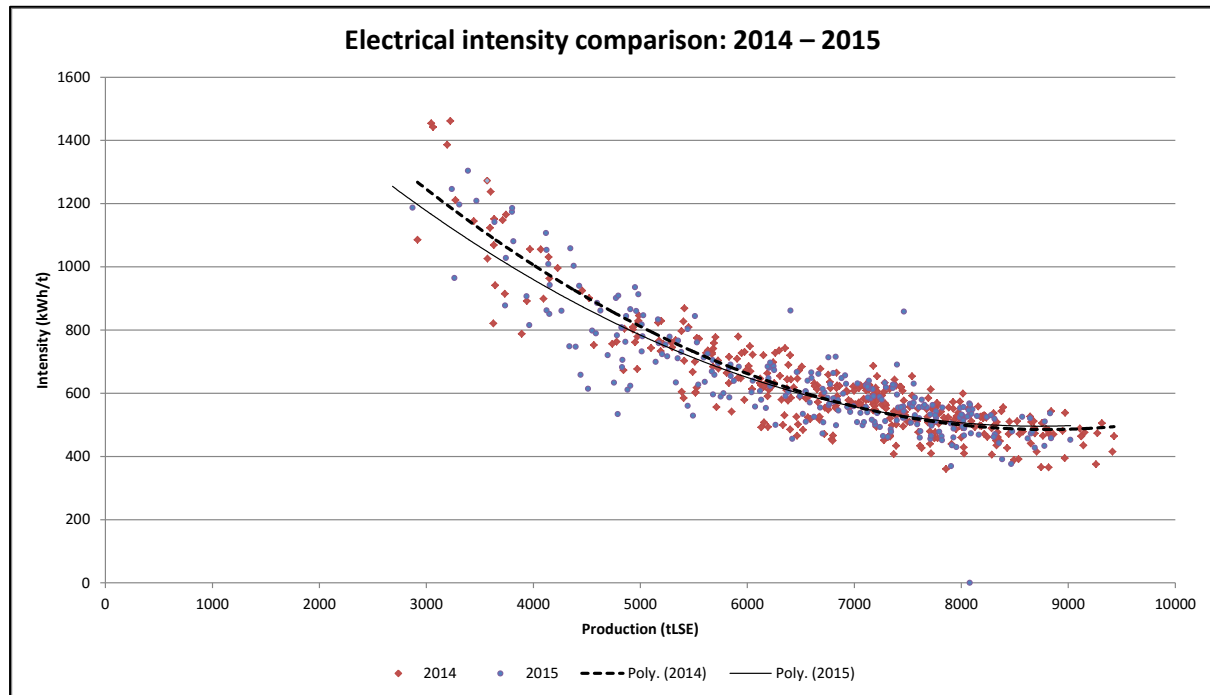


Figure 38: Intensity graph

3.4 Operational identification

The operational flow is an important part of the framework. In this section of the framework, the focus is on identifying processes, and characterising and analysing the system. Within the operational flow, the energy champion will be able to identify and prioritise electricity cost saving opportunities. This is the most technical part of the framework. Figure 39 shows the operational flow part of the framework.

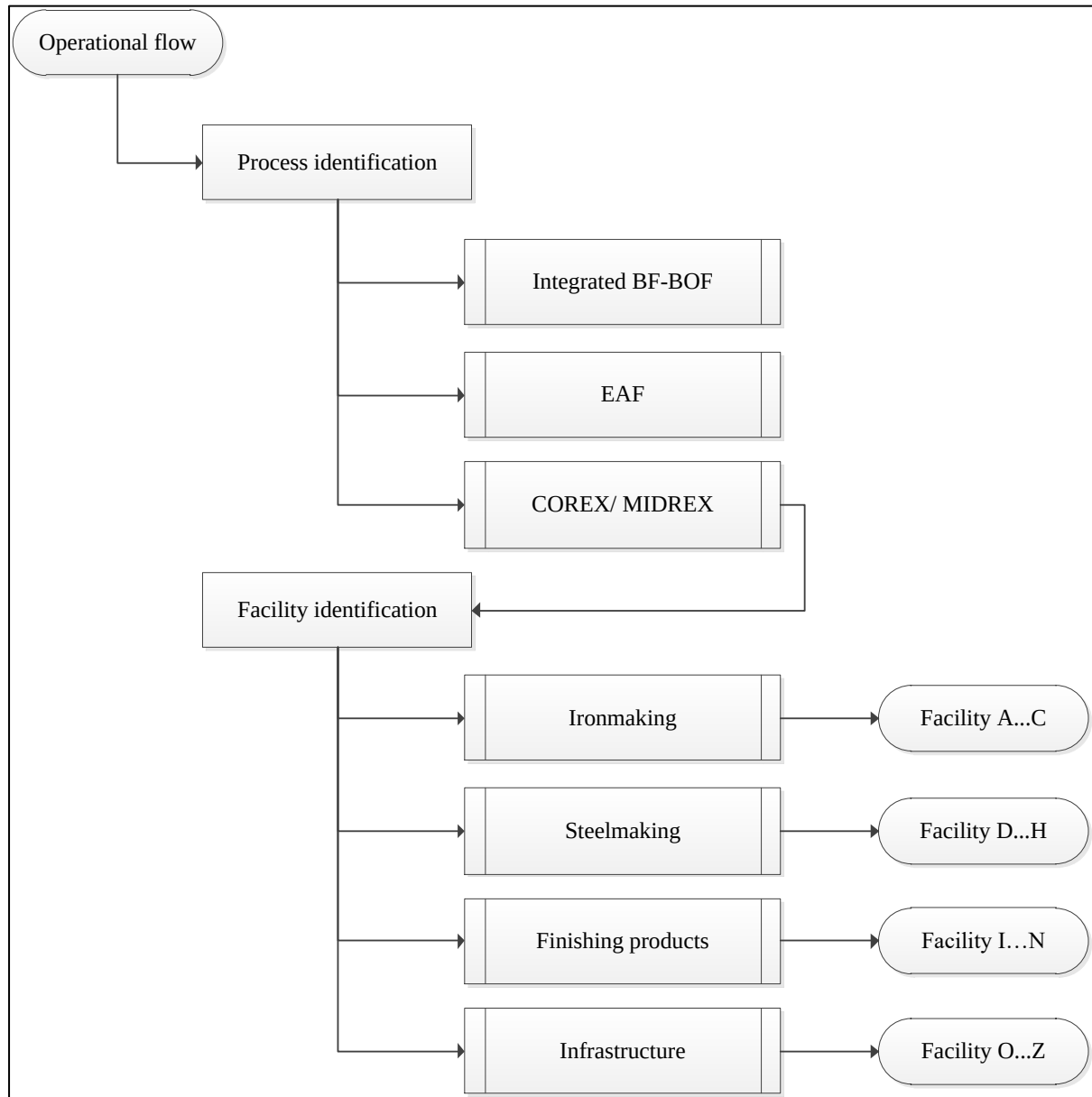


Figure 39: Operational flow

3.4.1 Process identification

From the literature review in Chapter 2, it was identified that there are different processes in the steelmaking industry. It is important to identify the type of steelmaking process at a particular plant. In the South African steelmaking industry, only two processes are currently used although there are three main processes that can be used, namely:

- The BF-BOF process;
- The COREX/MIDREX process; and
- EAF (decommissioned in 2013 in South Africa).

Historical data for plants could still show EAF as part of the plant's processes. Figure 40 shows the process identification step as part of the operational flow.

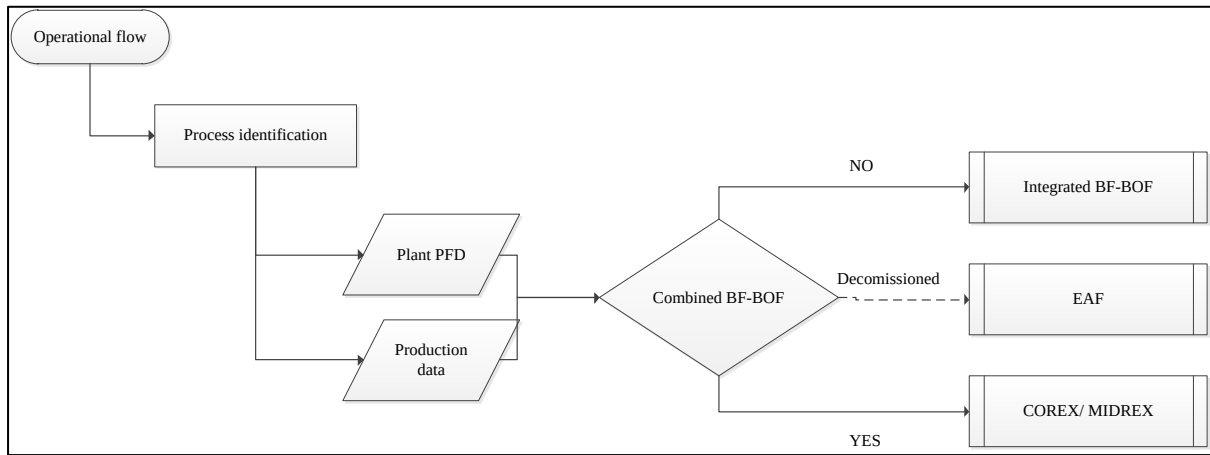


Figure 40: Process identification

In order to identify the process, a schematic of the steelmaking facility is required. A plantwide PFD or ironmaking- and steelmaking-specific PFD will be sufficient. If the blast furnace and the BOF are combined, it is known as the COREX/MIDREX process. If the blast furnace and the BOF are separated, it is known as the BF-BOF process. This is the simplest way to quickly distinguish between the two processes. The parameters required to identify the process are:

- A plant PFD; and
- Production data.

Process data is also preferred in the identification process. It may be possible that an EAF can be shown on a plant PFD, but has been decommissioned. Production data can be seen as a check on the PFD accuracy. The necessary layouts and parameters are discussed in Section 3.5.4 and Section 3.5.5 of the framework development.

3.4.2 Facility identification

Process and facility boundaries form part of the operational framework model. The boundaries for each facility in the steelmaking process need to be identified. For the operational framework, four primary facilities are identified for selection on a typical steel plant:

- Ironmaking;

- Steelmaking;
- Finishing products; and
- Infrastructure.

These four primary facilities were formulated from research obtained in Chapter 2 on steelmaking facilities in South Africa. Each of the primary facilities is made up of several secondary facilities. Figure 41 shows the facility identification step of the operational framework. The facilities may differ from one plant to another in:

- The quantity; and
- Type of facility.

The type of facility depends on the product that the plant delivers.

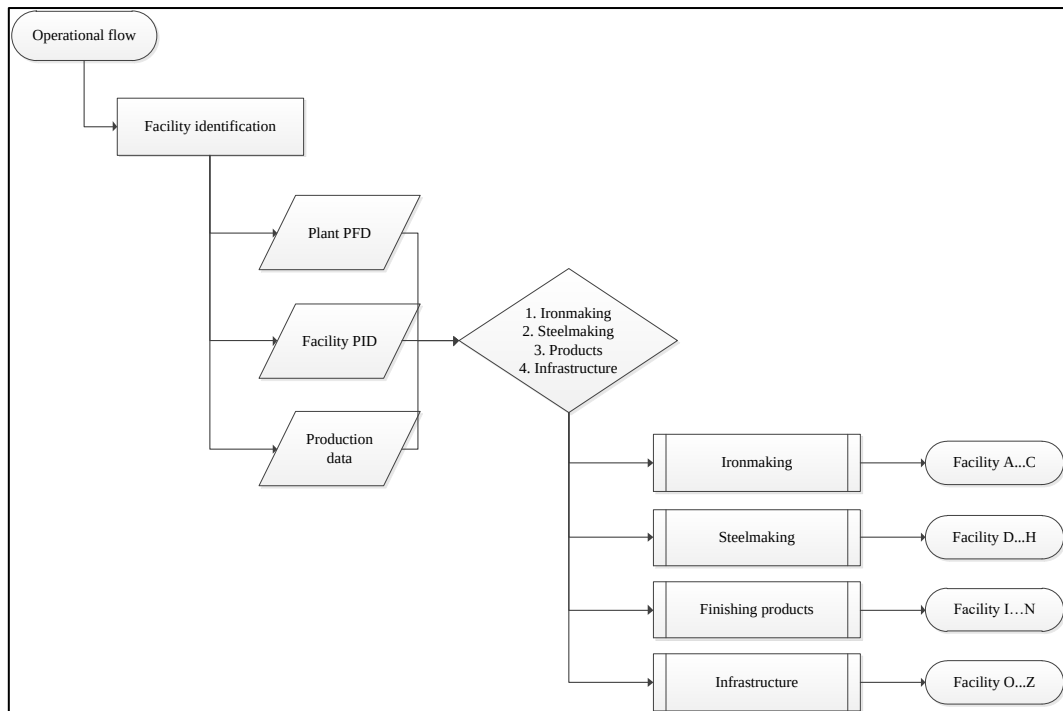


Figure 41: Facility identification

After the primary facility has been selected, the secondary facilities can be identified and named. From literature, the facilities in Table 15 were identified for the South African steel industry to be possible selection options in the operational framework.

Table 15: Facility identification sheet

Building block	Facility
Ironmaking	Sinter plant
	Coke oven batteries
	Blast furnace
	Direct reduction
Steelmaking	BOF
	Secondary metallurgy
	Continuous casting
Finishing products	Milling
	Rolling
	Pickling
	Galvanising
	Annealing
	Plating
	Coating
	Foundry
	Billet mill
	Bar mill
	Rod mill
Infrastructure	Boilers
	Power plant
	Compressed air
	Water treatment

From the information available in Table 15 and the operational flow, all facilities in the steelmaking plant can be identified and investigated. The required parameters to complete the facility identification are:

- Plant PFD;
- Production data; and
- Plant process and instrumentation diagram (PID).

It is necessary to have updated plant production data, proper plant PFDs and facility-specific PIDs. The identification parameters will be discussed further in Section 3.5.4.

3.5 System characterisation for identification and prioritisation

System characterisation forms part of the operational flow in the framework. With the system characterisation, all the necessary information is gathered to identify electricity cost saving opportunities. This section focuses mainly on the required system data and understanding operations as part of the framework. The information required to characterise the system can be divided into five categories. The breakdown of the information is presented in Figure 42, namely:

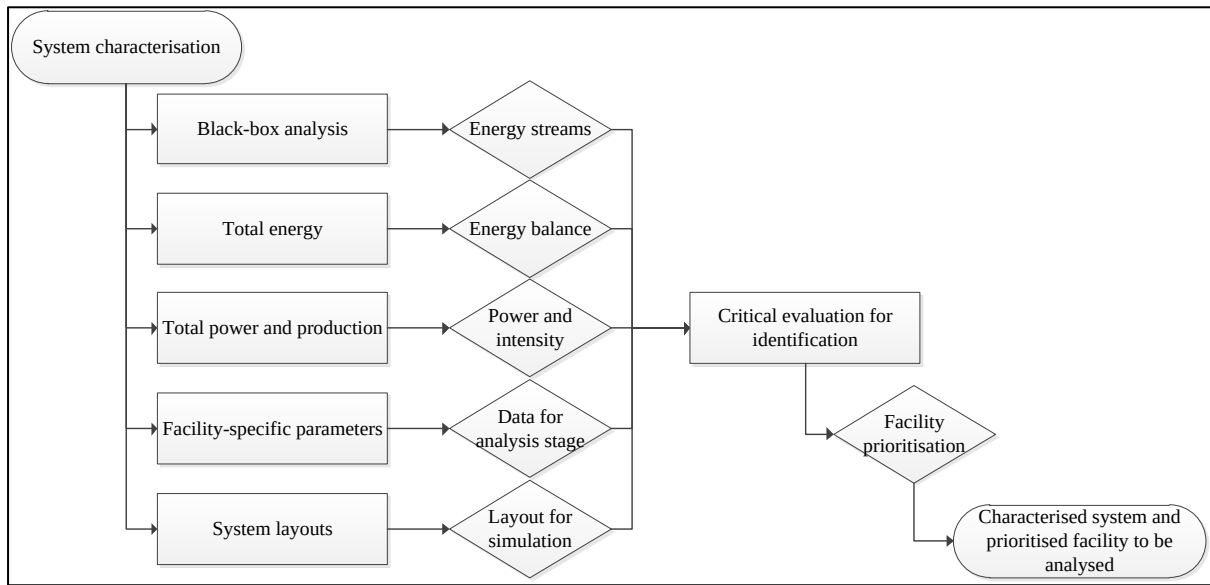


Figure 42: System characterisation

3.5.1 Black-box analysis

It is important to do a proper black-box analysis before commencing with the energy characterisation and obtaining the system parameters. The black-box analysis simplifies the process of understanding the energy use and system parameters such as production KPIs related to electricity.

The black-box analysis and facility boundary identification need to be completed before the development of energy balances can commence. It is important to know which energy streams enter and leave each facility. It is also important to understand the process in terms of raw product inputs and process outputs. The energy balance can be done once a year for each separate facility using the black-box analysis as a guideline.

Figure 43 shows an example of a BOF facility. The energy sources are shown entering from the top of the box; the raw products entering from the left of the box. All products including off-gases leave the box on the right. The energy-containing streams that enter the BOF facility are listed below and indicated with a red shape in Figure 43:

- Low-pressure steam;
- Electricity;
- Natural gas; and
- COG.

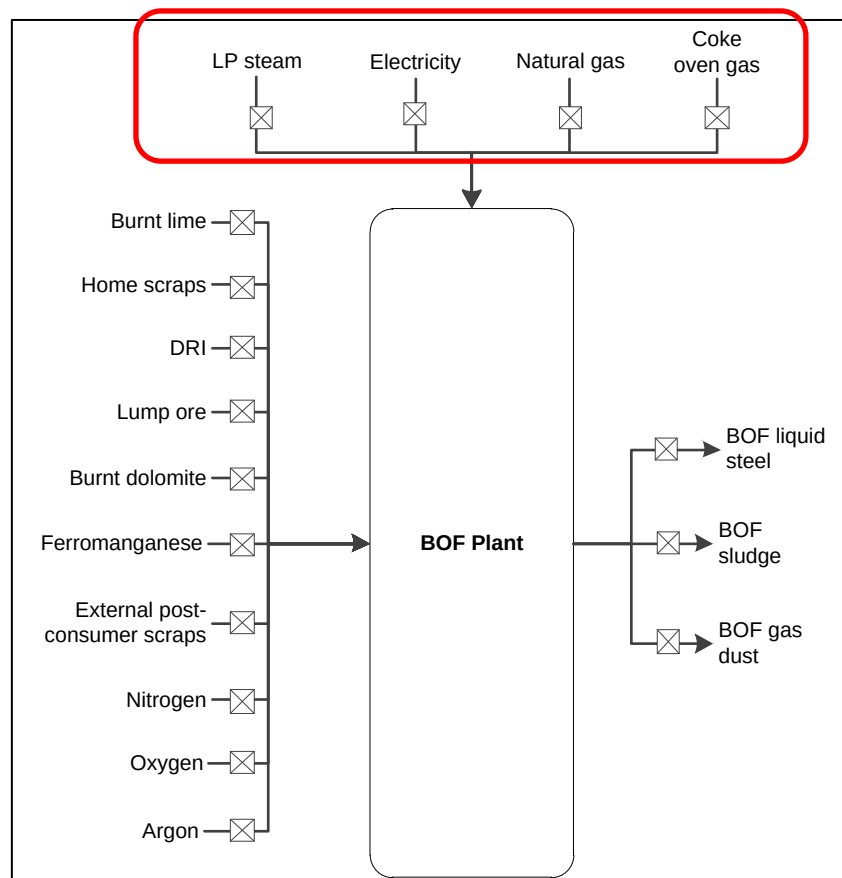


Figure 43: Example of steelmaking BOF facility black-box analysis

With the black-box analysis, no data is displayed on the diagram. This step shows that the facility-specific energy champion understands the facility in terms of the process, but most importantly understands the flow of energy in the facility.

Table 16 shows the parameters required for the energy champion to complete the black-box analysis as part of the system characterisation.

Table 16: System characterisation parameters

Data required	Schematics required
Production data	Plant PFD
Input data	Plant PID
Energy data	Facility-specific PID

3.5.2 Total plant energy

In this step, the total energy for each steelmaking plant is investigated. Firstly, an energy balance needs to be completed. An energy balance reporting sheet is developed. It is critical to understand the total amount of energy purchased as well as the cost of the energy. From the total energy balance, the total power and electricity intensity can be determined.

The energy-balancing reporting sheet will assist the energy champion to easily understand the quantity of energy input and output for the specific facility and process. This is also critical for energy intensity and ranking of the facilities for implementing electricity cost reduction strategies. In this step of the framework, all energy sources and carriers are documented and incorporated.

Table 17 shows the energy input sheet as an example. The energy sources are listed in the columns and the facilities listed separately in the rows. Together, they form an identification matrix to easily do the energy balance per plant. It is the same for the inputs and the outputs.

Table 17: Energy balance input and output sheet

No.	Process name (GJ)	COG in	COG out (GJ)	BFG in (GJ)	BFG out (GJ)	Electricity in (GJ)	Electricity out (GJ)	Net energy (GJ)
1	Coke plant	1 083 061	41 616	0	0	37 432	0	4 864 968
2	Sinter plant	0				147 282		442 751
3	Blast furnace		5 400 201			107 914		9 607 109
4	Direct reduction	22 221				54 016		706 071
5	BOF facility	118 792				80 421		424 849
6	Secondary metallurgy					57 555		76 950
7	Continuous casting					27 303		169 490
8	Hot strip mill	2 172 921				197 096		3 842 853

No.	Process name (GJ)	COG in	COG out (GJ)	BFG in (GJ)	BFG out (GJ)	Electricity in (GJ)	Electricity out (GJ)	Net energy (GJ)
9	Plate mill	681 696				24 346		824 568
10	Pickling plant					21 198		87 069

All the energy inputs and outputs can now be identified. The next step in the energy balance methodology is to calculate the net energy use or generation of each facility. As part of the energy balance reporting sheet, the net energy is calculated using Equation 5.

$$\text{Net energy} = \text{Total energy in} - \text{Total energy out} \quad \text{Equation 5}$$

If the answer gives a positive value, it means that the process generates energy. If a negative answer is obtained, the process uses that amount of energy.

For each process, the net energy is calculated as shown in Table 17. After the net energy has been calculated, the plant energy contributions and intensities can be calculated. They are needed to understand the influence each energy source has on the plant as a whole to make knowledgeable decisions when electricity cost saving opportunities are identified.

After doing all the energy balances, all the energy streams will be known. A total plant energy breakdown can be done to understand the influence of the different energy sources. A pie chart is used to display the portion of each contributing energy source. The energy distribution is quantified in terms of energy cost percentage.

Figure 44 shows the energy distribution diagram as example for a one-year period for a South African steelmaking plant. This graph shows the contribution of each energy source on the total energy use of the plant in terms of the cost of the specific energy commodity. Coal is the largest, and electricity the second-largest contributor in terms of cost.

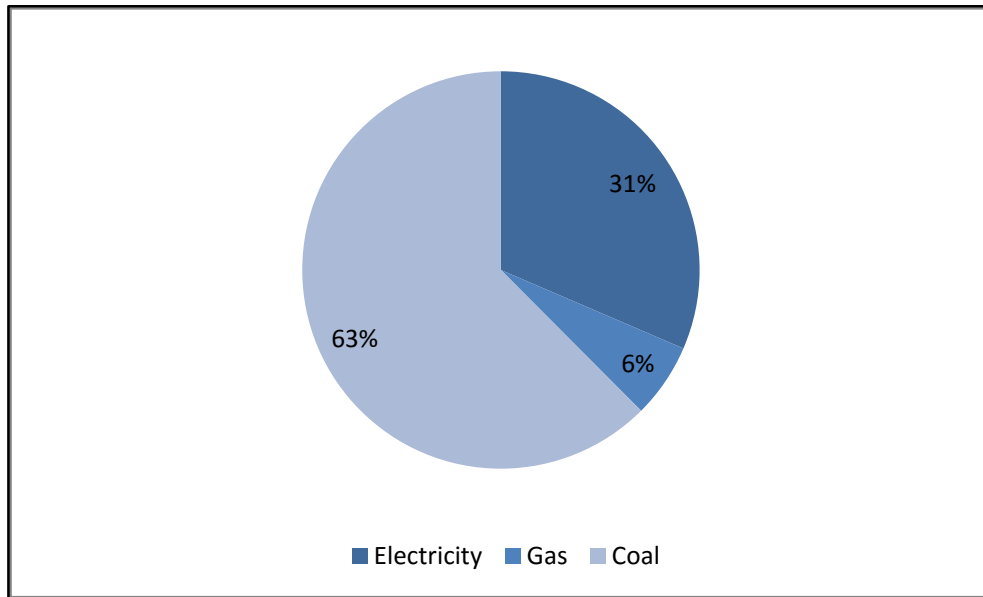


Figure 44: Energy pie chart diagram

On a facility-specific level, the energy use on each individual facility can also be displayed in the same way. However, a Sankey diagram is a more user-friendly way to display the energy use on different plants in terms of the energy commodities. Figure 45 shows a Sankey diagram for Plant A (included as a case study plant in Section 4.2).

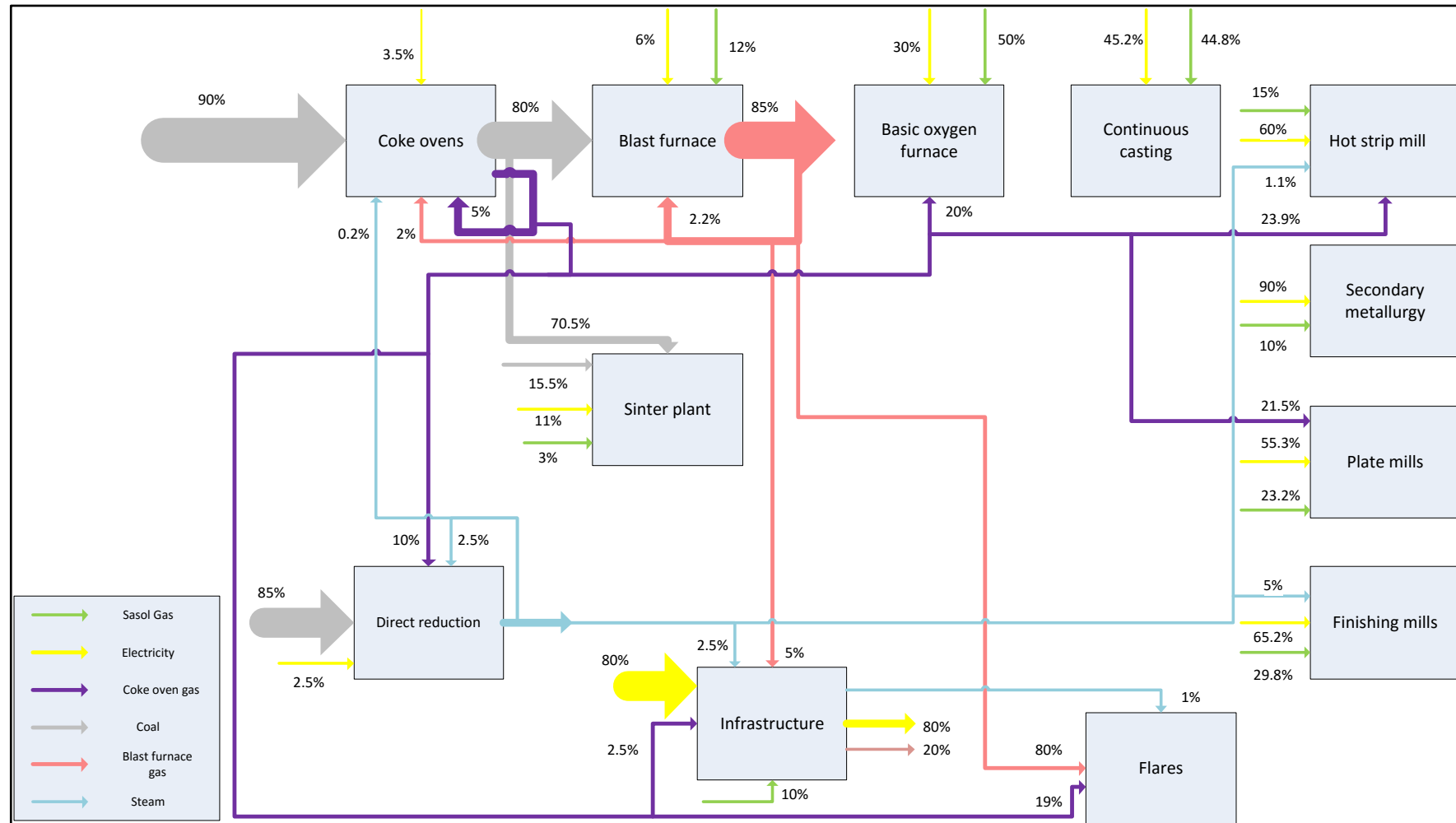


Figure 45: Sankey diagram for Plant A

This specific diagram will be discussed in Section 4.2.4. It is important to note that each colour represents a different energy stream. The energy streams are shaped in proportion to the magnitude of the specific energy stream.

Figure 46 is an example of an electricity intensity graph used to compare the performance of the plant in terms of energy intensity. The electricity intensity improves as more tonnes liquid steel are produced. An exponential trend line was best suited for the data points in Figure 46. The data used was for two weeks in 2014, just as an example.

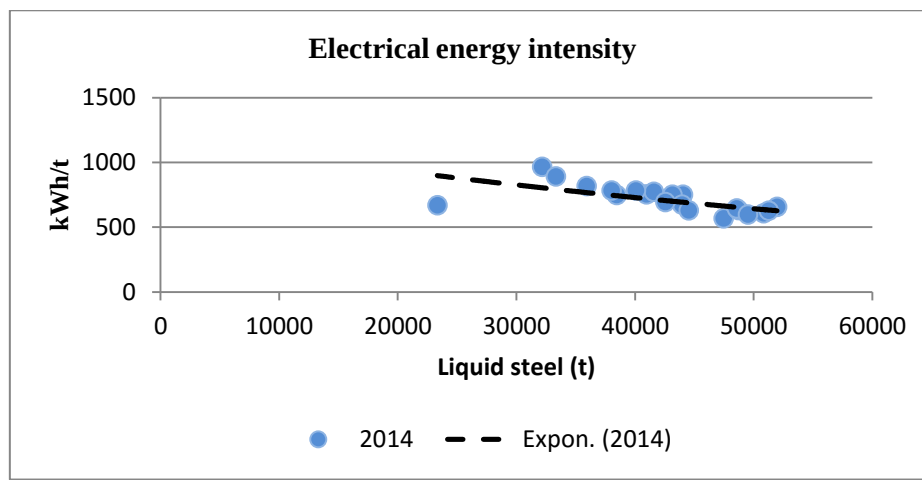


Figure 46: Example of energy intensity graph

As discussed in Chapter 1 and Chapter 2, this thesis focuses specifically on electricity and the framework to obtain cost savings. It is still important to understand the total holistic energy flow of the plant. The goal for the steelmaking plant is to show a decrease in the overall electricity intensity of the plant.

3.5.3 Total power and production

Power data needs to be gathered for all the facilities identified. After the data is collected, it needs to be processed. In order to use the power data, it can be divided into two processed data sets. Firstly, the power data in MW for the facility and, secondly, the electricity intensity in MW/t production.

The total annual power data in terms of MW is accumulated and 24-hour electricity usage profiles are compiled. The power profiles will be used in the decision-making process for prioritising cost reduction initiatives on the steel plant. The total power data is ranked from the highest user to the lowest user.

Figure 47 shows the total power usage profile for the facilities ranked from the highest to lowest user. The graph does not show real plant values. Facility A uses the most power annually and Facility L the least.

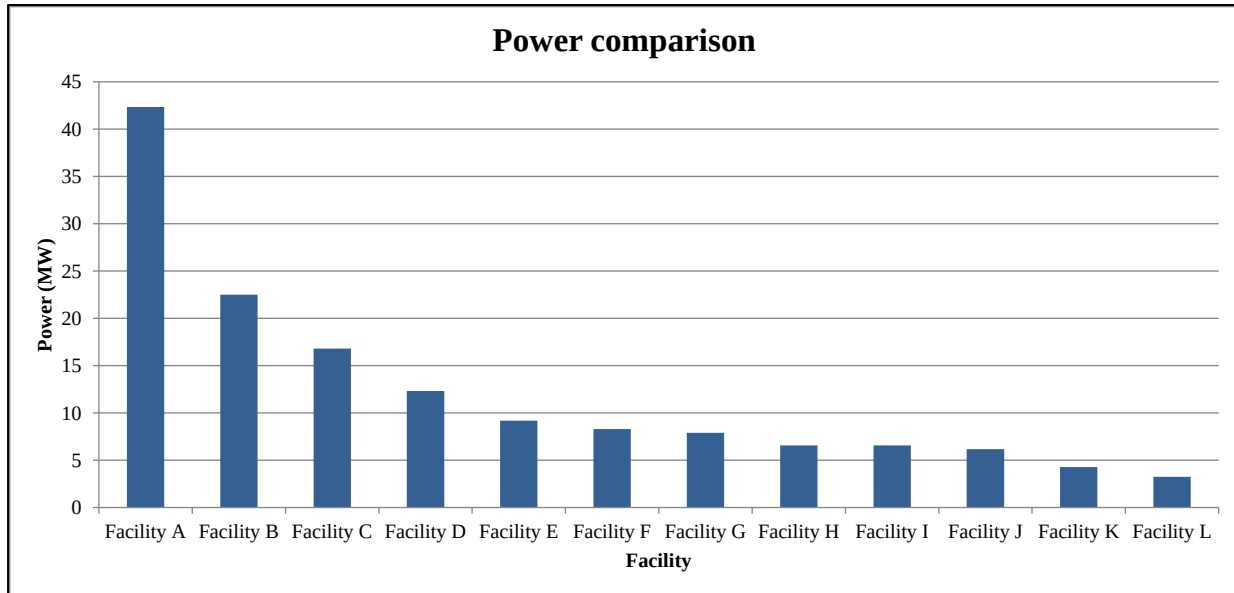


Figure 47: Total power profile

After all the facilities have been ranked from high to low in terms of the total power usage, the facilities are assigned a variable from Pt1 ... Pt_m and numbered from high to low. Table 18 shows the variable and number assignment.

Table 18: Total power usage ranking

Facility	Variable	Ranking
Facility A	Pt1	3
Facility B	Pt2	2
Facility C	Pt3	1

The intensity is calculated by dividing the MW by the production driver. This driver may vary from one facility to another. To use the correct production driver, an electricity intensity graph needs to be plotted to understand the correlation between electricity usage and the production driver selected.

All the different facilities or energy users on the plant can be compared to understand which facility or energy user is more energy efficient in terms of electricity intensity. An example from a typical plant can be seen in Figure 48. Facility A has a larger intensity than Facility L.

It means that for the same amount of production, Facility A uses more electricity than Facility L.

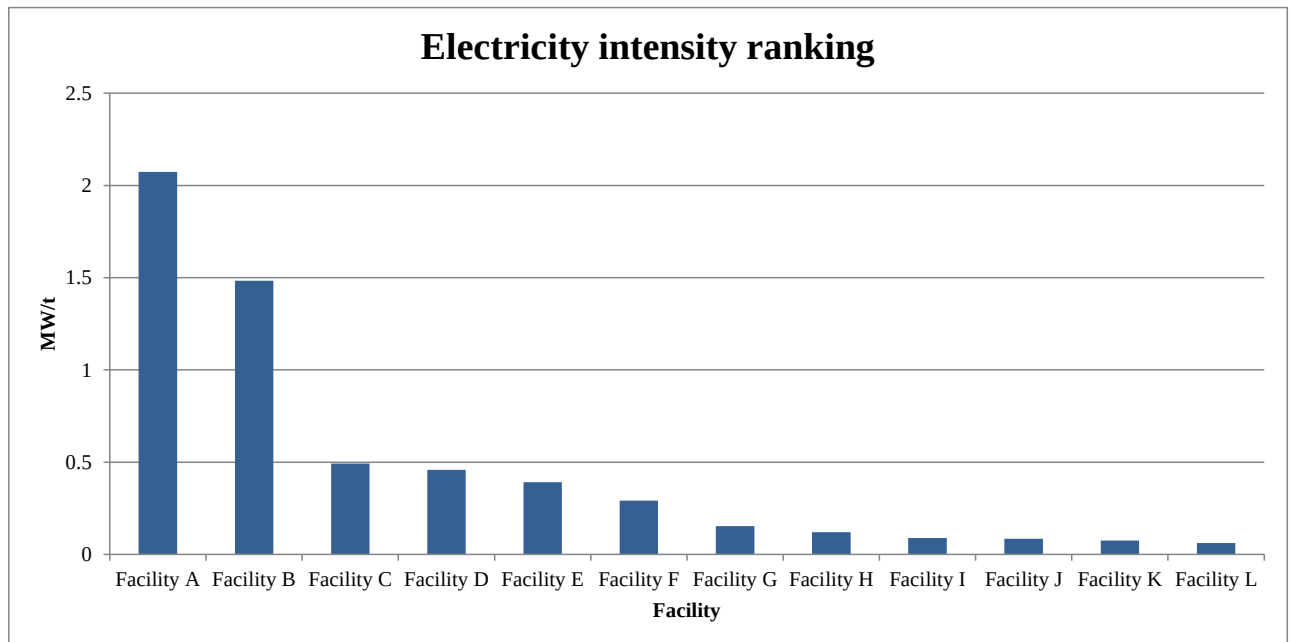


Figure 48: Electricity intensity ranking

After all facilities have been ranked from high to low in terms of electricity intensity, the facilities are assigned a variable from $P_{i1} \dots P_{im}$ and numbered from high to low for the ranking. Table 19 shows the specific electricity intensity ranking. The facility with the lowest electricity intensity is ranked using the lowest number.

Table 19: Electricity intensity ranking

Facility	Variable	Ranking
Facility A	P_{i1}	3
Facility B	P_{i2}	2
Facility C	P_{i3}	1

3.5.4 Facility-specific parameters

The parameters that characterise the specific facility need to be identified. The system parameters include selecting relevant data and system constraints for each of the facilities identified. Figure 49 shows a representation of the system parameter data required for the facility. The parameter data is divided into first-level data, second-level data and third-level data.

The first level of data only changes in value from one facility to another. This level's data gives a holistic view of the facilities' total power consumption and production rates. The second level of data is equipment-specific and focuses on the power consumption of the individual equipment. An inventory of the electricity users is also obtained with this step. The large energy using equipment is called significant energy users (SEUs).

The third level of data focuses on measurements that influence electricity usage. These measurements will change significantly from one facility to another. They are completely dependent on the process and product of the specific facility. The measurements for a blast furnace typically differ from those of a compressor plant.

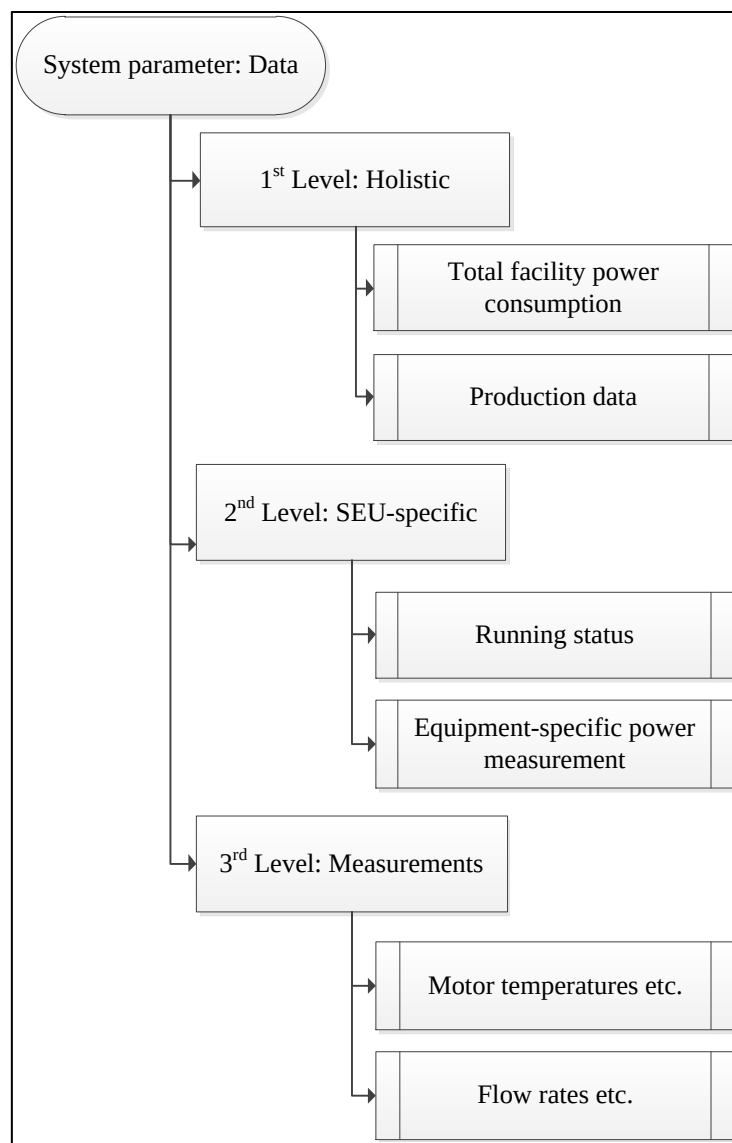


Figure 49: System parameter data required for system characterisation

Three months' data is required to compile a baseline to incorporate normal operating conditions. This data should not include data where SEUs were not shut down for significant amounts of time during maintenance periods. System constraints form part of the facility-specific parameters. It is necessary to know the constraints to identify opportunities for changes in the system. System constraints can include, but not limited to the following:

- Shift changes;
- Equipment restrictions;
- Upper and lower limits of processes; and
- Maintenance schedules.

All the parameters identified in Section 3.5.2 and 3.5.3 need to be incorporated in the total parameter list in the end. The system parameter and the system layout step as discussed in Section 3.5.4 and 3.5.5 can take place simultaneously.

3.5.5 System layouts

Layouts need to be compiled or obtained to understand the process of each facility and understand where the electricity is integrated in the process. The following layouts form part of the complete system layout:

- PFD;
- Existing process control specification layout;
- Electrical layout; and
- PID.

A typical PFD shows the basic flow of the process without minor detail. The purpose of the PFD is to understand the flow. Figure 50 shows a typical PFD compiled for Plant A, which is the case study that will be addressed in Section 4.2. It can be noted that there are two Direct Contact Aftercoolers (DCACs).

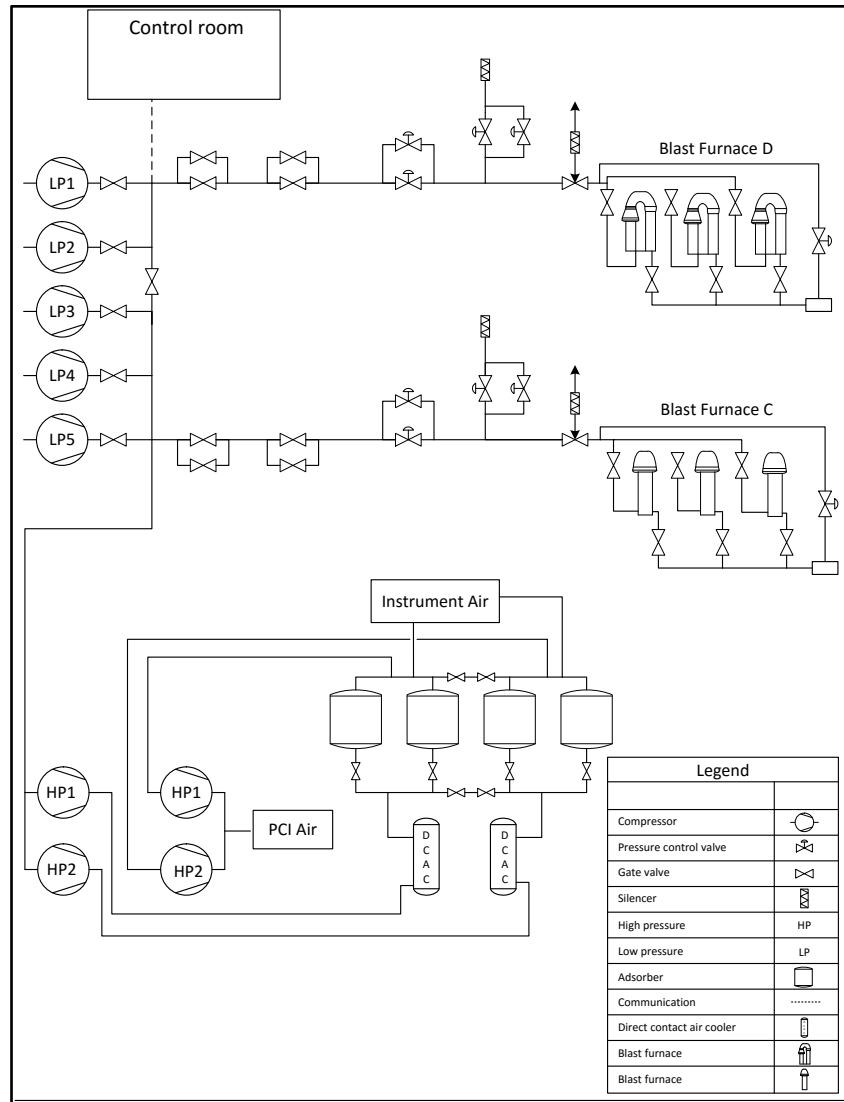


Figure 50: Plant A facility PFD

An important step of system layout is layout verification. It is important that the plant manager or an alternative competent person signs the layouts off. If the layouts are incorrect, other functions of the framework may be incorrect as a result.

After the PFDs have been obtained for each individual facility, operational control documentation and layouts are needed to understand the current operations of the plant. Figure 51 shows an example of a control diagram on Plant A.

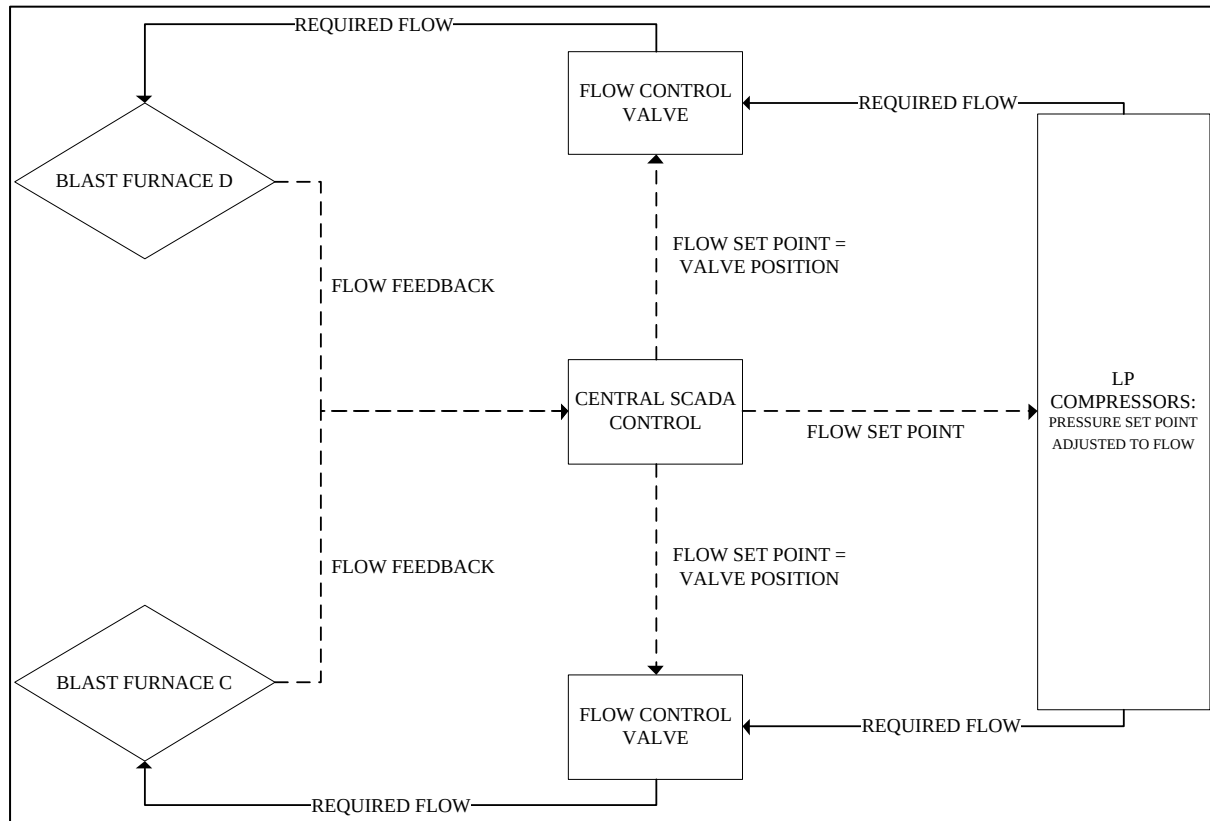


Figure 51: Control diagram for Plant A facility

Electrical layouts are important to see where power measuring points are situated at the specific facility. This is necessary to configure the measured data according to the measuring points. Figure 52 shows an example of an electrical layout obtained for one of the facilities on Plant A.

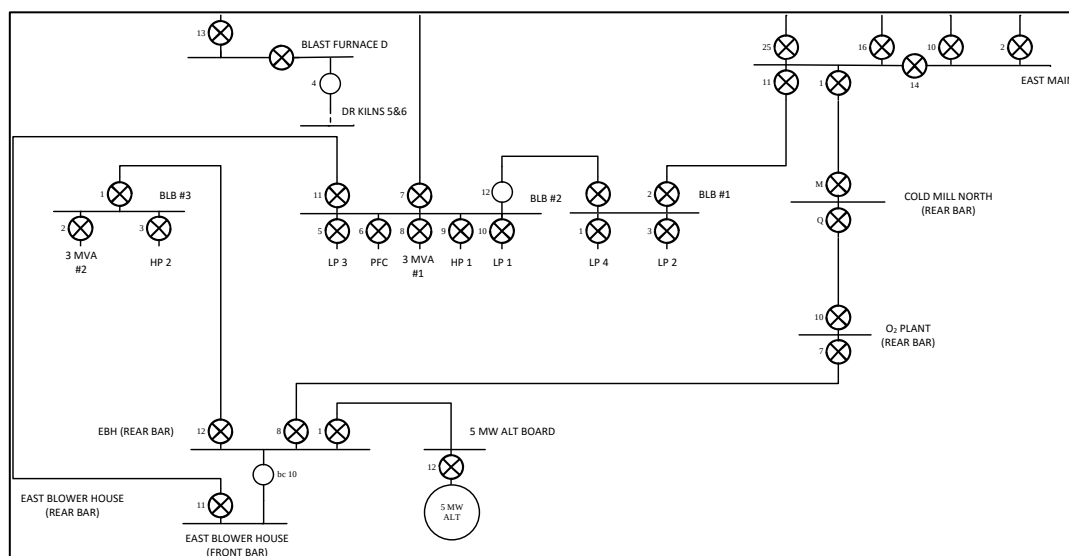


Figure 52: Electrical layout example from Plant A

The last layout required is the PID. This PID diagram indicates extensive detail of the process equipment at the facility. Figure 53 shows an example of a PID layout. The system analysis can now take place.

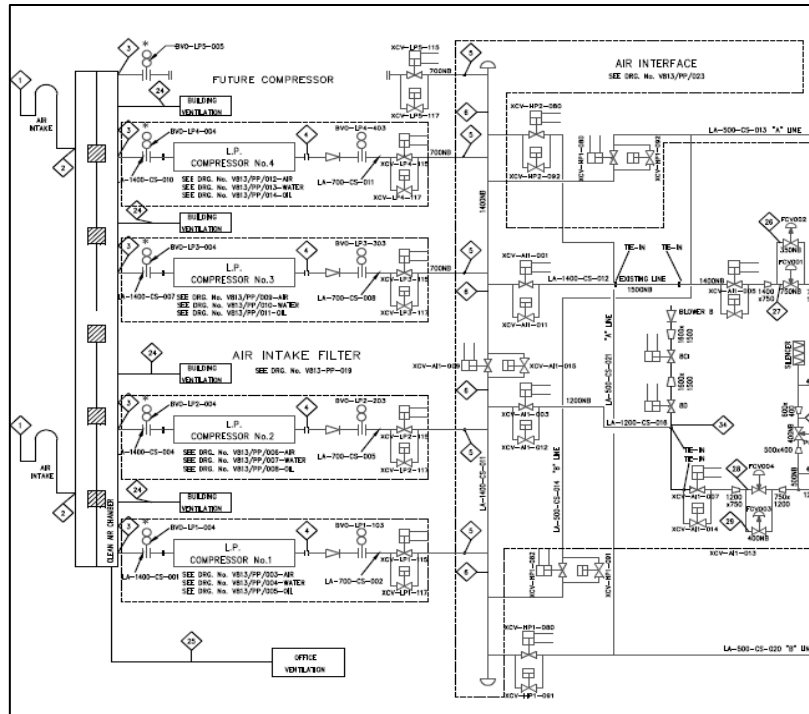


Figure 53: PID example from Plant A facility

After all the layouts have been compiled, verified and approved, the system characterisation is completed. The power data is analysed, system parameters obtained and layouts compiled. This information is sufficient to characterise the facility. The identification and characterisation can now take place.

3.5.6 Identification of initiative for electricity cost reduction

For electricity cost savings through operational changes, it is important to know that the Eskom TOU periods change from summer to winter season. It is also important to know the tariff rates for summer and winter time periods. The c/kWh rate was discussed in Section 3.3.4

Table 20 shows the Eskom TOU Megaflex structure. By understanding the prices for electricity and the different time periods, electricity cost savings can be obtained through DSM.

Table 20: TOU tariff structure

Summer/Winter	Day	Off-peak	Standard	Peak
Summer (Jan–May and Sept–Dec)	Weekday	00:00–05:00	06:00–07:00	07:00–09:00
		22:00–23:00	10:00–17:00	18:00–19:00
			20:00–21:00	
	Saturday	00:00–06:00	07:00–11:00	
		12:00–17:00	18:00–19:00	
		20:00–23:00		
	Sunday	00:00–23:00		
Winter (June–Aug)	Weekday	00:00–05:00	09:00–16:00	06:00–08:00
		22:00–23:00	19:00–21:00	17:00–18:00
	Saturday	00:00–06:00	07:00–11:00	
		12:00–17:00		
		20:00–23:00		
	Sunday	00:00–23:00		

This study ranked the DSM initiatives per most cost-effective initiative to implement. The ranking is shown in Table 21.

Table 21: DSM initiative ranking

Cost reduction initiative	Variable	Ranking (high to low)
Energy efficiency	X	3
Peak clipping	Y	2
Load shifting	Z	1

Ranking of DSM initiatives is based on the amount of time the cost saving is sustained over a day as well as the benefit on both cost and energy saving. Table 22 shows the evaluation on each of the DSM initiatives.

Table 22: DSM initiative evaluation

Cost reduction initiative	Energy reduction	Duration of initiative	Cost reduction	No change in production	Ranking per evaluation
Energy efficiency	Yes	24	Yes	Yes	3
Peak clipping	Yes	2	Yes	No	2
Load shifting	No	6	Yes	Yes	1

Electrical energy efficiency is generally seen as a result of better and more efficient plant equipment. However, energy efficiency can also be obtained through operational changes such as lowering set points and changing process configuration. With energy efficiency on a

production plant, the objective is to lower the load profile, but retain the production without compromising targets.

Peak clipping is based on a plant's willingness to reduce production for a short period during peak time. A cost saving is obtained, but there is a loss in production, which can have a larger cost implication. For production-driven plants, this initiative is not always a feasible option.

Load shifting is based on shifting the production to cheaper TOU periods to reduce costs. The same amount of energy is used with no loss in production. This DSM initiative is feasible for production-orientated plants. The most widely used initiative for operational changes is load shifting.

In this thesis, a quick identification tool is developed as part of the framework to identify which initiative can be implemented on a specific facility. It is important to note that when this initiative is identified, it still needs to be simulated for feasibility and verification.

A critical evaluation step was developed to identify the type of initiative that could possibly be implemented. There are three critical evaluation question sets.

The first question is: Does the facility have sufficient data to compile a 24-hour power profile or not? This data will be the plant load profile. There are plants that are not equipped with power meters and their load profiles cannot be compiled.

After the first question, Question Set 2 characterises the type of process involved with the specific facility. Table 23 summarises the critical evaluation Question Set 2. It is important to note that for a critical process with a too high risk, no operational changes can be implemented until an in-depth analysis has been done to understand the risks.

It is not worth the risk to compromise production targets for electricity cost reduction. A critical process can also be a bottleneck plant. This is when the facility needs to be processing at full production otherwise dependent facilities cannot produce product.

Table 23: Critical evaluation Question Set 2

Process type for critical evaluation	Energy efficiency	Peak clipping	Load shedding
Critical process	–	–	–
Batch process	1	1	–
Semi-batch process	1	1	(Depending on operational constraint)
Continuous process	1	1	1

Nine questions follow as part of Question Set 3 and are summarised in Table 24. There is no specific order in which the questions need to be answered.

Table 24: Critical evaluation Question Set 3

24-hour power profile	Description	Energy efficiency	Peak clipping	Load shedding
1 Peak demand	Identify the amount of energy use during Eskom peak periods	–	1	1
2 Night load	Identify the load during off-peak periods	–	–	1
3 Start-up	Identify the number of starts during a day	–	–	1
4 Shutdown	Identify the number of stops during a day	–	–	1
5 Weather effects	Identify if the facility operates differently due to seasonal effects	1	–	–
6 Loads that cycle	Identify loads that cycle, which means that equipment can be switched off	1	1	–
7 Interactions	Identify the relationship of one SEU on another	1	1	1
8 Occupancy effects	Identify if shifts influence power usage	1	1	1
9 Problem areas	Identify problem areas where there might be spikes in the profile	–	1	1

Figure 49 shows the critical evaluation flow. All the answers need to be positive to identify the type of initiative for operational changes as indicated in the PFD. After the questions have been answered, the facility energy champion will be able to identify which of the three initiatives could possibly and preferably be implemented on the facility investigated.

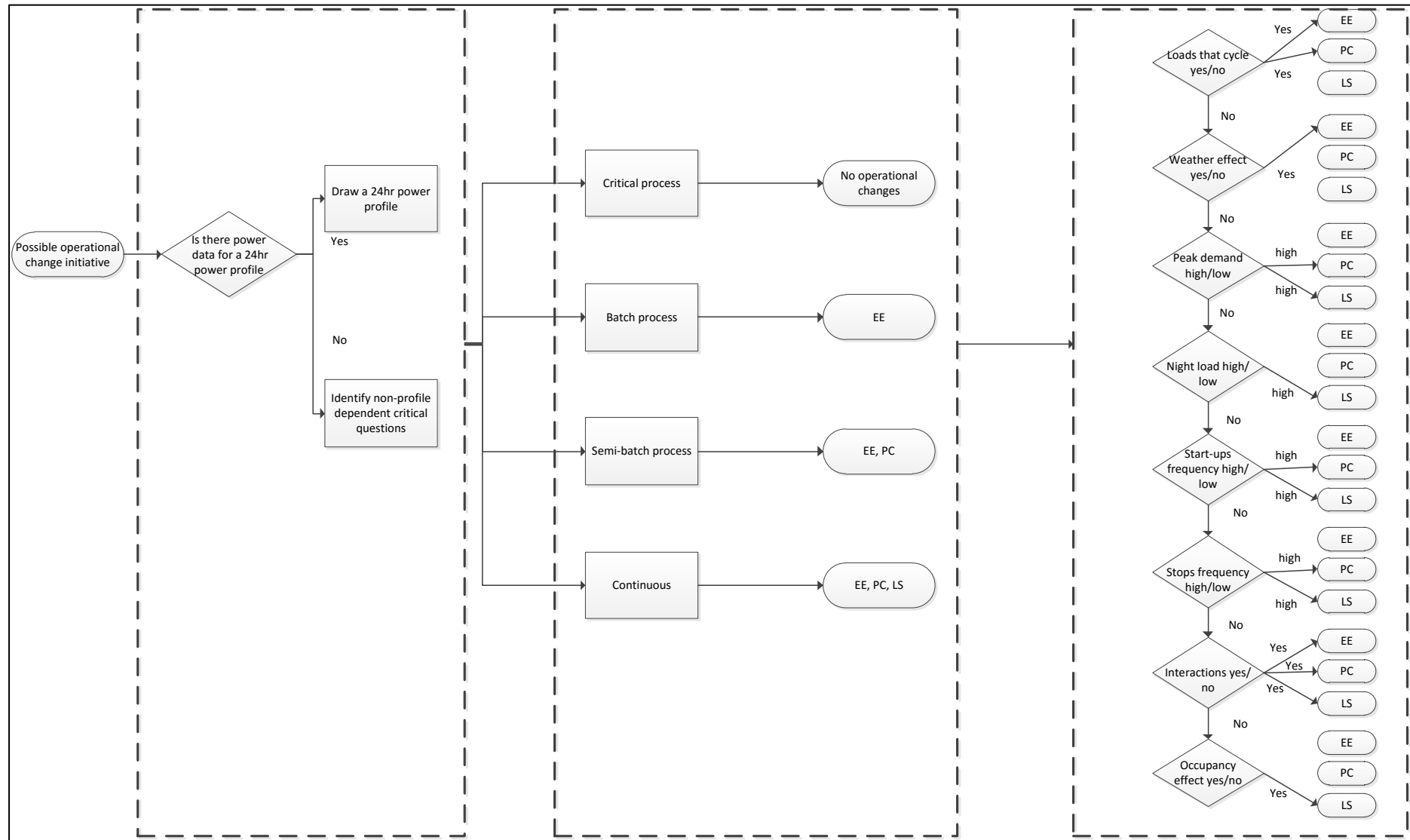


Figure 54: Critical evaluation

The identification takes place using the total power profile for the facility if available, together with the critical evaluation. From data obtained on various industries, three scenarios are identified. The three scenarios can be seen in Figure 55 to Figure 57. If the facility gives a flat power profile, it means that there are little or no equipment being switched on and off throughout the day.

An initiative that involves energy efficiency or peak clipping would most likely be for such a facility. If a profile fluctuates as seen in Figure 57, equipment is switched off and on throughout the 24-hour power profile. A load shifting initiative will be an ideal option for this specific facility. If the electricity load can be shifted through operational changes to the facility from the Eskom peak periods to the standard and off-peak periods, a cost saving can be obtained.

The light-blue blocks in the figures indicate the Eskom peak periods for summer months. It is important to note that the rankings are assumptions based on industry results.

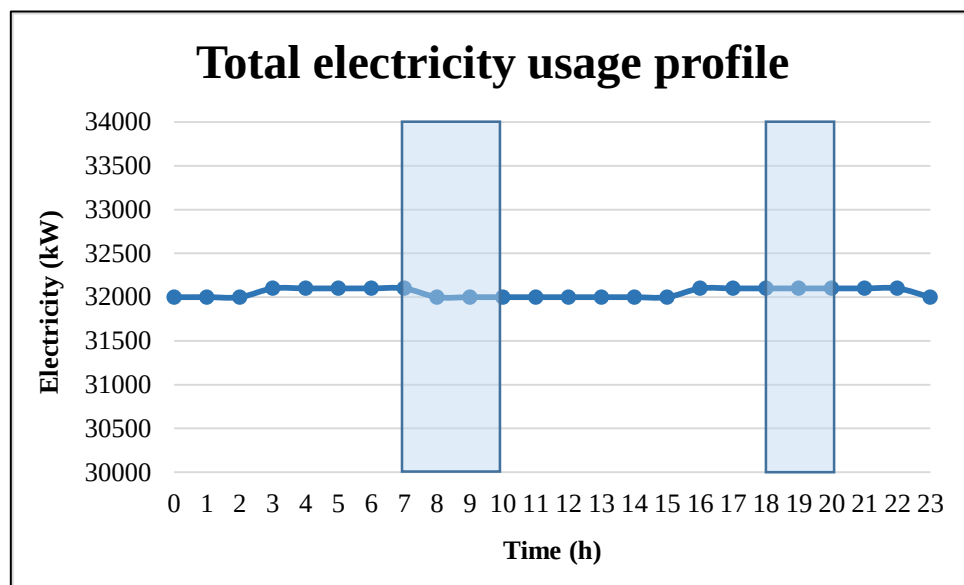


Figure 55: Total facility energy efficiency profile

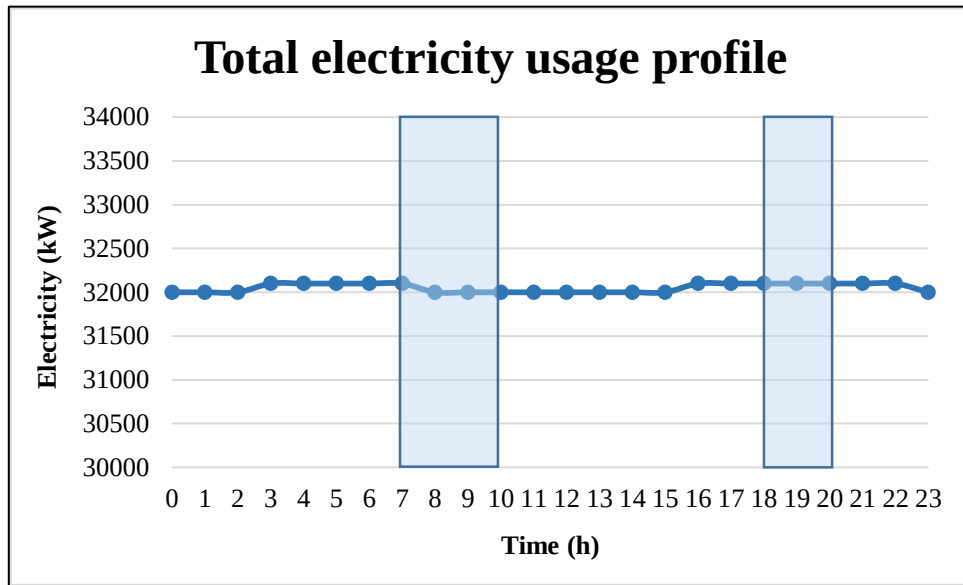


Figure 56: Total facility peak clipping profile

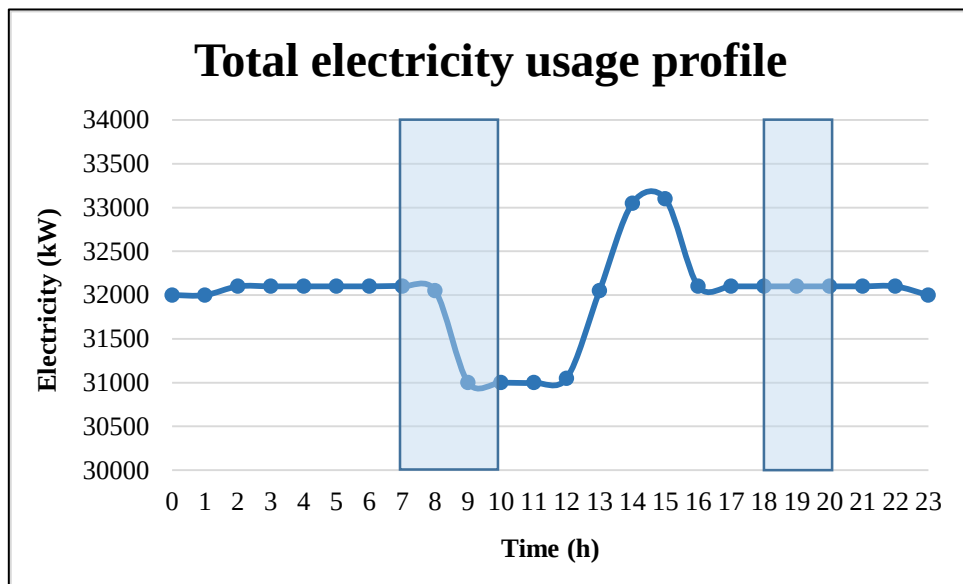


Figure 57: Total facility load shifting profile

3.5.7 Prioritisation of facilities for electricity cost reduction through operational changes

The system characterisation enables energy managers and energy champions on the different facilities to obtain all the necessary information. This information is required to identify the cost reduction initiative and to prioritise it for implementation at each facility.

The information obtained is required to identify and prioritise electricity cost saving opportunities through operational changes. A prioritisation function is developed for the user

to easily identify the specific steelmaking facility to focus on for electricity cost savings through operational changes. The function ranks the plant according to different variables that influence the function.

Capex is included in the calculation. The weight of capex in the equation is negative. A plant with an electricity cost reduction initiative that requires capex will automatically be ranked lower than a facility that does not require capex. Although capex is part of the budget of large plants, currently in South Africa, capex has been stopped or limited to projects with extremely low payback periods.

The prioritisation function is displayed in Equation 6:

$$f = ((x + y + z) + (A + B + C))(Pt1, Pt2, \dots Ptm + Pi1, Pi2, \dots Pim) \quad \text{Equation 6}$$

Where $x = EE$ $A = Eskom\ funding$
 $y = PC$ $B = 12L\ funding\ component$
 $z = LS$ $C = Plant\ capital\ required$
 $Pt1, Pt2, \dots Ptm = facility\ total\ power\ usage\ ranking$
 $Pi1, Pi2, \dots Pim = facility\ electricity\ intensity\ ranking$

Table 25 shows the ranking of the fixed variables. These rankings have been discussed in this section and developed throughout Chapter 3. It is important to note that each facility will have a different answer to the function. Depending on power profile and the set of critical evaluation questions, different initiatives can be implemented on different facilities.

Table 25: Ranking of fixed variables

Variable	Ranking
x	3
y	2
z	1
A	2
B	1
C	-2
Pt	From high to low depending on power ranking
$Pt2$	From high to low depending on power ranking
Ptm	From high to low depending on power ranking
$Pi1$	From high to low depending on intensity ranking
$Pi2$	From high to low depending on intensity ranking

<i>Pim</i>	From high to low depending on intensity ranking
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The initiative may also have a 12L component for a late tax benefit. Although a 12L tax benefit and IDM funding are not incorporated in the equations for the model, a 12L tax benefit may be claimed on the time period not funded by IDM. There is however no previous cases found in literature where both funding mechanism has been claimed together on one plant. If capex is required, it lowers the function output and the ranking.

The answer of the functions will then be ranked from high to low. The plant with the highest function will then be analysed first to understand the project to be implemented and the feasibility of such a prioritised project. Figure 58 shows the input and output flow for this function.

There are 4 scenarios that can be simulated for each DSM initiative. For each facility, there are 9 possible rankings. It is therefore important to identify the DSM initiative to incorporate the operational limitations of the plants.

$$f = ((x, y, z) + (A)) \times (Pt + Pi) \quad \text{Equation 7}$$

$$f = ((x, y, z) + (C)) \times (Pt + Pi) \quad \text{Equation 8}$$

$$f = ((x, y, z) + (A) + (C)) \times (Pt + Pi) \quad \text{Equation 9}$$

$$f = ((x) + (B) + (C)) \times (Pt + Pi) \quad \text{Equation 10}$$

Table 26 shows the calculated function values using random data. All possibilities are calculated and different function values are obtained.

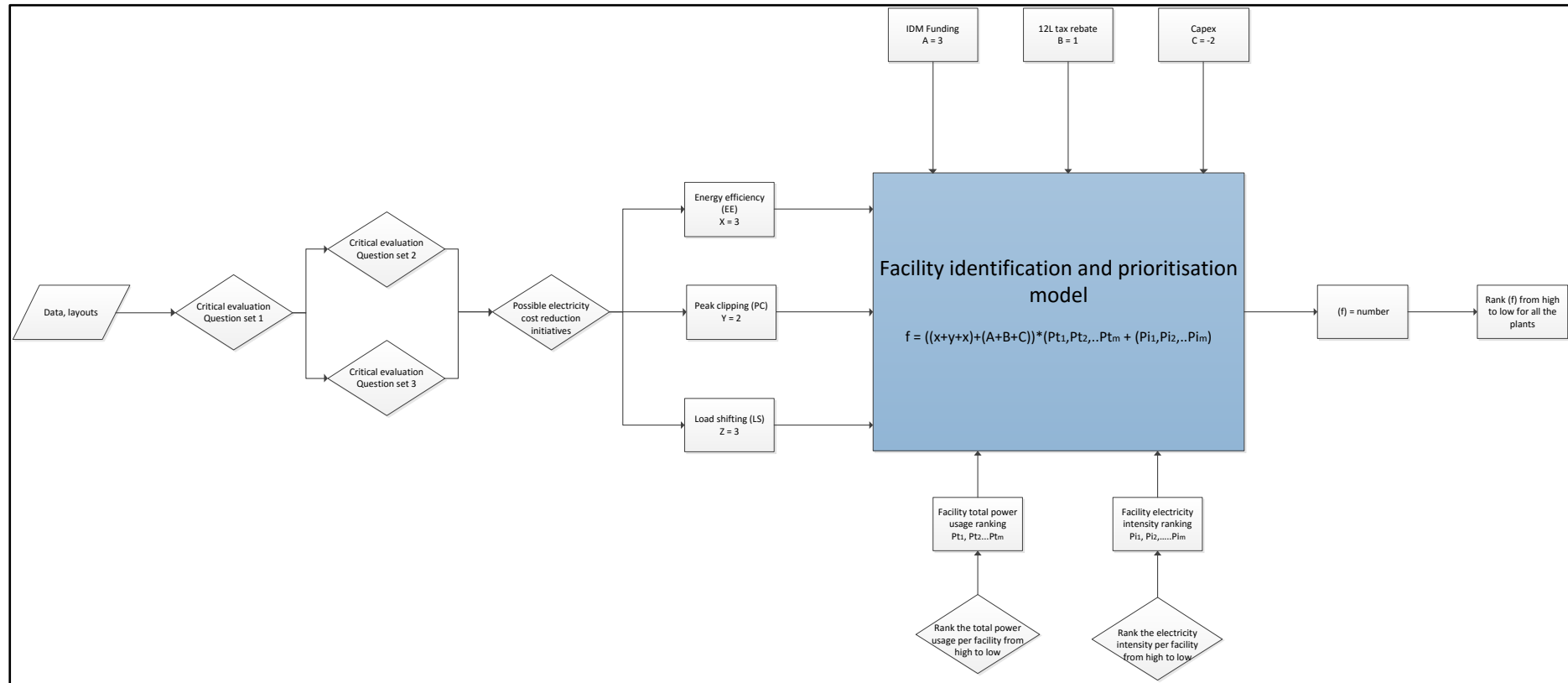


Figure 58: Flow of the prioritisation function

Table 26: Possible rankings for Facility A to Facility L

	EE & IDM	EE & Capex & 12L	EE & Capex	PC & IDM	PC & IDM & Capex	PC & Capex	LS & IDM	LS & IDM & Capex	LS & Capex
Facility A	294	98	196	245	147	0	196	98	−49
Facility B	258	86	172	215	129	0	172	86	−43
Facility C	252	84	168	210	126	0	168	84	−42
Facility D	246	82	164	205	123	0	164	82	−41
Facility E	240	80	160	200	120	0	160	80	−40
Facility F	240	80	160	200	120	0	160	80	−40
Facility G	234	78	156	195	117	0	156	78	−39
Facility H	234	78	156	195	117	0	156	78	−39
Facility I	204	68	136	170	102	0	136	68	−34
Facility J	198	66	132	165	99	0	132	66	−33
Facility K	198	66	132	165	99	0	132	66	−33
Facility L	186	62	124	155	93	0	124	62	−31

The function values for each operational possibility are plotted, which can be seen in Figure 59 and Figure 60. It can be seen from the graphs that an energy efficiency DSM-funded initiative with a 12L benefit is the best operational change scenario to have. Load shifting with no funding and no capex required is the least prioritised operational change for electricity cost saving.

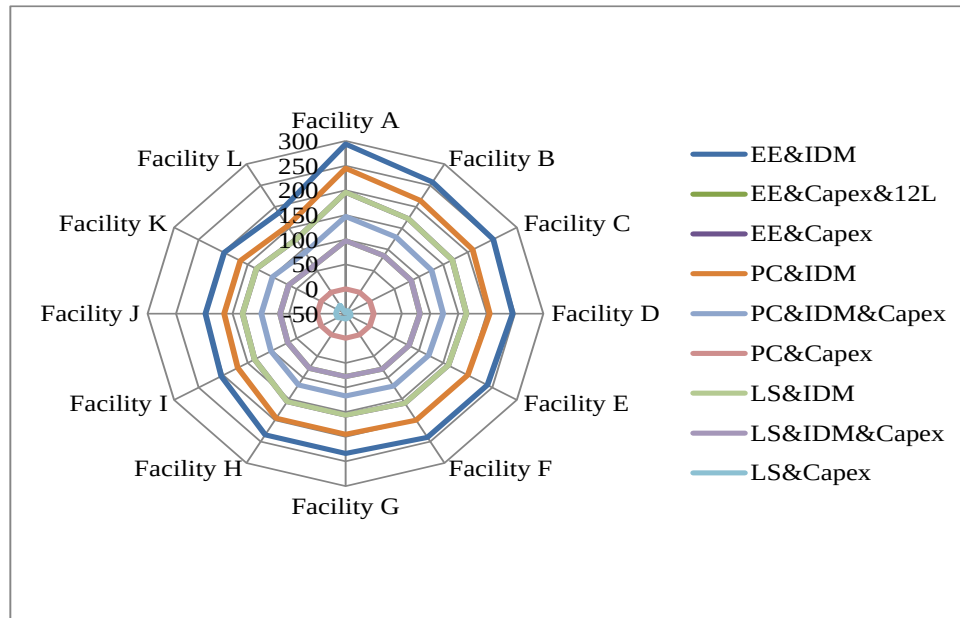


Figure 59: Facility function Graph A

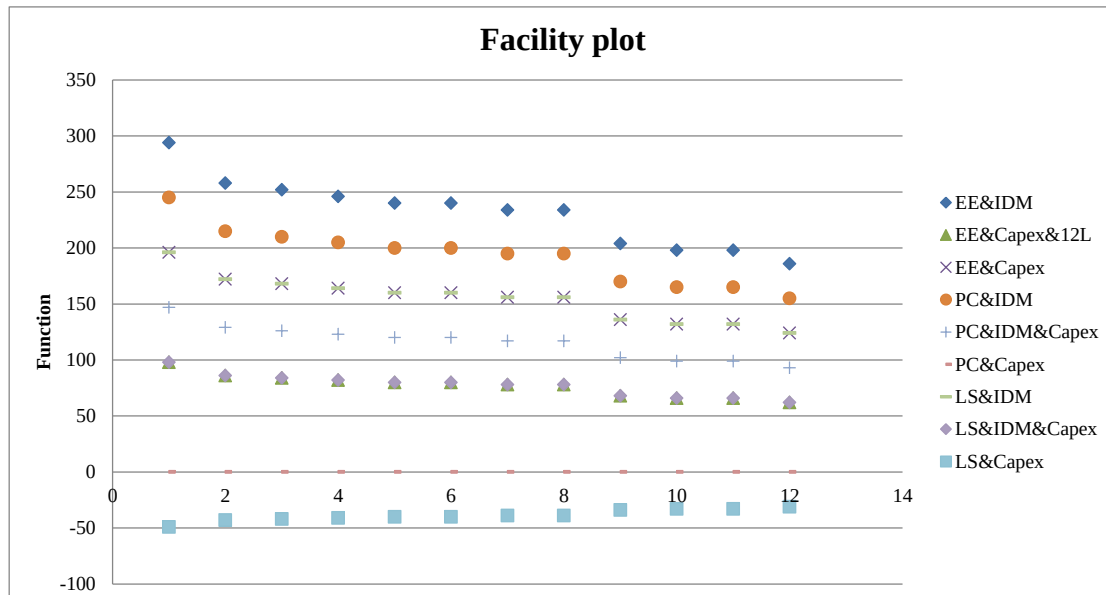


Figure 60: Facility function Graph B

Figure 61 shows the facility ranking with the operational changes scenarios. Facility A is the prioritised plant with an energy efficiency DSM-funded operational change scenario where a 12L tax component is also a feasible possibility.

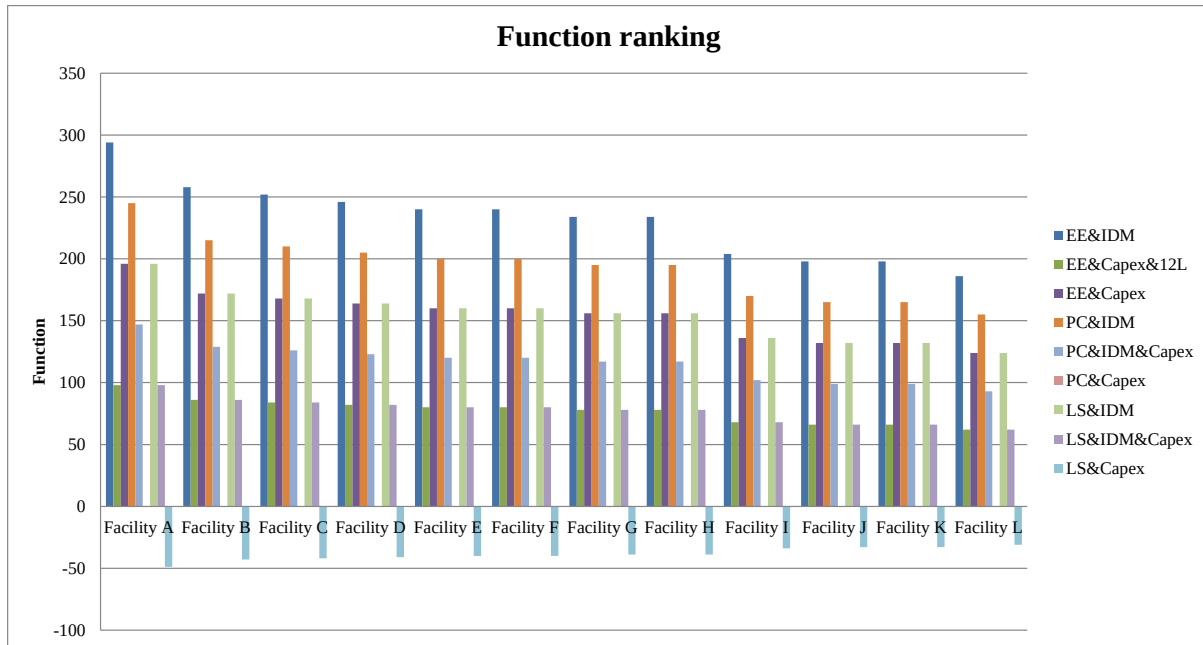


Figure 61: Facility prioritisation ranking with each operational change scenario

The possible operational changes are identified and the facilities ranked accordingly incorporating total power and energy intensity for all the facilities on the steelmaking plant. Certain parameters are required for analysing the ranked facilities to understand the constraints and limitations.

3.6 System analysis for project feasibility and implementation

3.6.1 System analysis flow

With system analysis, it is important that the process identification, facility identification and system characterisation are completed. An initial investigation is required to understand the possibility of implementing an electricity cost saving project with operational changes. It also allows the plant to apply for project funding if a funding opportunity is identified. Figure 62 shows the high-level system analysis flow.



Figure 62: System analysis operational flow

3.6.2 Initial investigation for funding application

The initial investigation is a quick and not all technical aspects are incorporated. If funding can be sourced for the project, a proposal needs to be submitted to the organisation or institute funding the project. It may take considerable time to process and approve an application for funding. Figure 63 shows the flow for initial project investigation.

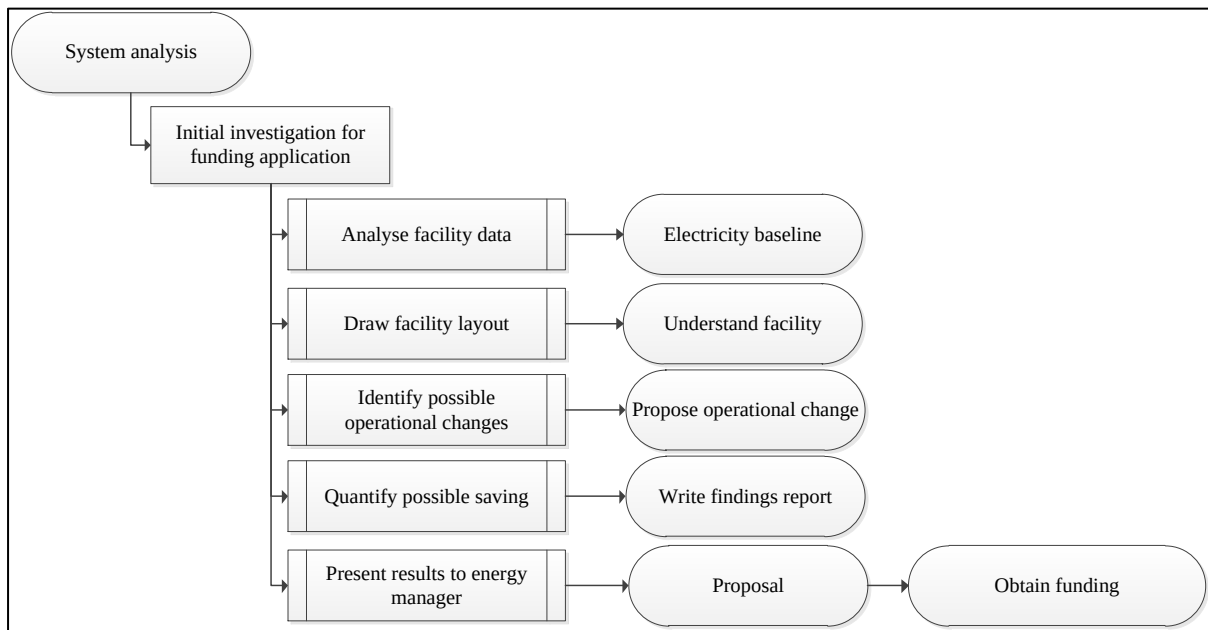


Figure 63: Initial investigation procedure

With the initial investigation, it is important to state a feasible case to implement operational changes. It can either be for plant representatives or management, or it can be for funding purposes. A proposal needs to be compiled. Important information required to state the case is:

- Facility data as obtained in Section 3.5.4;
- Facility layout;
- Operational changes as identified in Section 3.5.6;
- Findings report or proposal; and
- Presentation with summarised finding.

3.6.3 Operational changes – facility-specific

From the system characterisation in Section 3.5, the selection of relevant data and system constraints will be obtained and understood. The major facilities on the steelmaking plant will

also be known. The prioritisation model identified the ranking in which the analysis of the facilities must take place and the operational changes be implemented.

With all the parameters known, each facility can be analysed using the system analysis part of the framework. For the purpose of system analysis, a random facility is chosen as an example to develop the framework. The facilities are discussed in terms of the four primary facilities, namely:

- Ironmaking;
- Steelmaking;
- Finishing products; and
- Infrastructure.

For each of the primary facilities, the identified secondary facilities (the facilities themselves) are analysed in terms of their operational constraints, operational data, energy carriers and SEUs. The data, parameters and layouts obtained in the system characterisation section of the framework can now be used in the analysis of each facility. A coke-making facility will be discussed as an example.

Ironmaking: Coke-making

The coke-making facility forms part of the primary ironmaking facility. The facility identification was explained in Section 3.4.2. In Section 3.5, the system characterisation steps were completed. With the system analysis part of the framework, a breakdown of the facility is done. The coke plant was not necessarily identified and prioritised in Section 3.5.6 and Section 3.5.7. It is only used as an example.

After completing the system analysis together with the data, parameters and layouts obtained, the electricity cost savings can be implemented. Figure 64 shows the new system analysis methodology implemented on the coke-making facility that is part of the case study Plant A, which will be discussed in Section 4.2.

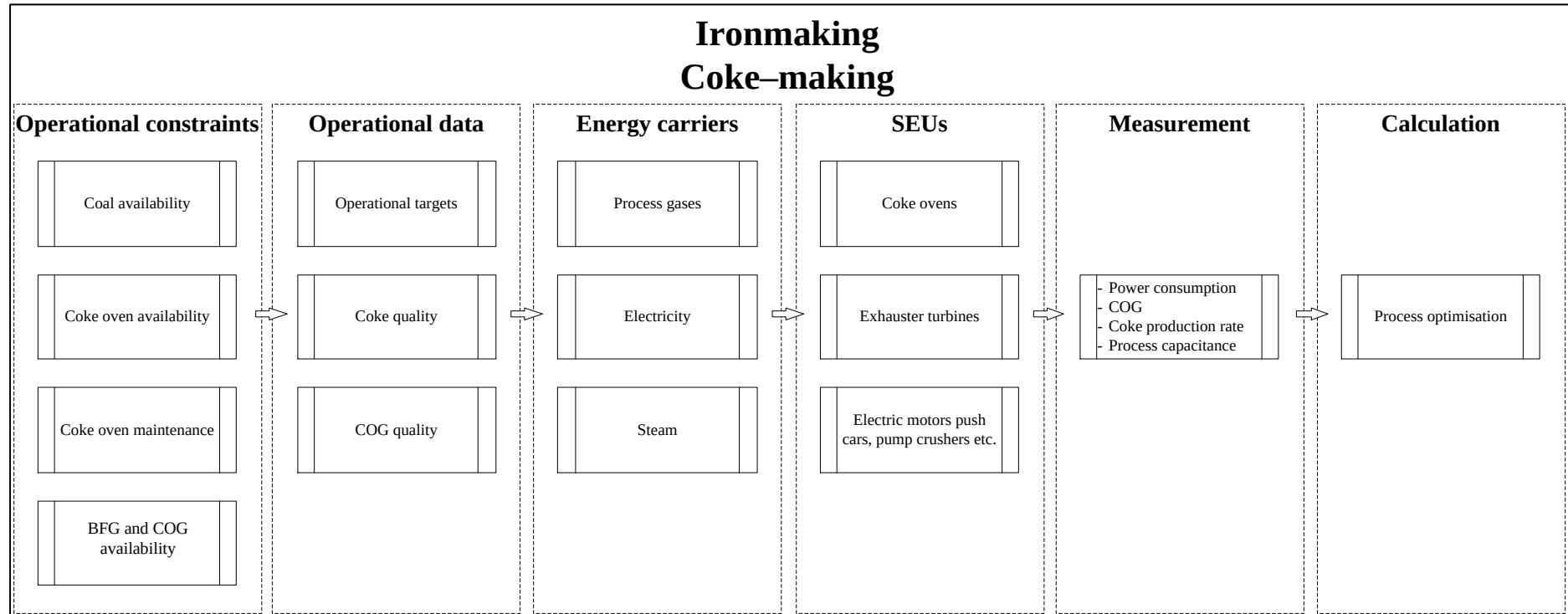


Figure 64: Example of system analysis

The system analysis is divided into six steps as shown in Table 27.

Table 27: System analysis steps

System analysis steps	Step description
1	Operational constraints
2	Operational data
3	Energy carriers
4	SEUs
5	Measurement
6	Optimisation

The coke-making plant is analysed as an example in this section. Coal is railed to the plant and offloaded by one of three tipplers, weighed, and stored in coal-blend silos. The coal is then transferred to constant weigh feeders, crushed, screened and transferred to one of the four service bunkers, which are located on top of each battery pair.

Coal from the service bunkers is top-charged via gravity with a coal charging car into the slot-type ovens. Each oven shares a common heating flue with the adjacent oven. The coke-making process involves carbonisation of coal to high temperatures (1 100 °C) in an oxygen-deficient atmosphere to concentrate the carbon. The hot coke is discharged into the quench cars via pusher machines. A coal blend, consisting of 20% imported coal and 80% local coal, is charged at an average of 150 ovens per day. The operational constraints are listed as:

- Coal availability;
- Coke oven availability;
- Coke oven maintenance; and
- BFG and COG availability.

The operational data required can be listed as:

- Operational target;
- Coke quality; and
- COG quality.

Process gases, electricity and steam are the energy carriers for the coke plant. The coke ovens are heated with a mixture of BFG and COG. The batteries and ovens operate at different gas ratios. The coke ovens produce COG which is cleaned in the by-product plant and distributed to the rest of the works. The energy carriers can be summarised as:

- Process gases;
- Electricity; and
- Steam.

SEUs in the coke plant include the coke ovens that consume most of the process gases. The exhauster turbines, which extract the COG from the coke ovens, are operated with 42 bar steam at 46 t/h. Various electric motors on the coke plant consume electricity. These motors operate push cars, guide cars, pumps, cooling towers and crushers. The SEUs can be summarised as:

- Coke ovens;
- Converter turbines; and
- Electric motors.

Producing coke for use in the blast furnace is the main driver for electricity consumption on the coke plant. There is no capacity to sell coke currently due to the blast furnace demand and coke plant production difficulties.

The next step in the system analysis includes the actual measurement, simulation and the optimisation. This step is crucial for projecting potential electricity cost reduction initiatives. At this stage of the framework, the facility can be simulated to establish a baseline for the electrical energy usage.

After the baseline simulation is completed, the identified operational change initiatives can be simulated to quantify the savings that can be achieved if implemented.

3.6.4 Simulate and measure operational change

The energy champion needs to identify if adequate software is available to do a proper simulation. Simulations can be built in any software such as Process Toolbox (PTB). For this study, the simulations are done on PTB in combination with Microsoft Excel®, which can aid manual simulations. At this point in the framework, the necessary data and layouts have been obtained to complete a sufficient simulation.

The site layouts, in the form of PFDs and PIDs, can now be used to compile a simulation layout for the specific facility. After the layout of the simulation has been finished, the baseline value inputs can be added to the simulations. The simulation can run and the outputs

can be verified. After the baseline simulation has been completed, the operational change is simulated and the outputs verified. The electricity cost reduction is now quantified. If the simulation is complete and accurate, the findings can be documented for implementation.

Figure 65 shows the step-by-step process to follow to complete the simulation step as part of the system analysis. From the quantification of the savings, the feasibility of the initiative can be determined using the economic markers.

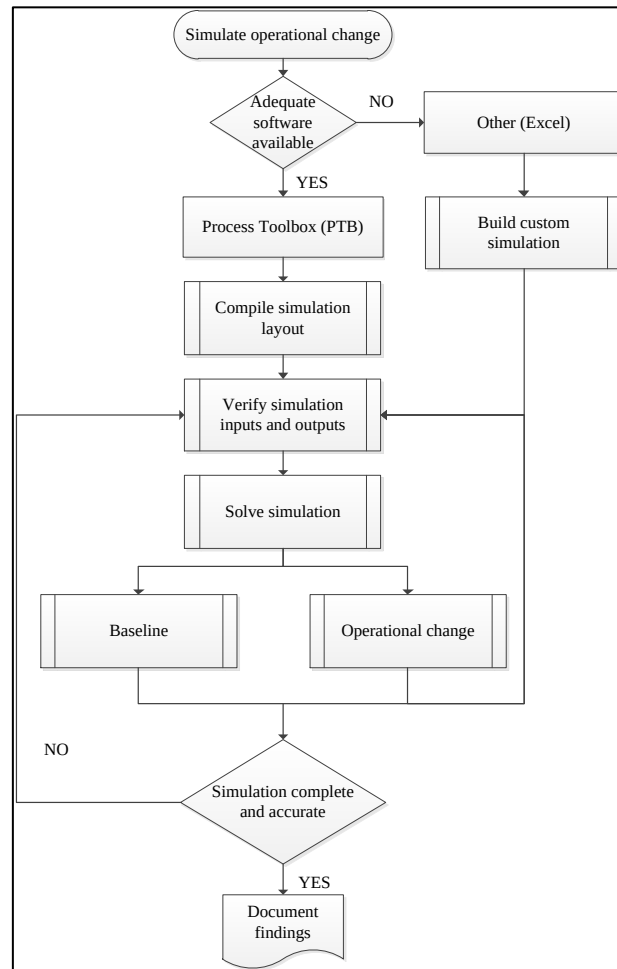


Figure 65: Simulation flow

PTB is a transient thermal hydraulic system simulation and optimisation tool. It is beneficial for designing, analysing and optimising system performance. Figure 66 shows the typical layout for a PTB simulation. This example is of a compressed air simulation.

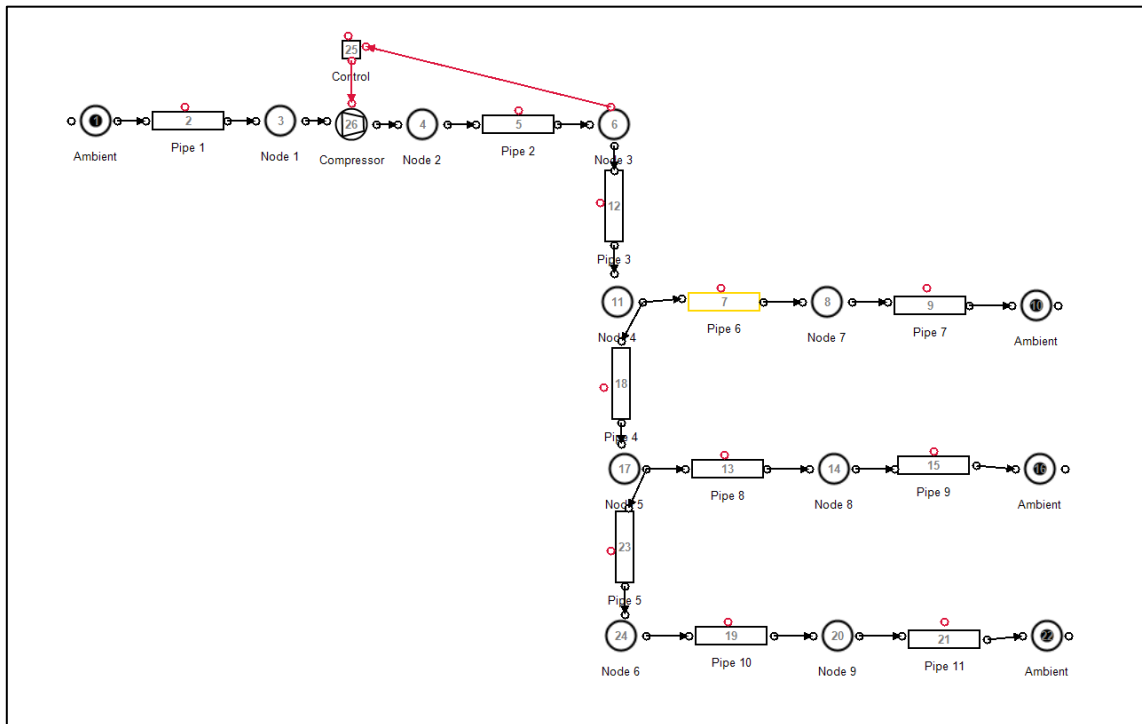


Figure 66: Example of simulation in PTB

Table 28 gives the legend for the components used in the simulation.

Table 28: Simulation legend

Simulation component	Component name
	Air pressure boundary
	Air pipe
	Air node
	Air dynamic compressor

3.6.5 Implementation and evaluation of results

After the facility has been analysed, the operational change simulated and the possible savings quantified, the feasibility of the initiative can be evaluated. The evaluation is done using the economic indicators as discussed in Section 3.3.2. If the initiative is feasible to implement in terms of the objectives set out in the framework, it can be implemented.

After the implementation of the framework, the results need to be analysed and compared with the simulated savings. The result of the implemented framework needs to be the same or better than the predicted simulated savings.

3.7 Operational framework roadmap

The roadmap follows the framework from start to end to identify and prioritise possible projects for operational changes to reduce electricity costs. As discussed in Chapter 2, the roadmap is the strategic plan that outlines activities to be able to achieve a certain goal.

The roadmap goal is to reduce electricity costs through changes in operation. The framework can be described as the outlined activity to obtain this goal. In this section, the framework will be summarised and combined to find a step-by-step methodology to implement the framework on a real-life application. In this section, the document flow for incorporating all the steps will also be discussed.

3.7.1 Step-by-step framework summary incorporating ISO 50001

ISO is a current topic that is important for reporting and regulation purposes. The framework complies with the outcomes stipulated in the ISO 50001 documentation. The framework also complies with the PDCA cycle as stated in the ISO 50001 energy management strategy and compliancy. The fact that the framework can be ISO 50001-compliant, makes it simple for the plant to apply for ISO 50001 certification. Figure 67 shows the summary of the framework roadmap for the ISO 50001 PDCA cycle.

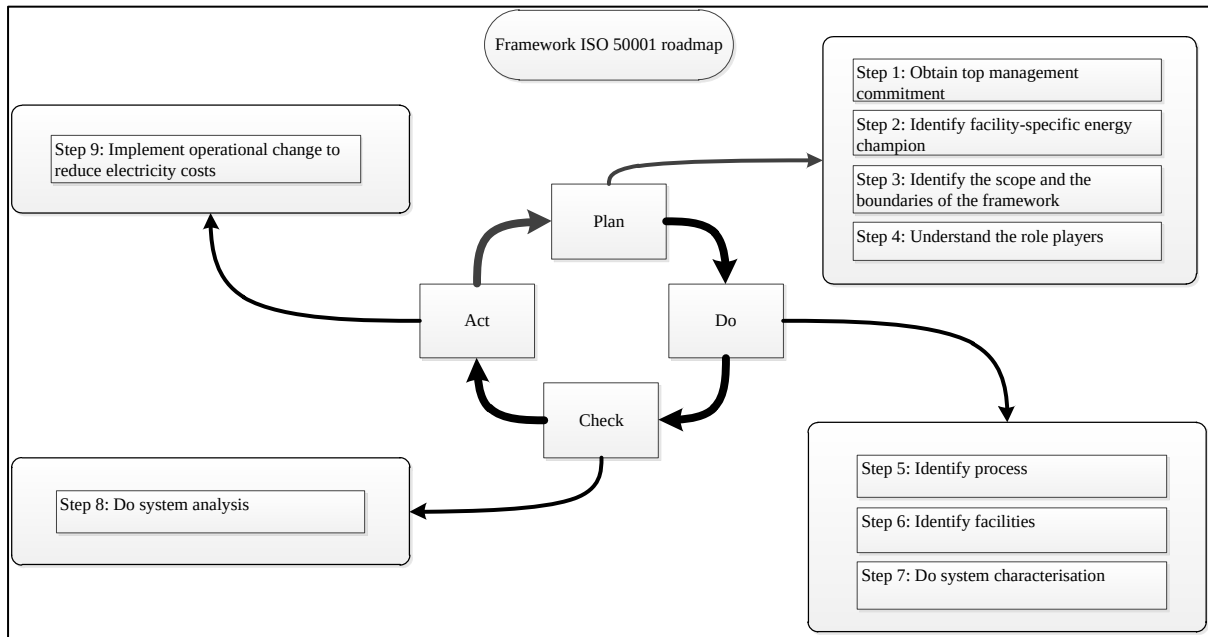


Figure 67: ISO 50001 roadmap

The step-by-step framework consists of nine steps that can be followed to implement the framework and achieve the roadmap goal. These steps are summarised below.

Step 1: Obtain top plant management commitment – Plan

- Obtain letter of appointment for an energy manager.

Step 2: Identify facility-specific energy champion – Plan

- Energy manager to document all energy champion appointments.

Step 3: Identify the scope of the framework – Plan

- This framework is developed for operational changes with electricity as boundary.
- Study the framework overview to understand the framework flow.

Step 4: Understand the role players – Plan

- Understand the energy policies and purchasing contracts of the steelmaking plant (if available).
- Understand the governmental regulations in South Africa.
- Understand Eskom's pricing structure and energy purchasing contract.
- Understand the 12L tax incentive and obtain documentation from SANEDI.
- Understand how to evaluate electricity cost savings and the tracking thereof.

Step 5: Identify process – Do

- Study the process for steelmaking at the plant.

Step 6: Identify facilities – Do

- Study the facilities as part of the larger steelmaking plant.

Step 7: Do system characterisation for identification and prioritisation – Do

- Do a black-box analysis.
- Do an energy balance.
- Obtain facility total power usage and rank it.
- Calculate electricity intensity and rank it.
- Obtain system parameters and system layouts.
- Identify the facility with the operational initiative to be analysed.

Step 8: Do system analysis for project feasibility and implementation – Check

- Document a system description.
- Identify the operational data that influences the facility.
- Identify and document the operational constraints.
- Identify all the energy carriers in the facility.
- Identify and list the SEUs.
- Identify possible operational change scenarios.
- Identify the important measurements for simulation purposes.
- Simulate a baseline for the facility in terms of electrical energy.
- Simulate the process change to obtain electricity cost savings.
- Check the feasibility of the project in terms of electricity cost reduction.
- Do a detailed project investigation and feasibility calculation.
- Submit proposal.

Step 9: Implement operational change to reduce electricity costs – Act

- Document savings.
- Report on findings from the framework and savings obtained.

3.8 Conclusion

Chapter 3 focused on developing the framework for operational changes to reduce electricity cost. It is the core of the study and this thesis. All the models and techniques used in the framework will be verified and validated in Chapter 4. The chapter focused on the following building blocks as part of the framework:

- Facility engagement and planning;
- Role players; and
- Operational flow.

The framework was developed incorporating techniques in the industry as well as standards in the steelmaking industry.

Chapter 4: Implementing the framework to reduce electricity costs



Hot rolled coil¹⁸

¹⁸ SMC metal fabricators, “Equipment list,” SMC metal fabricators, [Online]. Available: <https://www.smcmetal.com/equipment-capabilities/equipment-list-2.html>. [Accessed 25 October 2016].

4.1 Introduction

In Chapter 2, literature was gathered to aid in developing a framework for operational changes to reduce electricity costs. The development of the framework, as discussed in Chapter 3, focused on the South African steelmaking environment amidst an economic growth strain period.

In this chapter, the implementation of the framework is evaluated on two of South Africa's largest steelmaking plants. Both steelmaking plants form part of the same global company. If the framework can be applied successfully to the steelmaking plants, it will validate the impact of the framework and the objective of electricity cost savings.

The framework provides steelmaking plants with an easy-to-use and step-by-step guideline for operational changes to obtain electricity cost savings. The implementation of the framework focuses on applying the steps to identify, prioritise and implement electricity cost saving initiatives through operational changes. The framework steps incorporate the ISO 50001 methodology. The following sections in Chapter 4 discuss the implementation and application of the framework in detail.

4.2 Implement the framework: Case Study 1

4.2.1 Background on Plant A

Plant A is a steelmaking plant situated in South Africa and form part of a global steel group. Plant A is one of the largest suppliers of flat steel products in sub-Saharan Africa. The plant is an inland steelmaking plant, which makes it unique – especially for the export market. The objective on corporate level for Plant A is to grow an established share in the local steel market in South Africa.

Plant A has the capacity to produce 2.9 million tonnes of liquid steel per annum. In 2014, Plant A used 75% of its available capacity. Plant A has completed two capex projects in 2016, namely, installing BOF off-gas coolers Units 1 and Unit 2, as well as converting capability to produce double-reduce material. It is evident that limited capex is spent on projects for this steelmaking group. No capex was specifically spent on reducing electricity costs.

Plant A is used to verify the framework. An Eskom DSM-funded project was identified and implemented by an ESCo together with Plant A. The compressor plant was identified as the highest priority plant for implementing operational changes to reduce electricity costs.

The electricity cost saving project implemented by the ESCo was the project identified on the compressor plant within the framework. The compressor plant forms part of the infrastructure unit on Plant A. The application of the framework on Plant A and the resulting electricity cost reduction are discussed in the subsections that follow.

4.2.2 Facility engagement

Step 1: Obtain top management commitment – Plan

Top management commitment was received for Plant A and an energy team appointed. The energy team leader was appointed within the Business Improvement Unit of the plant. The energy manager is tasked with reducing energy costs on the plant – not only focusing on electricity cost savings, but also on all energy commodities. The energy manager reports quarterly to the executive committee of the plant.

Step 2: Identify facility-specific energy champion – Plan

An energy champion was appointed on each of the facilities. The facility-specific energy champion is tasked with executing energy cost saving measures on the specific facility where appointed. The appointments were handled by the energy manager. Due to confidentiality, no names or appointment letters may be disclosed in this thesis.

The energy manager appointed the facility-specific energy champions prior to the framework being implemented on Plant A. Although the energy manager and facility energy champions have already been appointed, this step forms part of the overall framework for electricity cost reductions. The responsibilities of the energy champion were reviewed and it was understood that Plant A energy champions are committed to the specific responsibilities.

Step 3: Identify the scope and boundaries of the framework – Plan

For Plant A, the scope of the framework is to obtain electricity cost savings through operational changes with no capex. The framework developed in Chapter 3 is implemented on Plant A. The objective within the framework is to identify, prioritise and implement operational changes to obtain electricity cost savings.

Plant A is under economic strain and no capex is available for energy cost saving projects. The framework focuses on electricity cost reduction only. This is because coal is integrated in the process as input to ironmaking.

Coal, in the form of coke, is required in the reduction of iron ore. The coke burns in the blast of hot air to form carbon dioxide, which is a strong exothermic reaction. This reaction is the main source of heat for the furnace [59].

Electricity contributes more than gas to the total cost of the plant's energy use. Since it is the second-largest cost contributor, it is the preferred energy source to focus on.

Plant A and Plant B (to be discussed in Section 4.4) management summarised the following outlook for 2016 in the yearly financial results:

- Gross domestic product growth: 0.2% for South Africa while 6.5% for China;
- Plant A and Plant B expected to retain market share;
- Average steel price expected to improve;
- Operational excellence initiatives to contribute; and
- Profitability dependent on delivery of current ongoing initiatives.

The outlook for current gross domestic product growth in South Africa is dim with only 0.2% growth. Both Plant A and Plant B depend on operational excellence initiatives to contribute to the profitability and sustainability of these plants within the South African and global steel market.

4.2.3 Role players

Step 4: Understand the role players – Plan

The role players for achieving the objective were identified in Section 3.3.1. Plant A is no different to the norm. The role players were evaluated and considered. Table 29 shows the summary of the role players that are involved with Plant A to implement the proposed framework.

Table 29: Summary and description of Plant A's role players

Role players	No. 1	No. 2	No. 3	No. 4
Steel plant	Plant A is responsible for appointing an energy management team (internal or external).	Plant A will evaluate possible projects identified and determine their feasibility.	Plant A will sign off on any proposed operational changes.	
Regulation	Plant A complies with steel regulations and standards (SANS 10400-M).	Plant A is registered as a tax entity and complies with SARS tax regulations.	Plant A is not ISO 50001-certified, but is working towards compliancy.	Plant A is dependent on government policies regarding import duties.
Eskom	Plant A purchases electricity from Eskom on a Megaflex tariff structure.	Plant A is dependent on procurement of DSM IDM-funded projects.	Plant A will be audited by the Eskom project engineer for DSM-funded projects.	
12L tax incentive	Plant A will be eligible for a 12L tax break if funding is granted for an application.	Plant A will be audited by an energy management company to verify the 12L tax claim.		
M&V	Independent M&V teams will audit Plant A with the implementation of DSM-funded projects and for a tax rebate claim.			

Evaluate the project

Plant A evaluated the success of the framework-proposed operational changes for electricity cost reductions with the following known evaluation techniques as discussed in Chapter 3:

- ROI (in percentage);
- Simple payback period (in years);
- Internal rate of return (in percentage); and
- NPV (in rand).

Understand the KPIs

The KPIs for Plant A are set out by the chief technical officer. Plant A uses kWh/t liquid steel produced for production facilities. Within the application of the framework, it is not required to identify new KPIs. kWh/t is used as the main KPI for implementing operational changes to reduce electricity cost on Plant A.

4.2.4 System characterisation

Step 5: Identify process – Do

PFDs and liquid steel production data was obtained from Plant A. The steelmaking process used on Plant A is the integrated BF-BOF process. The complete BF-BOF process PFD and a snapshot of the data important for decision-making can be seen in Appendix D: Plant A – Case Study 1.

Step 6: Identify facilities – Do

In this step of the framework, all the facilities on steelmaking Plant A were identified using the four primary facility building blocks identified in the framework. Table 30 shows the primary and secondary building blocks, and the 26 facilities identified on Plant A. These facilities will be considered in the prioritisation model.

Table 30: Identified facilities on Plant A

Primary building blocks	Secondary building blocks
Ironmaking	Sinter plant
	Coke plant
	Two blast furnaces
	Direct reduction plant
	Foundry
Steelmaking	BOF
	Secondary metallurgy
	Continuous casting
Finishing products	Continuous pickling plant
	Cold mill
	Hot strip mill
	Plate mill
	Batch annealing
	Continuous annealing

Primary building blocks	Secondary building blocks
Infrastructure	Hot dip galvanising
	Electrolytic galvanising
	Tin plating
	Organic coating
	Compressor plant
	Water treatment plant
	Boilers
	Power plant
	Buildings
	Transport
	Flares

Step 7: Do system characterisation for identification and prioritisation – Do

Do a black-box analysis

Firstly, a black-box analysis was performed on all the facilities identified in Step 6. This can be seen in Appendix D: Plant A – Case Study 1. Figure 68 shows the sinter plant and BOF plant facility for Plant A. The energy streams enter the facility from the top as indicated with the red shapes.

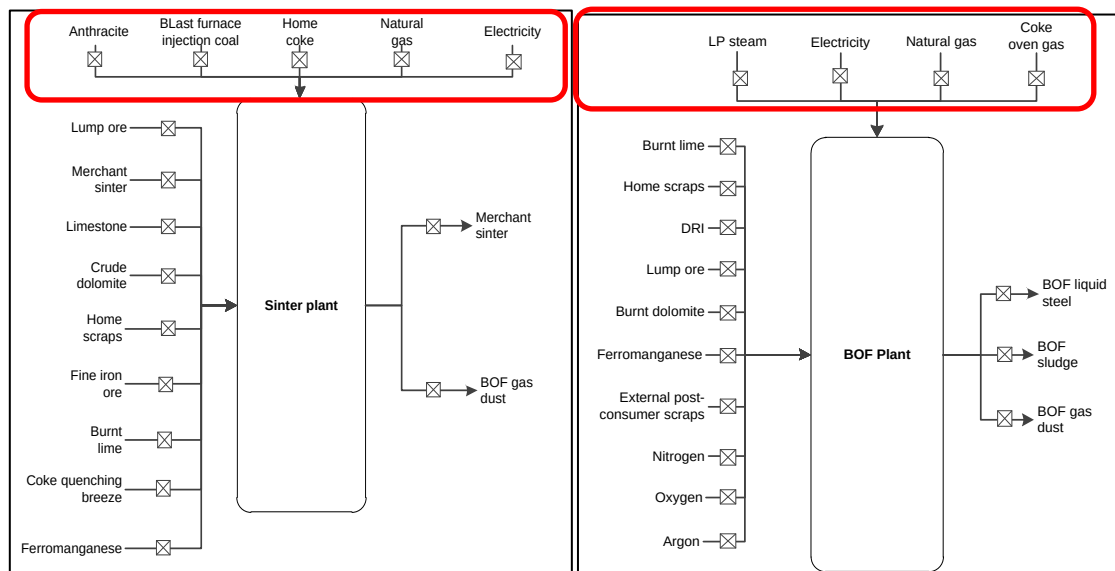


Figure 68: Black-box analysis for the sinter and BOF facilities of Plant A

Balance the energy

After the black-box analysis has been completed, the energy balances for the facilities commenced. The energy balance data can be seen in Appendix D: Plant A – Case Study 1. Together with the energy balance, an energy source cost contribution breakdown and a Sankey diagram were compiled.

Table 31 shows some of the energy data used in the energy balances. The data used in the energy balance is for one year.

Figure 69 shows the breakdown of energy commodities in terms of costs. Electricity is the second-largest energy contributor in terms of cost for Plant A. The gap between electricity and, both natural and industrial gas, is a large margin supporting the case of specifically focusing on reducing electricity cost.

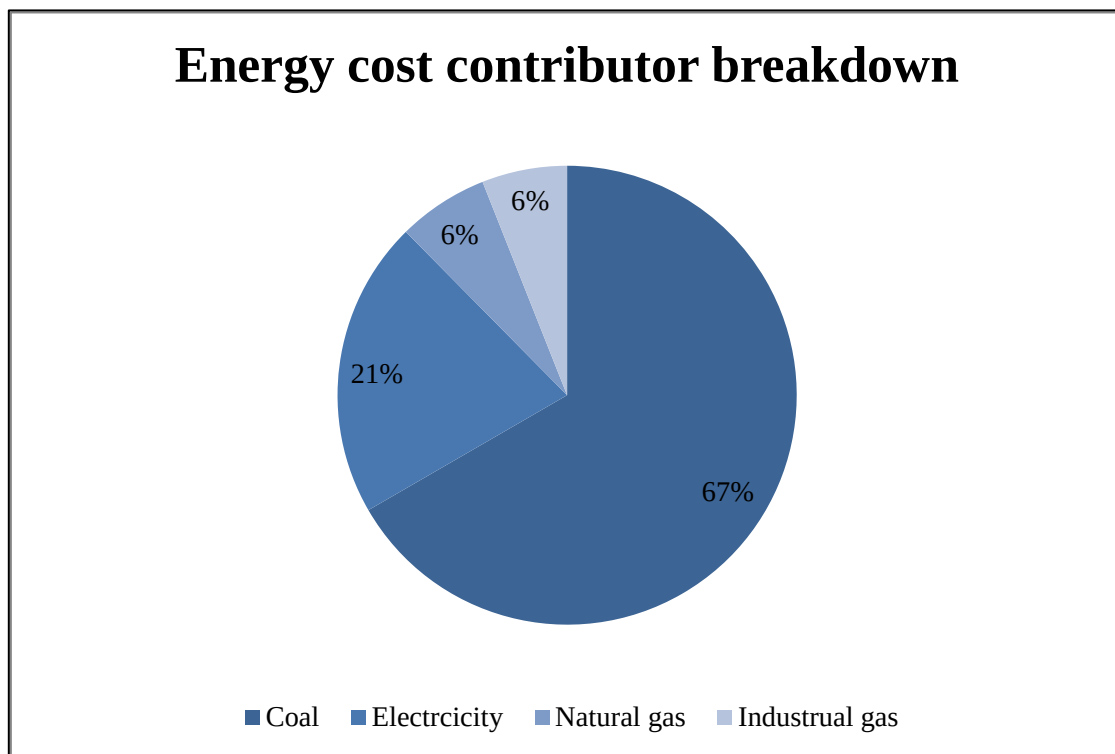


Figure 69: Breakdown of energy source in terms of costs (R) for Plant A

Table 31: Energy balance sheet for the facilities on Plant A

Process no.	Process name	Electricity (GJ)		HP steam (GJ)		LP steam (GJ)		Steam (GJ)		Total coal (GJ)	
		Input	Output	Input	Output	Input	Output	Input	Output	Input	Output
1	Coke plant	37 432			0	338 909		338 909	0	1 157 486	858 388
2	Sinter plant	147 282						0	0	142 453	
3	Blast furnace	107 914				54 339		54 339	0	1 331 604	
4	Direct reduction	54 016	38 397	155 135	301 044		260 163	155 135	561 207	474 699	
5	BOF plant	80 421				10 538		10 538	0		
6	Secondary metallurgy	57 555						0	0		
7	Continuous casting	27 303						0	0		
8	Hot strip mill	197 096				11 122		11 122	0		
9	Plate mill	24 346						0	0		
10	Pickling plant	21 198				65 871		65 871	0		
11	Cold rolling	72 608				54 857		54 857	0		
12	Continuous annealing	69 234				30 106		30 106	0		
13	Batch annealing	15 431						0	0		
14	Hot dip galvanising	57 517				1 427		1 427	0		
15	Electro-galvanising	14 148				2 057		2 057	0		
16	Tinplating	28 548				48 452		48 452	0		
17	Organic coating	6 372				14 078		14 078	0		
18	Foundry plant	4 404						0	0		
19	Power plant		131 737	644 704		57 396		702 100	0		
20	Boilers	2 508		221 458	1 410 576		0	221 458	1 410 576		
21	Compressed air plant	370 849						0	0		

Process no.	Process name	Electricity (GJ)		HP steam (GJ)		LP steam (GJ)		Steam (GJ)		Total coal (GJ)	
		Input	Output	Input	Output	Input	Output	Input	Output	Input	Output
22	Water treatment plant	25 608				186 161		186 161	0		
23	Internal transports							0	0		
24	Buildings	6,682						0	0		
25	Others	15,918				69,683		69,683	0		
26	Flares					5,490		5,490	0		

The Sankey diagram is compiled using the energy balance data for one year. It shows the contribution of each energy stream in Plant A to and from all facilities. The Sankey diagram is ideal because it shows the energy balances visually in the form of the process at hand.

Figure 70, which is a screenshot of the compiled Sankey diagram, shows that the coal energy stream and the off-gases with large calorific values contribute the largest portion to the energy flow on Plant A. Infrastructure, which contains the compressor plant, uses the largest portion of the electricity per primary building block on Plant A.

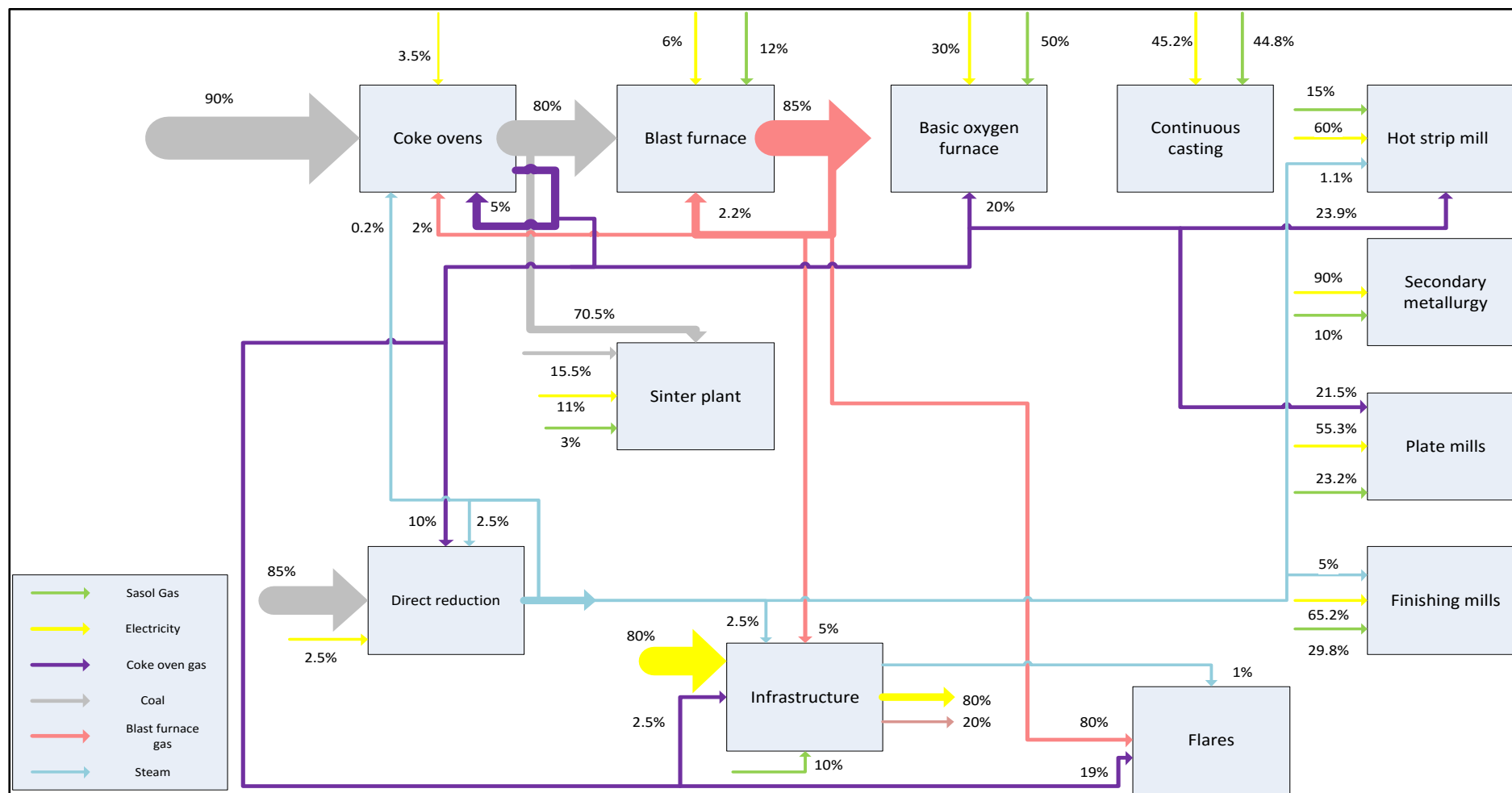


Figure 70: Sankey diagram to identify the size of the different energy streams

Total facility power and facility electricity intensity

Total facility power is one of the variables that determines the ranking of the facilities for implementing operational changes t/o reduce electricity cost. The total power is acquired in total average MW for one year on all the facilities. This data is incorporated in the total energy balance sheet for the plant.

For Plant A, the data is readily available on the local SCADA. The data is shown in Appendix D: Plant A – Case Study 1. Figure 71 ranks the facilities from the facility with the largest power use to the facility with the lowest power use. Over a period of one year, the compressor plant facility was the largest power consumer on Plant A. The foundry plant and boilers use the least amount of electricity if it is considered that transport, flares and the power plant use negligible small amounts of power as indicated in Figure 71.

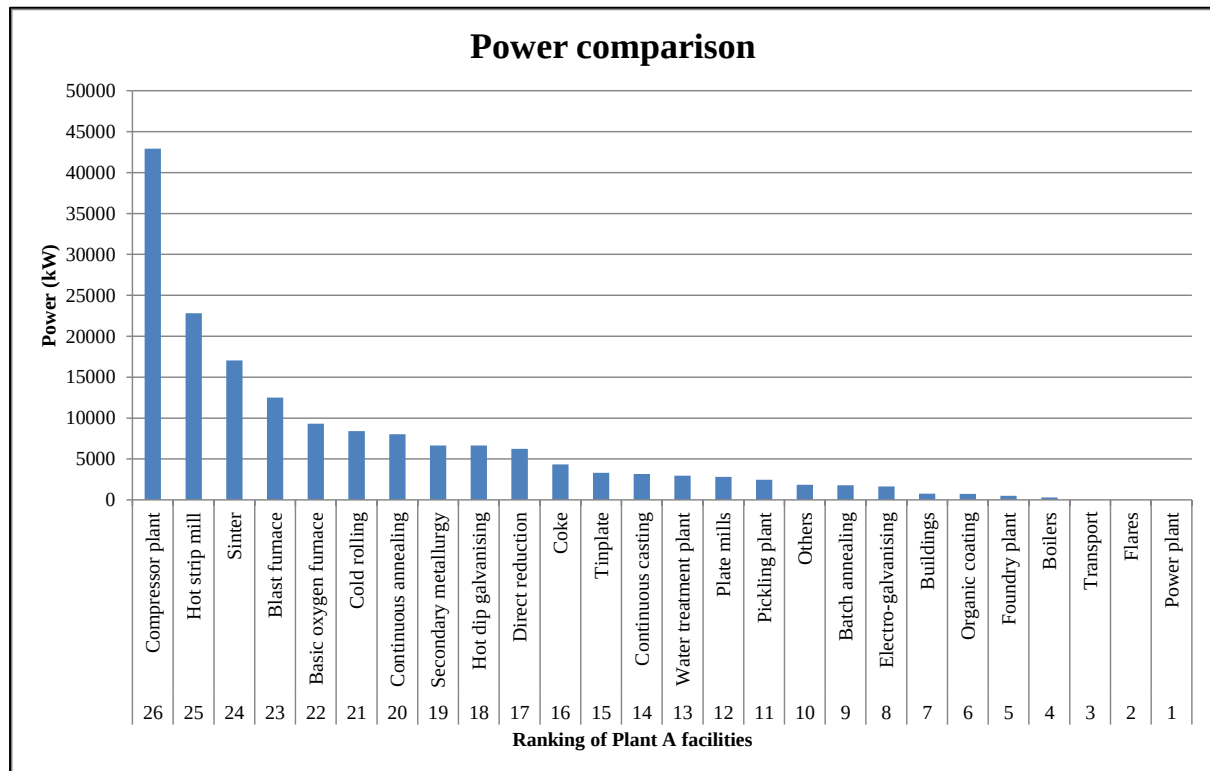


Figure 71: Plant A total facility power

After the total power has been ranked, the electricity intensities are calculated for all facilities. The intensities were ranked from the highest to the lowest intensity in terms of MWh/t. ‘Intensity’ means the amount of electrical energy used per tonne of product produced. The intensity can be calculated using either power or energy. A plant with a high

electricity intensity uses a higher amount of power for the same amount of production than a plant with low electricity intensity.

The electricity intensity ranking forms part of the identification and prioritisation model and is an input for the model. Figure 72 shows the ranking with the foundry plant being the highest and coke-making facility one of the least electricity-intensive facilities. The foundry plant has a ranking of 26 while the power plant has a ranking of 1. The facility with the highest power usage is not necessarily the facility with the highest electricity intensity. Although the foundry is electricity-intensive, it is ranked the fifth-lowest electricity consumer on Plant A.

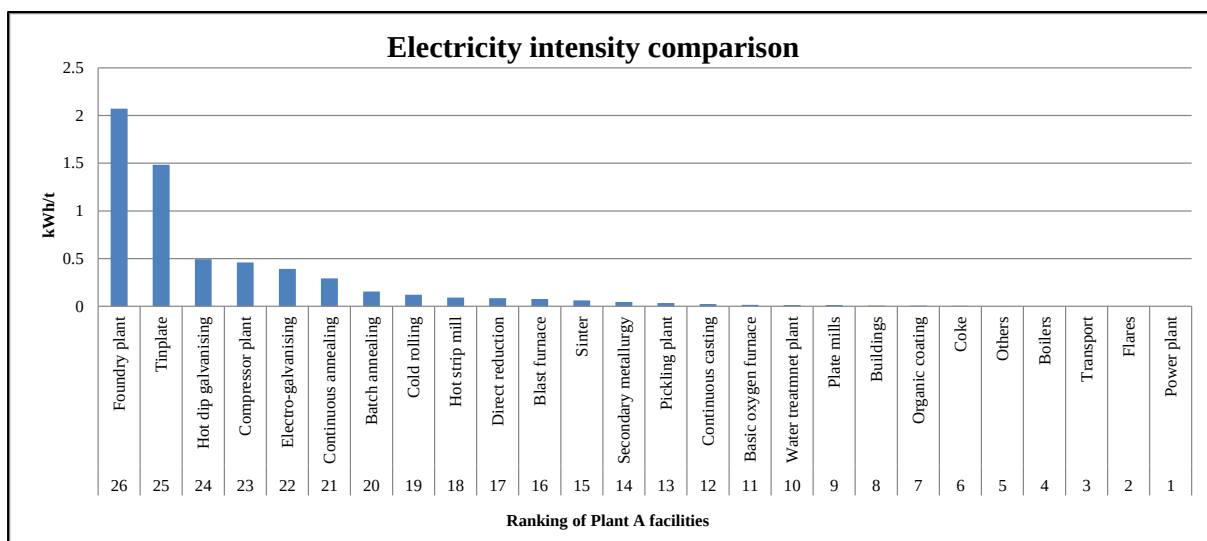


Figure 72: Electricity intensity comparison for Plant A

Complete system parameters and layouts

Plant A is used to verify the developed framework. A cost reduction initiative was implemented on the compressor plant. The system parameters were only obtained for the compressor plant. The parameters and layouts can be seen in Appendix D: Plant A – Case Study 1. The data that was obtained focused on the three levels of measurement for the compressor plant.

- First level: Holistic data approach:
 - Total facility power, compressed air pressure and airflow rate.
- Second level: Equipment-specific approach:
 - Data such as inlet guide vane angles, running statuses and compressor-specific power and flow rates.

- Third level: Measurements:
 - Bearing and motor temperatures to identify system constraints.

Although the data was obtained in this step of the framework, the data is only analysed, used and discussed in the system analysis step in Section 4.2.5.

The layouts obtained for the compressor plant facility during the implementation of the framework are the following:

- PFD;
- Control layouts;
- Electrical layouts; and
- PID.

These layouts can be seen in Appendix D: Plant A – Case Study 1.

Identify initiative for electricity cost reduction through operational changes

The critical evaluation question sets developed in Chapter 3 are applied on all the facilities and the results are shown in Table 32. Figure 73 shows the foundry plant operational change identification. There is no total plant power available for the foundry plant; it is a batch process. This means that only energy efficiency and peak clipping would be viable operational changes for the foundry plant.

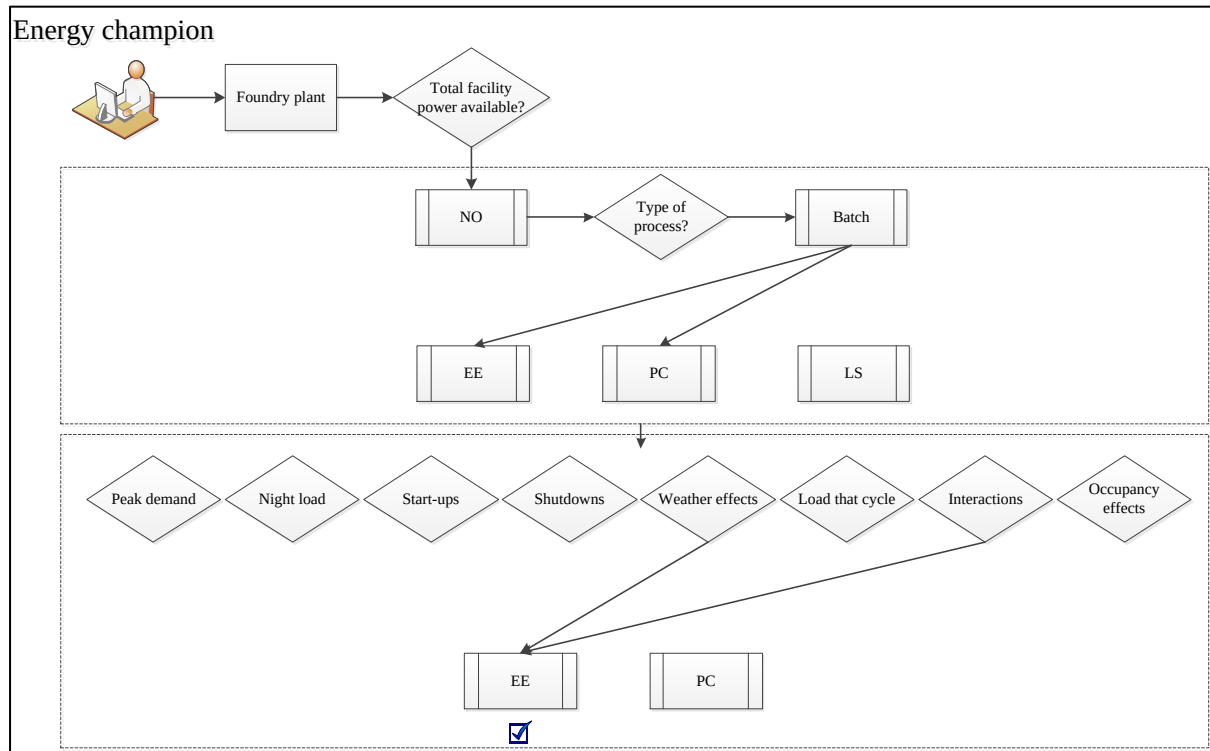


Figure 73: Operational change identification flow

Weather might influence the power as well as the interaction between facilities. Both operational effects point to energy efficiency as the preferred operational change initiative. The identification for some of the other facilities is shown in Appendix D: Plant A – Case Study 1. This is to understand how the critical evaluation is applied to identify the operational change possible on a specific facility.

Table 32: Critical evaluation applied on Plant A's facilities

Plant A specific facility	Question Set 1	Question Set 2	Question Set 3	Initiative for model
Foundry plant	No	EE, PC	EE	EE
Tinplate	No	EE, PC, LS	PC, LS	PC
Hot dip galvanising	No	EE, PC, LS	EE, PC, LS	EE
Compressor plant	Yes	EE, PC, LS	EE,	EE
Electro-galvanising	No	EE, PC, LS	PC, LS	LS
Continuous annealing	No	EE, PC, LS	PC, LS	LS
Batch annealing	No	EE, PC	EE,	EE
Cold rolling	No	EE, PC,	PC, LS	LS
Hot strip mill	No	EE, PC, LS	PC, LS	PC
Direct reduction	No	EE, PC, LS	EE	EE
Blast furnace	No			

Plant A specific facility	Question Set 1	Question Set 2	Question Set 3	Initiative for model
Sinter	No	EE, PC, LS	EE	EE
Secondary metallurgy	No			
Pickling plant	No	EE, PC, LS	PC, LS	LS
Continuous casting	No			
BOF	No			
Water treatment plant	No	EE, PC, LS	EE, PC, LS	EE
Plate mills	No	EE, PC, LS	EE, PC, LS	LS
Buildings	No	EE, PC, LS	EE, PC, LS	EE
Organic coating	No	EE, PC, LS	EE,	EE
Coke	No	EE, PC, LS	EE	EE
Others	No	EE, PC, LS	EE, PC, LS	EE
Boilers	No	EE,	EE, PC, LS	EE
Transport	No	EE, PC, LS	EE, PC, LS	EE
Flares	No	EE,	EE,	EE
Power plant	No			

A power profile needs to be compiled for each of the facilities. To verify the framework, the operational changes were implemented on the compressor plant. Due to some facilities not being equipped with power meters, only the compressor plant had a total power profile available. At the time of thesis write-up, power meters have been installed on the different facilities.

Figure 74 shows the total power for the compressor plant facility with a 2 MW fluctuation on the total power baseline. After initial investigation, it was found that each low-pressure compressor had an installed capacity of 8 MW, which meant that the 2 MW fluctuation was not on- or offloading of a compressor. Load shifting would therefore not be a feasible option. The critical evaluation question sets together with the power profile identified an energy efficiency project as a possible operational change for electricity cost reduction.

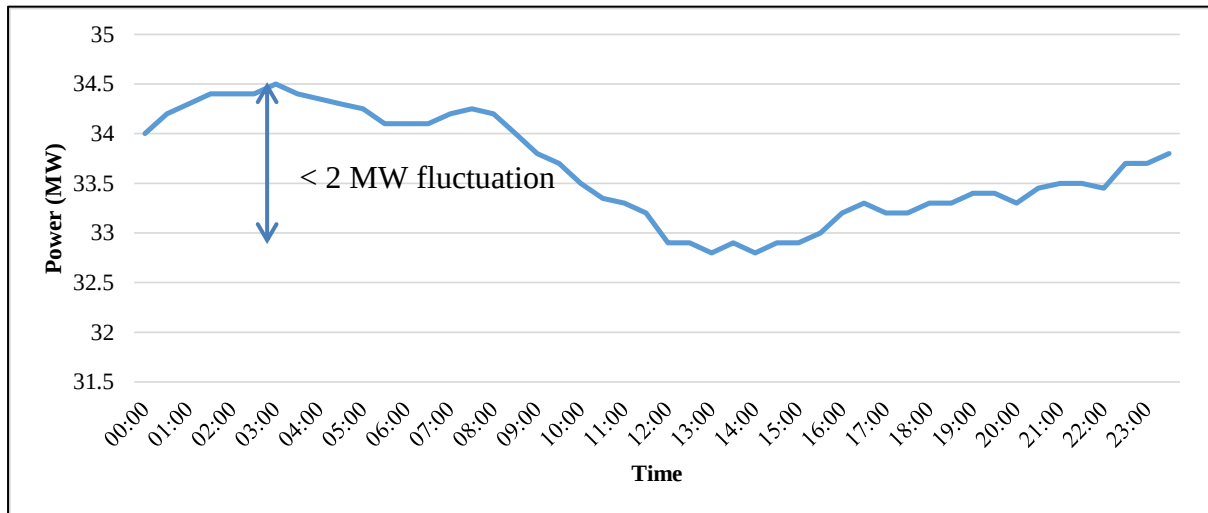


Figure 74: Compressor plant total power profile

Prioritise the facilities for electricity cost reduction through operational changes

The prioritisation model was applied to the facilities on Plant A to identify and prioritise the facilities for electricity cost reduction initiatives through operational changes. The application of the model to Plant A's facilities with the development of the functions are shown in Appendix D: Plant A – Case Study 1. The result of the applied model is shown in Figure 75. It can be seen that the Compressor plant are the highest ranked plant.

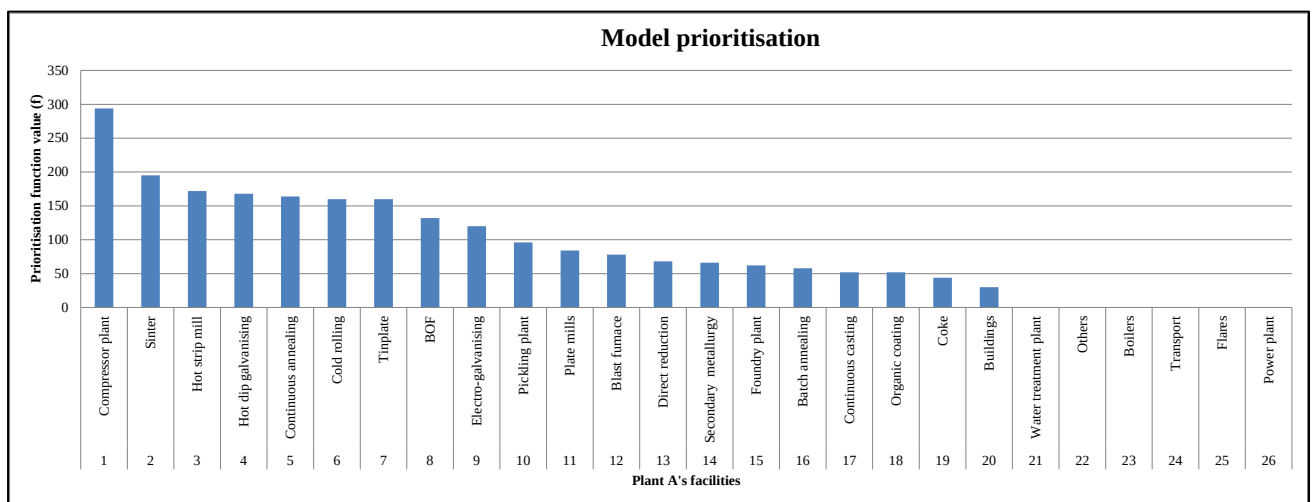


Figure 75: Model output and prioritisation for operational changes

Table 33 gives the results of the model with the function for prioritisation. The compressor plant is first and the sinter facility second. The application of the prioritisation function is shown in Appendix D: Plant A – Case Study 1. The compressor plant is prioritised as the first facility for operational changes to reduce electricity costs.

Table 33: Facility identification and prioritisation result for Plant A

Number	Facility	(f)
1	Compressor plant	294
2	Sinter plant	195
3	Hot strip mill	172
4	Hot dip galvanising	168
5	Continuous annealing	164
6	Cold rolling	160
7	Tinplate	160
8	BOF	132
9	Electro-galvanising	120
10	Pickling plant	96
11	Plate mills	84
12	Blast furnace	78
13	Direct reduction	68
14	Secondary metallurgy	66
15	Foundry plant	62
16	Batch annealing	58
17	Continuous casting	52
18	Organic coating	52
19	Coke	44
20	Buildings	30
21	Water treatment plant	0
22	Others	0
23	Boilers	0
24	Transport	0
25	Flares	0
26	Power plant	0

In Section 4.2.5, the compressor plant will be analysed first to identify how the operational changes will influence the facility. The initiative is simulated for the specific plant to determine the feasibility of an initiative.

4.2.5 System analysis

Step 8: Do system analysis for project feasibility and implementation – Check

Document the system description and operational data

The compressed air system at Plant A consists of two systems, a low-pressure ring and a high-pressure ring. The low-pressure compressors include five centrifugal compressors. The low-pressure ring supplies Blast Furnace C and Blast Furnace D as well as the high-pressure inlet. The high-pressure compressors include two four-stage centrifugal compressors.

The high-pressure ring supplies instrumentation air to the different facilities. The compressor specifications are indicated in Table 34. Ambient air enters the clean air chambers of the low-pressure compressors where it is compressed to approximately 375 kPa at a volumetric flow rate of 2 000 Sm³/min from each low-pressure compressor into a common manifold.

Table 34: Plant A compressor specifications

Compressor	Motor power rating [kW]	Max flow [Sm ³ /min]	Priority
LP1	9 600	2 500	Baseload
LP2	9 600	2 500	Baseload
LP3	9 600	2 500	Baseload
LP4	9 600	2 500	Standby
LP5	9 600	2 500	Baseload
HP1	2 100	1 050	Baseload
HP2	2 100	1 050	Baseload

There are four low-pressure compressors running during normal operation with one compressor on standby. The compressed air is supplied to two high-pressure compressors, Blast Furnace D and Blast Furnace. A simplified compressed air layout of Plant A's compressed air system is illustrated in Figure 76.

The two blast furnaces are supplied with low-pressure air at approximately 300 kPa. The blast furnaces consume on average 2 800 Sm³/min (Blast Furnace C) and 3 800 Sm³/min (Blast Furnace D) respectively depending on the blast furnace load and production targets. During normal operation, both blast furnaces are operational, and four of the low-pressure

compressors supply the required compressed air. Cowper stoves, which preheat air for the blast furnaces, are filled approximately every 20 minutes. During this time, the total air consumption is increased by approximately 400 Sm³/min.

Approximately 2 000 Sm³/min of the low-pressure air is tapped off and used for the high-pressure ring. The two high-pressure compressors deliver air at 650 kPa at a flow rate of 1 900 Sm³/min over the first two stages, and at 1 250 kPa at a flow rate of 100 Sm³/min after the fourth stage. The air supplied to the instrumentation network is tapped off from the high-pressure compressors after the second stage of compression. The air supplied for PCI is tapped off after the fourth stage of compression from high-pressure compressors. Table 35 summarises the compressed air consumers and the operational data influencing the system.

Table 35: Compressed air consumers and operational requirements

Consumer	Average consumption [Sm³/min]	Average required pressure [kPa]
Blast Furnace C (low-pressure)	2 800	280
Blast Furnace D (low-pressure)	3 800	300
Works (high-pressure)	1 900	600–650
PCI air (high-pressure)	100	650
Stove filling (low-pressure)	400	300

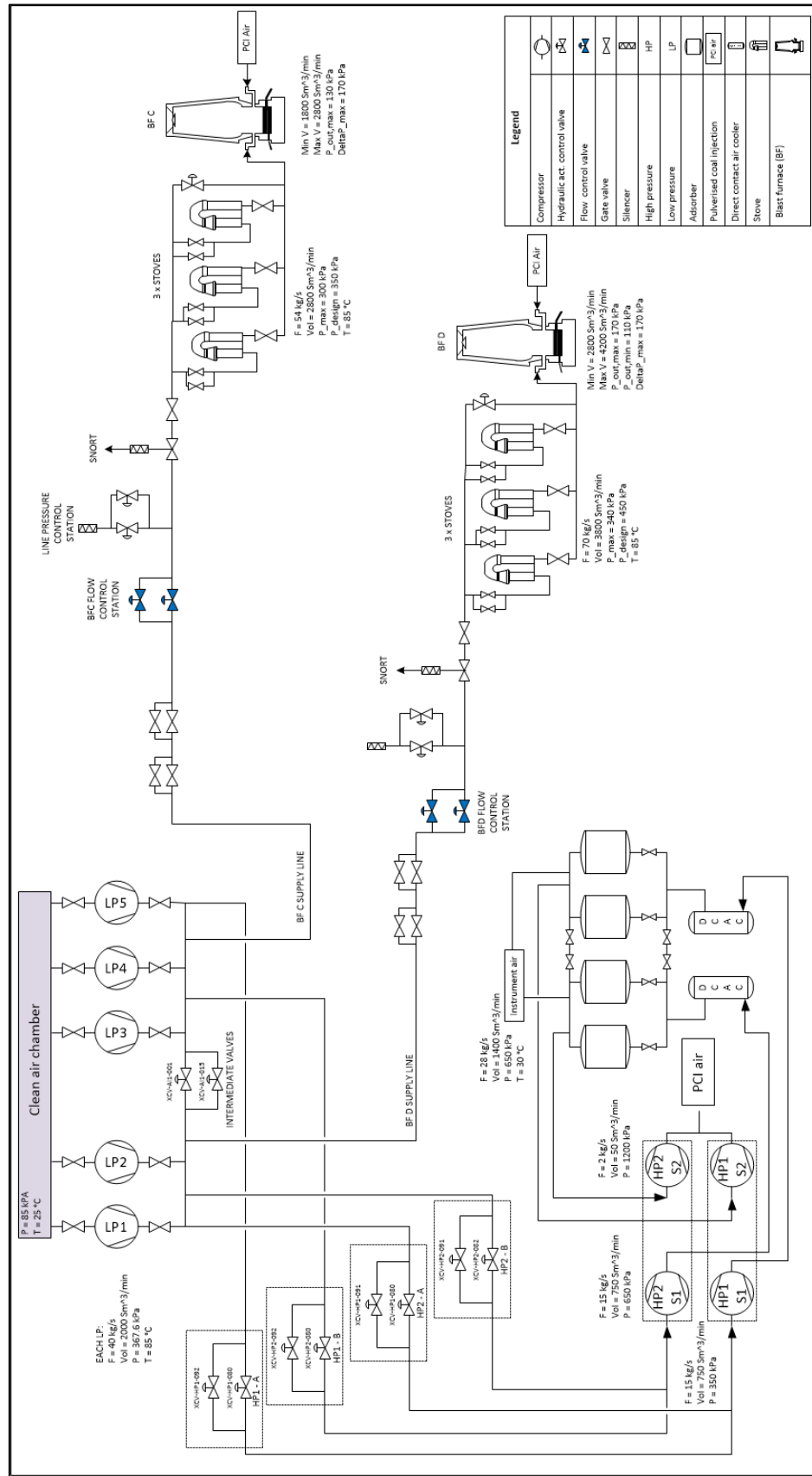


Figure 76: Plant A compressed air system layout

Identify and document the operational constraints

With present operation at the compressor plant facility, the compressor guide vane angle can vary between a minimum of 30% and a maximum of 70%. There are situations where the flow demand is below the minimum combined flow of the four low-pressure compressors. In this case, either the blow-off valves for some of the compressors are opened or one compressor is switched off.

Due to the present motor configuration and its operating range, the compressors cannot operate at a guide vane angle of more than 70%. In the case of the guide vane angle going higher than 70%, the motor exceeds its maximum rated power of 9.6 MW.

Identify all the energy carriers and SEUs in the facility

Compressors are the SEUs of the compressor plant. The energy source is electricity which is converted to compressed air, which is the energy carrier.

Identify possible operational change scenarios and a baseline

In times of low demand, one of the four compressors can either be offloaded or switched off per standard procedure. The remaining compressors will consume more power while operating at a higher guide vane angle, but will result in electricity cost saving.

In the case of high demand and a maximum of three compressors running, an additional compressor needs to be started to prevent operating at a guide vane angle above 70%. The low-pressure compressors can deliver the same flow with lower delivered header pressure. The operational control scenarios can be summarised as follows:

- The pressure set point on the low-pressure ring will be dropped from 375 kPa to 355 kPa.
- The load on the high-pressure compressors will increase.
- With only Blast Furnace D running, three low-pressure compressors are required.
- With Blast Furnace C and Blast Furnace D running, four low-pressure compressors will be needed.
- In an emergency, the set point of the low-pressure compressors will be reverted to 375 kPa and the system will be restored to its original operating conditions.

The demand for compressed air at the site is not seasonal and daily usage is expected to remain consistent for the duration of the assessment period. A three-month period of continuous metering was seen as sufficient to characterise the daily electricity demand. Weekdays, Saturdays and Sundays have been characterised separately. Historical data was available, which has been used to characterise the baseline.

Partial plant closure: In August 2015, Blast Furnace C was shut down. Blast Furnace C is an older, smaller furnace than Blast Furnace D. To cater for this abnormal operation, two baselines have been characterised.

Data from 2014 was used to determine the baseline for when both Blast Furnace C and Blast Furnace D operated simultaneously. Data from 2015 and 2016 was used to find an accurate baseline, which only applies to Blast Furnace D. Only the five low-pressure compressors were considered during the baseline and assessment periods. The identified energy efficiency intervention was possible only on these compressors.

In developing the baseline, the blast furnace flow set point was found to be the most suitable driver for determining the savings obtained from implementing an operational change scenario on the low-pressure compressors.

A linear regression model was developed from the blast furnace set point and the low-pressure power consumption data. The data range was from 7 September 2014 to 30 November 2014. Figure 77 shows the linear regression scatter plot. It can be observed from Figure 77 that the compressors consume approximately 16 MW at a flow set point of 0 Sm³/min.

A flow set point of 0 Sm³/min does not imply that compressors are stopped. The compressor control is configured to reduce compressor output to minimum safe conditions for a set point of 0 Sm³/min. Guide vanes angles will typically change to minimum openings. Blow-off valves will typically be opened to protect the compressors from surge at these conditions. Power will therefore still be consumed even though the flow set point is zero. Equation 11 shows the linear equation.

$$y = 3.2662x + 16045 \quad \text{Equation 11}$$

With

$x = \text{Blast furnace set point}$

$y = \text{Power consumption}$

$$R^2 = 0.9434$$

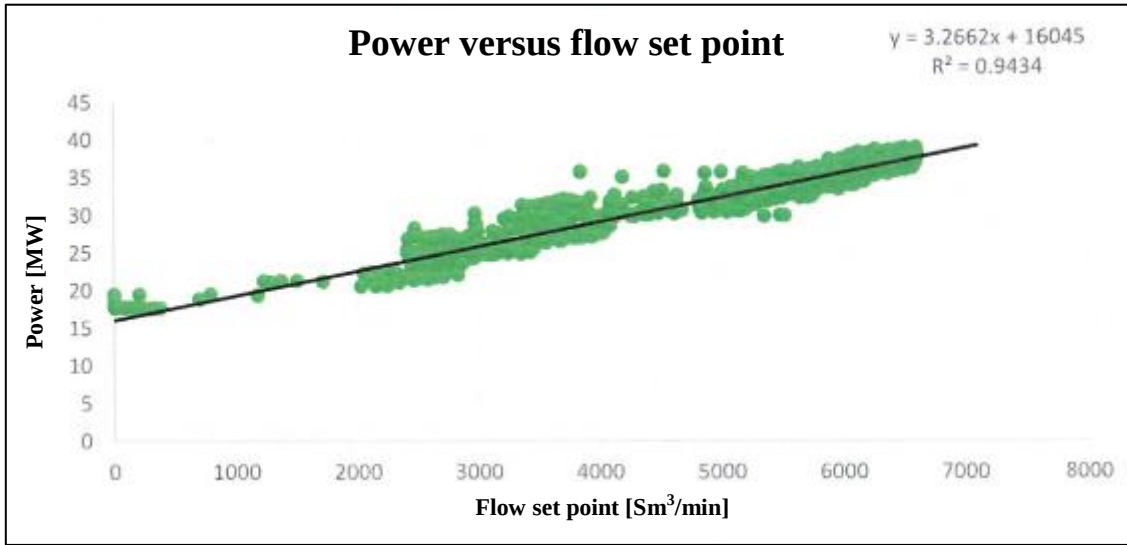


Figure 77: Linear regression scatter plot

From the same data, a power consumption power profile could be developed. The profile was multiplied with a scaling factor to determine a scaled baseline. The scaling factor was calculated using the linear regression model formula as follows:

$$\text{Factor} = \frac{3.2662x + 16045}{y} \quad \text{Equation 12}$$

With

$x = \text{Average blast furnace set point of day}$

$y = \text{Average baseline power}$

The baseline profile was presented in half-hourly intervals. It was calculated from the average half-hourly consumption for each day during the baseline period. Figure 78 shows the baseline power profile in half-hourly intervals for an average day.

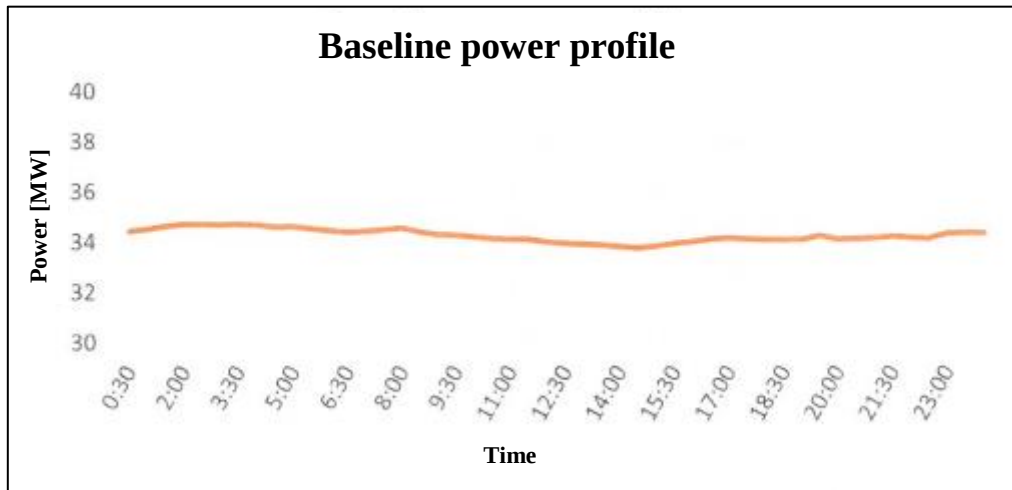


Figure 78: Baseline power profile

The half-hourly saving was calculated with the following formula:

$$\text{Power saving} = \text{Scaled baseline} - \text{Actual consumption} \quad \text{Equation 13}$$

The savings could therefore be calculated in half-hourly intervals to use the Eskom TOU tariff structure. The overall saving for the day was the average of the half-hourly savings.

Identify the important measurements for simulation purposes

Several measurements, layouts and data are required to complete a baseline and optimised simulation. When the baseline simulation was done, all the necessary data was available on the design specification sheet for the compressor plant. Table 36 shows the important data needed to complete the simulation. The compressor efficiency and the compressor motor efficiency were based on assumptions.

Table 36: Data required for simulation of operational changes

Variable	Unit
Five low-pressure compressor motor power rating	MW
Two low-pressure compressors motor power rating	MW
Compressed air flow at different points	kg/s
Compressed air pressure at different points	kPa
Compressor efficiency	0.95

Compressor motor efficiency	0.75
Air temperature at different points	°C

Simulate a baseline for the facility in terms of electrical energy

PTB was used for simulating the baseline for the compressor plant. Normal operating conditions were used for the simulation with historical data before the operational changes were made to reduce electricity costs. Historical data was not available for all the required variables and some of the data was gathered from design specification sheets.

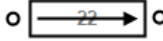
Table 37 shows the baseline simulation assumptions and data used. The simulation's layout is based on the actual plant layout. Table 38 shows the components used in the simulation.

Table 37: Baseline simulation assumptions

Description	Assumption
Atmospheric pressure	85 kPa
Intake air filter pressure drop	2 kPa
Low-pressure compressor inlet pressure	83 kPa
Low-pressure compressor outlet pressure	455 kPa (370 kPa gauge pressure)
Low-pressure compressor air flow rate	40 kg/s (2 100 Sm ³ /min)
Low-pressure compressor aftercooler pressure drop	5 kPa
Low-pressure common manifold valve position	Open
Low-pressure common manifold pressure	445 kPa (360 kPa gauge pressure)
Blast Furnace D flow requirement	70 kg/s (3 600 Sm ³ /min)
Blast Furnace D intake pressure	385 kPa (300 kPa gauge pressure)
Blast Furnace D top pressure	225 kPa (140 kPa gauge pressure)
Blast Furnace D pressure drop	160 kPa
Blast Furnace C flow requirement	54 kg/s (2 800 Sm ³ /min)
Blast Furnace C intake pressure	335 kPa (250 kPa gauge pressure)

Blast Furnace C top pressure	205 kPa (120 kPa gauge pressure)
Blast Furnace C pressure drop	130 kPa
High-pressure flow rate	15 kg/s (770 Sm ³ /min)
High-pressure Stage 1 inlet pressure	440 kPa (355 kPa gauge pressure)
High-pressure Stage 1 outlet pressure	745 kPa (660 kPa gauge pressure)
High-pressure Stage 2 outlet pressure	1 300 kPa (1 215 kPa gauge pressure)
PCI flow requirement	2 kg/s (100 Sm ³ /min)
PCI pressure	1 285 kPa (1 200 kPa gauge pressure)
Instrumentation flow demand	28 kg/s (1 450 Sm ³ /min)
Instrumentation pressure	710 kPa (625 kPa gauge pressure)

Table 38: PTB simulation components used and their application for this application

Simulation component	Component name	Component use in compressor plant simulation
	Air pressure boundary	Compressor plant inlet air conditions
	Air pipe	Inlet filter pressure drop and aftercooler pressure drop
	Air node	Specification of condition between two components and common manifold for the low-pressure compressors
	Air dynamic compressor	Low- and high-pressure compressors
	Air demand	Represents blast furnace compressed air flow demand
	Proportional integral controller	Controls the compressor on pressure reduction (operational change)

A dynamic compressor component was used in PTB. The dynamic compressor component generates pressure differences in the flow network to induce airflow through the network. For this thesis, an in-depth analysis of the simulation was not necessary. The important aspect was to understand the typical data that was required as well as the results obtained from the simulation. The simulation layout can be seen in Figure 79.

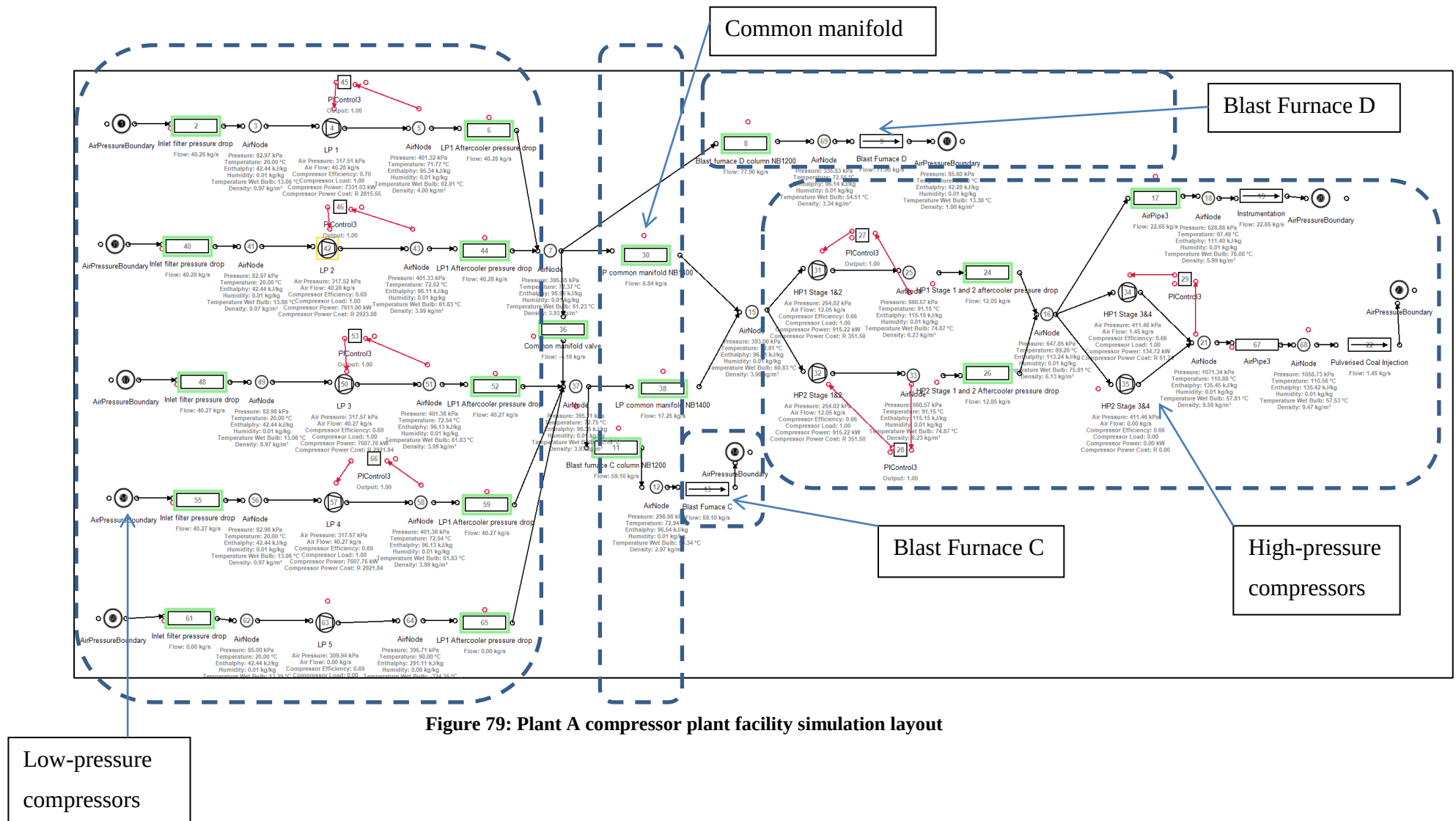


Figure 79: Plant A compressor plant facility simulation layout

Simulate the process change to obtain electricity cost savings

The process change for electricity cost reduction was based on lowering the low-pressure pressure set point by 20 kPa. With the lowered set point, energy efficiency could be achieved that resulted in electricity cost savings. Proportional integral controllers were used in the simulation to set a specific pressure set point for the low-pressure compressors.

Table 39 shows the operational change simulation assumptions. The simulations were run 168 times with 60 time steps each. After the simulation was run, the process change simulation was compared with the baseline simulation.

Table 39: Process change measure optimised assumptions

Description	Assumption
Atmospheric pressure	85 kPa
Intake air filter pressure drop	2 kPa
Low-pressure compressor inlet pressure	83 kPa
Low-pressure compressor outlet pressure	435 kPa (350 kPa gauge)
Low-pressure compressor air flow rate	40 kg/s (2 100 Sm ³ /min)
Low-pressure compressor aftercooler pressure drop	5 kPa
Low-pressure common manifold valve position	Open
Low-pressure common manifold pressure	425 kPa (340 kPa gauge)
Blast Furnace D flow requirement	70 kg/s (3 600 Sm ³ /min)
Blast Furnace D intake pressure	385 kPa (300 kPa gauge)
Blast Furnace D top pressure	225 kPa (140 kPa gauge)
Blast Furnace D pressure drop	160 kPa
Blast Furnace C flow requirement	54 kg/s (2 800 Sm ³ /min)
Blast Furnace C intake pressure	335 kPa (250 kPa gauge)
Blast Furnace C top pressure	205 kPa (120 kPa gauge)
Blast Furnace C pressure drop	130 kPa

High-pressure flow rate	15 kg/s (770 Sm ³ /min)
High-pressure Stage 1 inlet pressure	420 kPa (335 kPa gauge)
High-pressure Stage 1 outlet pressure	745 kPa (660 kPa gauge)
High-pressure Stage 2 outlet pressure	1 300 kPa (1 215 kPa gauge)
PCI flow requirement	2 kg/s (100 Sm ³ /min)
PCI pressure	1 285 kPa (1 200 kPa gauge)
Instrumentation flow demand	28 kg/s (1 450 Sm ³ /min)
Instrumentation pressure	710 kPa (625 kPa gauge)

Electricity cost reduction simulation result

PTB has a function where the optimised process change simulation can be compared with the baseline simulation. The comparison indicates the following results:

- Total energy (kWh);
- Average power (kW); and
- The total cost (R).

As can be seen from the screenshot from the simulation model in Figure 80, the results are indicated for both the simulations. First the baseline simulation's results are shown, then the operational change simulation's results, finally, the saving results. The saving results were calculated using the difference between the operational change simulation and the baseline simulation.

Baseline	Last	Saving
Total Energy (kWh) 315,454.00	Total Energy (kWh) 300,084.26	Total Energy (kWh) 15,369.74
Average Power (kW) 35,050.44	Average Power (kW) 33,342.70	Average Power (kW) 1,707.75
Total Cost (R) 165,882.07	Total Cost (R) 157,745.72	Total Cost (R) 8,136.35

Figure 80: Baseline simulation versus operational change simulation

The results show a total energy saving of 15 370 kWh for the compressor plant with a total cost saving of R8 136 over the period simulated. The results can be quantified to the total savings over a year. However, from this quick simulation analysis it is clear that a saving can be obtained with the proposed operational change.

Do a feasibility calculation

First, the feasibility calculations are done to consider the viability of the proposed operational change to reduce electricity costs. For this specific operational change, no capex was required from the plant. Eskom DSM funded an ESCo to implement the project, thus the capex is zero since the funding was received. No investment cost was necessary for the project. No installation was required from Plant A. The simple payback period is zero. The ROI for the project is zero.

Step 9: Implement operational change to reduce electricity costs – Act

Document savings

After the system analysis was completed, the identified operational changes could be implemented. This is necessary to understand the amount of electricity cost savings achieved. As previously explained, the operational changes proposed were implemented on Plant A and electricity cost savings were achieved.

Table 40 shows the energy efficiency savings achieved from June 2016 to August 2016. An average amount of 1.92 MW energy efficiency savings was achieved through operational changes to the compressor plant facility. The savings were calculated from the baseline developed previously.

Table 40: Energy efficiency savings achieved

Month	Energy efficiency saving (MW)
June	1.387
July	2.218
August	2.160
Average	1.922

Table 41 shows the electricity cost savings achieved through the operational changes. The cost saving for a 1.92 MW energy efficiency reduction could result in an annual cost reduction of R9.9 million.

Table 41: Cost savings achieved annually

Saving	Electricity cost saving
Winter	R3.6 million
Summer	R6.3 million
Total	R9.9 million

Report on findings from the framework and savings obtained

It is important to report on the success of the framework and the electricity cost reduction. An example of a report for the facility energy champion can be seen in Appendix D: Plant A – Case Study 1. It is important that the energy champion tracks the progress of the savings and the performance of the operational change results continuously.

4.3 Verification and validation of the framework

The framework developed in Chapter 3 was verified to identify if the specification has been met. The result of implementing the framework needs to show a reduction in electricity costs through operational changes. The framework consists of several elements that have specifications that need to be verified.

Table 42: Framework elements verified

Framework section	Element to be verified	Specification	Verification method
System characterisation	Identification and prioritisation model	Identify and prioritise the facility to implement operational changes on.	Excel-based simulation.
System analysis and implementation	Simulation	Simulation needs to project possible electricity cost reduction through operational changes.	Theoretical compressor calculations to identify the simulation.
	Cost reduction	Need to obtain electricity cost reduction with operational changes.	Use implemented results.
	Capex	Need to identify, prioritise and implement savings without capex investment.	Identify if any investment was required.
	Easy-to-use framework	Identify if the framework can easily be applied on a	Quantify the time to apply the framework.

Overall framework	Application	steelmaking plant.	
		Have all the elements been verified?	Verify all the elements.

Simulation

The compressor plant simulation was verified using the theoretical equation for compressed air. The theoretical calculation was done and a saving calculated with a 20 kPa drop in the low-pressure header set point.

Step 1:

The first step in the theoretical calculation was to determine the standard conditions. It was required to convert m^3/min to kg/s .

Table 43 shows the standard conditions for air.

Table 43: Standard conditions for air

Air parameters	Value
Density (kg/m^3)	1.2
T, K	288
P, Pa	101 000
R, ($\text{Pa} \times \text{m}^3$)/kg K	287.1

Using the values in Table 44 and a Sm^3/min value of 7 885 Sm^3/min , the standard conditions could be calculated as 160.7 kg/s . This value is used in Step 2 of the theoretical calculations.

Step 2:

Calculate the inlet conditions and convert kg/s to m^3/s by using Table 44 to convert mass in kg to volume in m^3 .

Table 44: Inlet conditions

Parameters	Value
Density (kg/m^3)	1.0
T, K	293
P, Pa	85 000
R	287.1
m, kg/s	160.7
V1, m^3	158.9

In order to calculate the volume flow, Equation 15 is used.

$$V = \frac{mRT}{P} \quad \text{Equation 14}$$

With $m = \text{molar mass}$
 $R = \text{universal gas constant}$
 $T = \text{absolute temperature}$
 $P = \text{pressure}$

Using the values in Table 43, $V = 158.86$.

With all the necessary values obtained and the variables calculated, the original power consumption, the reduced pressure and power consumption can be calculated (Equation 16).

$$WD = \frac{n}{n-1} P_1 V_1 \left[\frac{P_2^{\frac{n-1}{n}}}{P_1} - 1 \right] \quad \text{Equation 15}$$

With $n = \text{Compressor efficiency}$
 $P = \text{Pressure}$
 $V = \text{Volume flow}$
 $WD = \text{Work done}$

Using Equation 16, the power could be calculated. The inputs as well as the power consumption are shown in Table 45.

Table 45: Theoretical compressor power reduction calculation

	Original work done	Reduced pressure work done
n	1.4	1.4
P1, kPa atmospheric	85	85
V1, m³/s	159	159
P2, kPa gauge	375	355
Work done per second, kW	29 304	28 338
Efficiency	0.7	0.7
Power consumption, kW	42 470	41 070
Power per compressor, kW	10 618	10 267

Finally, the power saved could be calculated by subtracting the reduced pressure work done from the original work done. The saving achieved was 1.4 MW if the savings on the individual compressors were added. The predicted saving from the simulation was 1.7 MW. There is a difference of 300 kW because of system efficiency that improved and was

considered with the simulation. The theoretical calculation excluded system efficiency and only calculated the power saving from the compressor motor power. The simulation was therefore seen as verified by the theoretical calculation.

Electricity cost reduction

The framework guides the user towards implementing operational changes to reduce electricity costs. The savings obtained from the implementation on Plant A verified that cost savings in the range of R10 million can be obtained. This is a significant reduction in electricity costs and the electricity cost reduction element can be deemed verified.

“No capex”

The “no capex” element can be verified because the operational changes did not require any investment from Plant A. It is important to note that man-hours were used and software implemented. These costs were covered by the funding received from Eskom through DSM initiatives. The “no capex” element of the framework is thus verified through the implementation of the framework on Plant A.

Easy-to-use and quick to implement

This part of the framework has to be verified in terms of the time that was used to implement operational changes for electricity cost reduction. For this part of the verification, the capex plan for Plant B was used to identify the time to implement a normal identified capex project for electricity cost reduction. Due to confidentiality, only three projects are named.

The equations for feasibility discussed in Section 3.3.1 were applied and the results are shown in Table 46. Three capex projects, already identified by the plant, and the indicators calculated were also included in the table to compare the time for implementation and its related costs. The values from the plant were real values and were used as comparison for the operational change project. All the values were calculated over a one-year period. The following equations were used in obtaining the results:

$$\text{Payback period} = \frac{\text{Capex}}{\text{ZAR saving}} \quad \text{Equation 16}$$

$$\text{NPV} = (\text{ZAR saving} \times (\text{Estimated lifetime} - \text{Implementation time})) - \text{Capex} \quad \text{Equation 17}$$

$$\text{Required annual man- hours} = (\text{Implementation time} \times 0.1) + (\text{Estimated lifetime} \times 0.05)$$

$$\quad \text{Equation 18}$$

$$\text{Annual man-hour cost} = \text{Required annual man-hours} \times R2\,000\,000$$

Equation 19

Assumptions:

- R1 is assumed for zero capex spent.
- 10% of the compressor plant energy champion would be spent on implementing the operational change to reduce electricity cost.
- 5% of the compressor plant energy champion would be spent on the project performance for the lifetime of the project.
- One man-year costs R2 000 000 for involving a facility manager.

Table 46: Verification of project cost indicators and implementation time

No.	Project	Plant	Capex	MWh saving	GJ saving	Rand saving	Payback period	Imp. time	Estimated lifetime	Required man-years	NPV	Man-hour cost
1	Install VSD drive on induced draught fan 2.	Sinter	R440 000	701	2 523	R433 795	1.01	1	10	1.3	R3 464 157	R2 600 000
2	Replace soft starter with VSD	N/A	R1 500 000	693	2 497	R429 260	3.49	1	10	1.3	R2 363 340	R2 600 000
3	Replace existing light fittings and lamps with energy saving lighting at the whole plant.	N/A	R5 900 000	4 308	15 509	R2 666 400	2.21	2	10	1.6	R15 431 200	R3 200 000
4	Operational change	Compressor plant	R1	16 837	60 612	R9 907 910	0	0.5	10	0.55	R94 125 152	R1 100 000

The comparison in Table 46 shows that the operational change initiative satisfies the specification and the objective. The payback period is the shortest together with a shorter implementation time. The payback period is so small that it can be seen as zero. The required man-years are less than for the capex projects. The NPV, in terms of the current value, is an important indicator and is more than double that of the largest proposed capex project.

4.4 Implement the framework: Case Study 2

4.4.1 Background on Plant B

Plant B is a steelmaking plant situated in South Africa and forms part of a global steel group. Plant B is South Africa's foremost supplier of profile products. This plant is regarded among the lowest billet cash-cost producers in the world. Plant B employs around 2 050 permanent and 630 contract employees.

Plant B has a capacity of 1.9 million tonnes of liquid steel per annum, which is 1 million tonnes less than Plant A. Plant B focuses on profile products such as low- and medium-carbon commercial grades, micro-alloyed and high-alloy steels. Over the past year, significant capex has been invested to refurbish parts of the plant. According to plant management, these investments have optimised plant operation and sustained global competitiveness.

Plant B's management focuses on expanding its strong position in the African steel market. To expand the position, continuous improvement is required in all business units. For this reason, the developed framework is applied to Plant B to identify and prioritise operational changes for electricity cost reduction. Plant B and Plant A form part of the same global company. Step 1 to Step 4 of the framework for Plant B are similar to Plant A.

4.4.2 Facility engagement

Step 1: Obtain top management commitment – Plan

For Plant B, top management commitment was received and an energy team appointed. The energy team leader was appointed and the plant had a separate energy business unit, which makes the focus on energy-related projects better. The focus is to reduce energy costs on the plant, not only focusing on electricity cost savings, but on all the energy commodities. The

energy manager needs to report quarterly to the executive committee of the plant. The energy manager on Plant B reports to the same executive committee as Plant A.

Step 2: Identify facility-specific energy champion – Plan

As was the case with Plant A, an energy champion was appointed on each of the facilities. The facility-specific energy champion was tasked with executing energy cost saving measures. The appointments were handled by the energy manager. Due to confidentiality, no names or appointment letters may be disclosed in this thesis.

The energy manager appointed the facility-specific energy champions before the framework was implemented on Plant B. Although the energy manager and facility energy champions have already been appointed prior to the verification, this step forms part of the overall framework for electricity cost reductions. In Section 3.2.2, the criteria are included to assist with appointing facility-specific energy champions.

Step 3: Identify the scope and the boundaries of the framework – Plan

The scope of the framework is to obtain electricity cost savings. The framework developed in Chapter 3 is implemented on Plant B. The objective is to identify, prioritise and implement the electricity cost savings

Plant B is under economic constraint and has limited capex to spend on energy cost saving projects. A large amount of capex was spent on Plant B to refurbish parts of the plant, but limited capex was spent on electricity cost reduction. The framework is important to remain competitive during an economic growth strain period. The framework focuses on electricity cost reduction since gas and coal are integrated as process commodities.

Plant B summarised the following outlook for 2016 in the yearly financial results:

- Gross domestic product growth: 0.2% for South Africa while 6.5% for China;
- Plant A and Plant B expected to retain market share;
- Average steel price expected to improve;
- Operational excellence initiatives to contribute; and
- Profitability dependent on delivery of current ongoing initiatives.

The outlook for the current gross domestic product growth in South Africa is dim with only 0.2% growth. Both Plant A and Plant B depend on operational excellence initiatives to

contribute to the profitability and sustainability of these plants within the South African and global steel market.

4.4.3 Role players

Step 4: Understand the role players – Plan

The role players for achieving the objective were identified in Section 3.3.1. Plant B is no different to the norm. The role players were evaluated and considered. Table 47 shows the summary of the role players that are involved with Plant B to implement the proposed framework.

Table 47: Summary and description of Plant B's role players

Role players	No. 1	No. 2	No. 3	No. 4
Steel plant	Plant B is responsible for appointing an energy management team (internal or external).	Plant B will evaluate possible projects identified and determine their feasibility.	Plant B will sign off on any proposed operational changes.	
Regulation	Plant B complies with steel regulations and standards (SANS 10400-M).	Plant B is registered as a tax entity and complies with the SARS tax regulations.	Plant B is not ISO 50001-certified, but is working towards compliancy.	Plant B is dependent on government policies regarding import duties.
Eskom	Plant B purchases electricity from Eskom on a Megaflex tariff structure.	Plant B is dependent on procurement of DSM IDM-funded projects.	Plant B will be audited by the Eskom project engineer for DSM-funded projects.	
12L tax incentive	Plant B will be eligible for a 12L tax break if funding is granted for an application.	Plant B will be audited by an energy management company to verify the 12L tax claim.		
M&V	Independent M&V teams will audit Plant B with the implementation of DSM-funded projects and for a tax rebate claim.			

Evaluate the project

Plant B evaluated the success of the framework proposed operational changes for electricity cost reductions with the following known evaluation techniques as discussed in Chapter 3:

- ROI (in percentage);
- Simple payback period;
- Internal rate of return (in percentage); and
- NPV (in rand).

Understand the KPIs

It was not necessary to determine new KPIs for measuring the electricity cost saving reduction as a KPI has already been determined by Plant B's global head office. Plant B used kWh/t liquid steel produced for production facilities. This KPI is used when the framework is applied to Plant B.

4.4.4 System characterisation

Step 5: Identify process – Do

PFDs and liquid steel production data was obtained from Plant B. It was identified that the steelmaking process used on Plant B was the integrated BF-BOF process. The complete BF-BOF process PFD and a snapshot of the data important for decision-making can be seen in Appendix E: Plant B – Case Study 2.

Step 6: Identify facilities – Do

In this step, all the facilities on Steelmaking Plant B were identified using the four primary building blocks identified in the framework. Table 48 shows the primary and secondary building blocks, and the 17 facilities identified on Plant B. These facilities will be considered in the prioritisation model.

Table 48: Identified facilities on Plant B

Primary building blocks	Secondary building blocks
Ironmaking	Sinter plant
	Coke plant
	One blast furnace

Primary building blocks	Secondary building blocks
Steelmaking	BOF
	Secondary metallurgy
	Continuous casting
Finishing products	Rod mill
	Medium mill
	Bar mill
	Billet mill
Infrastructure	Compressor plant
	Water treatment plant
	Boilers
	Power plant
	Buildings
	Transport
	Flares

Step 7: Do system characterisation for identification and prioritisation – Do

Do a black-box analysis

Firstly, a black-box analysis was performed on all the facilities identified in Step 6. The black-box analysis performed on all the facilities can be seen in Appendix E: Plant B – Case Study 2. Figure 81 shows the bar mill and billet mill facilities for Plant B. The energy streams enter the facility from the top as indicated by the red shapes.

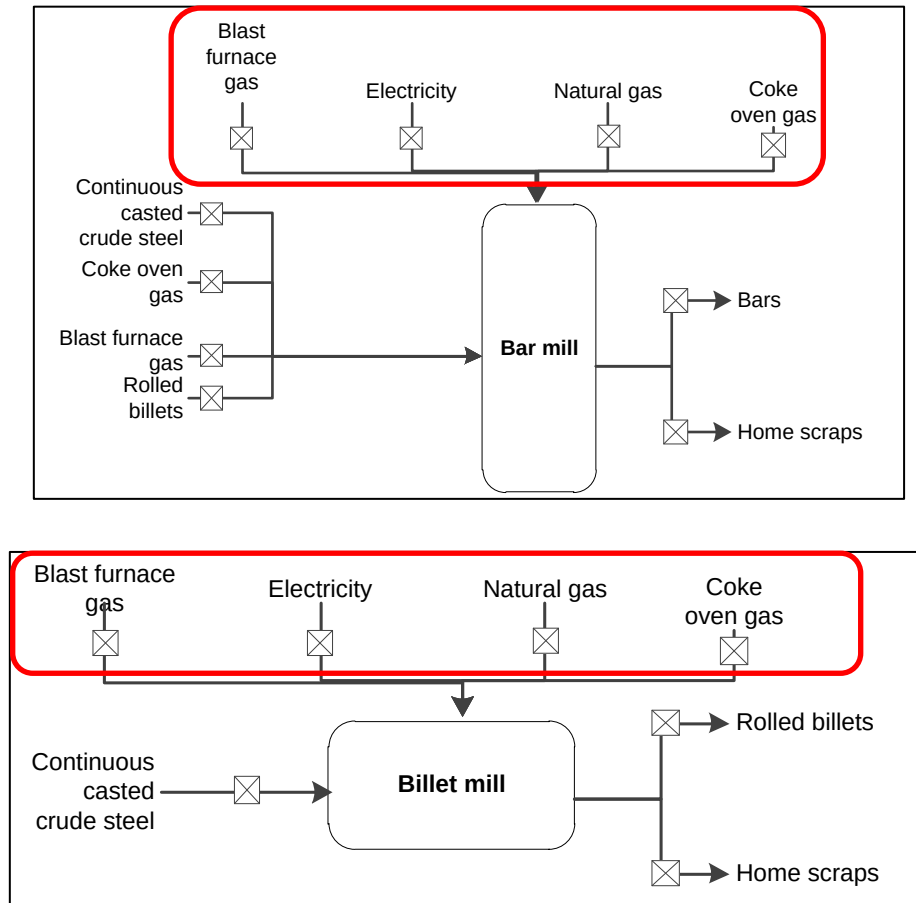


Figure 81: Black-box analysis for the bar mill facility and billet mill facility for Plant B

Balance the energy

After the black-box analysis has been completed, the energy balances for the facilities commenced. The energy balance data can be seen in Appendix E: Plant B – Case Study 2. Together with the energy balance, an energy source contribution breakdown and a Sankey diagram were compiled. The data used in the energy balance was for one year. Figure 82 shows the breakdown of energy commodities in terms of costs. Electricity was the second-largest energy contributor in terms of cost at Plant B.

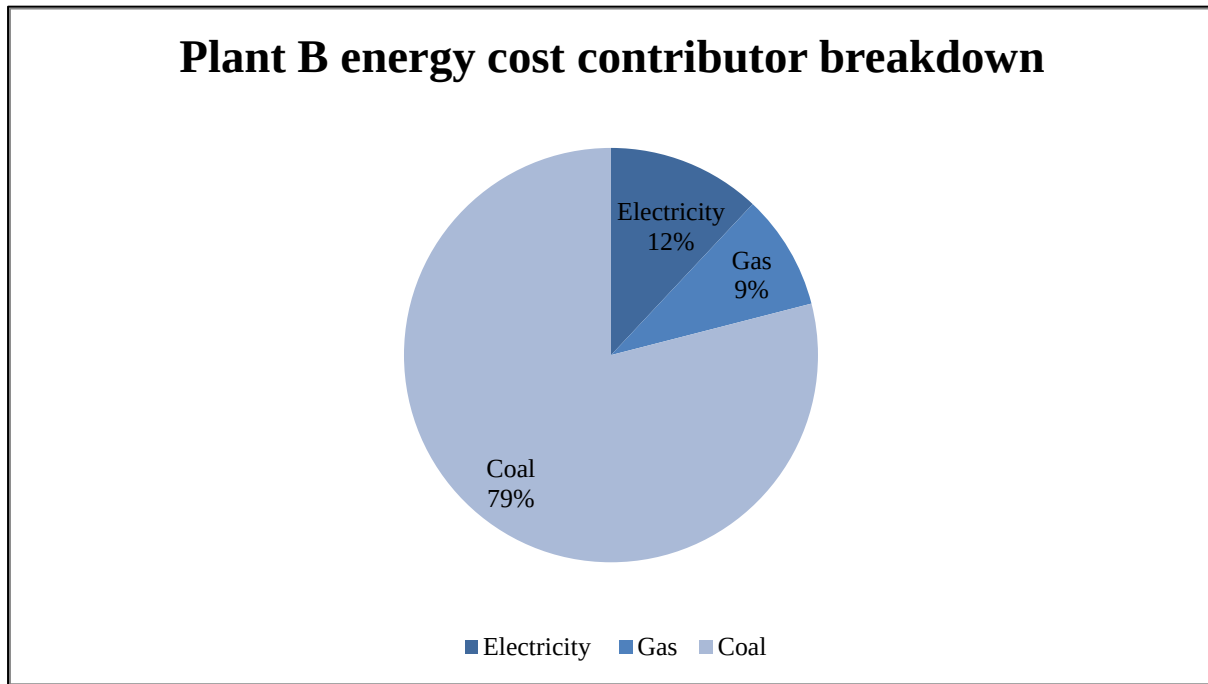


Figure 82: Breakdown of energy source in cost percentage contribution

After the breakdown, the Sankey diagram was compiled using the energy balance data for one year. The Sankey diagram shows the contribution of each energy stream in Plant B to and from all facilities. A Sankey diagram is used because it shows the energy balances visually in the form of the process at hand. Figure 83 shows a screenshot of the compiled Sankey diagram. The coal energy stream and the off-gases with large calorific values, such as BFG and COG, contributed the largest portion to the energy flow on Plant B.

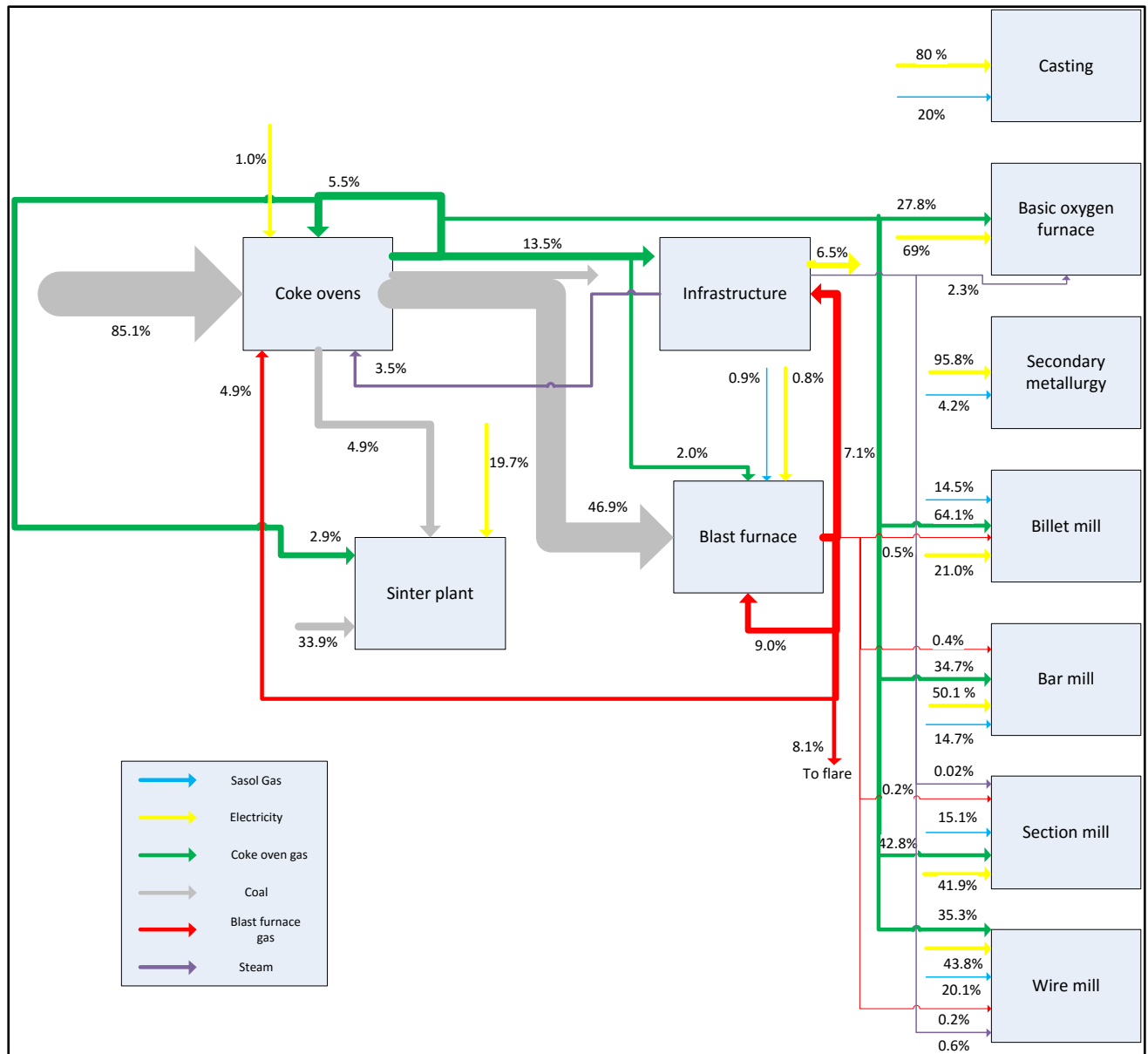


Figure 83: Sankey diagram to identify the size of the different energy streams

Total facility power

Total facility power is one of the variables that determines the ranking of the facilities for implementing operational changes to reduce electricity cost. The total power was acquired in total kW for one year on all the facilities. This data was incorporated in the total energy balance sheet for the plant.

For Plant A, the data was readily available on the local SCADA. Figure 84 shows the ranking of the largest electricity consumer of the facility to the lowest electricity consumer. Over a period of one year, the steel plant facility was the largest consumer of electricity on Plant B. For Plant B, it was decided that the framework would be applied on a higher level and the facilities be grouped into nine major facilities. This reduced the identification and prioritisation time.

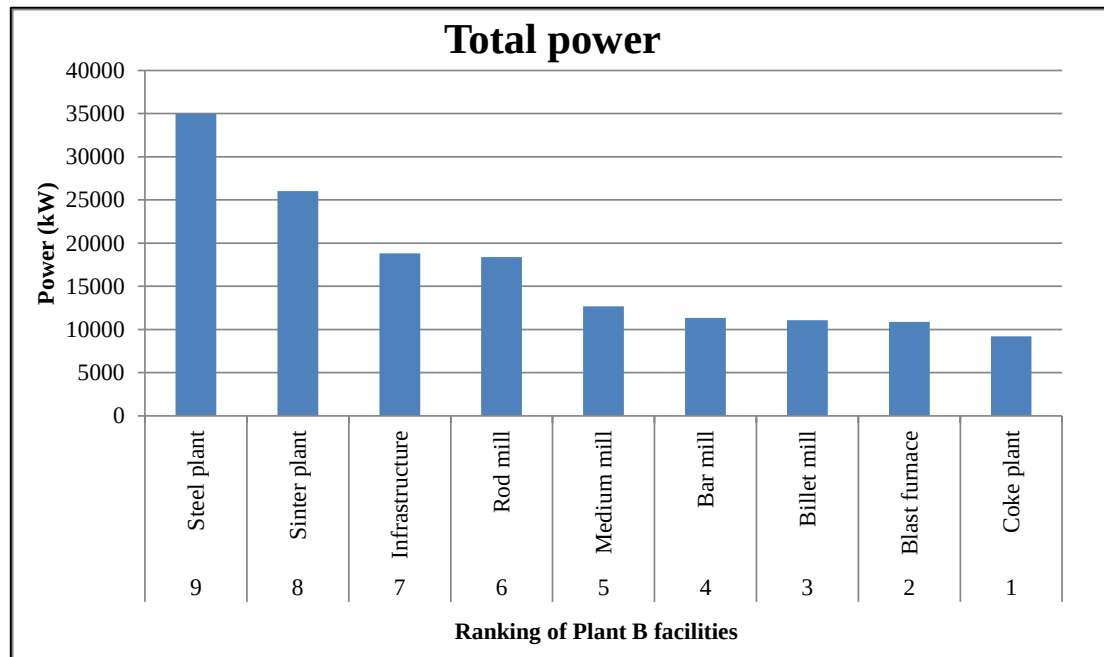


Figure 84: Plant B total facility power comparison

The electricity intensities were calculated for all facilities. The intensities were ranked from the highest to the lowest intensity. ‘Intensity’ means the amount of kW used per tonne of product produced. A plant with a high electricity intensity uses a higher amount of power for the same amount of production than a plant with a low electricity intensity.

The electricity intensity ranking forms part of the model and is one of the inputs for the model. Figure 85 shows the ranking with the medium mill facility being the most and the blast furnace facility the least electricity-intensive facility.

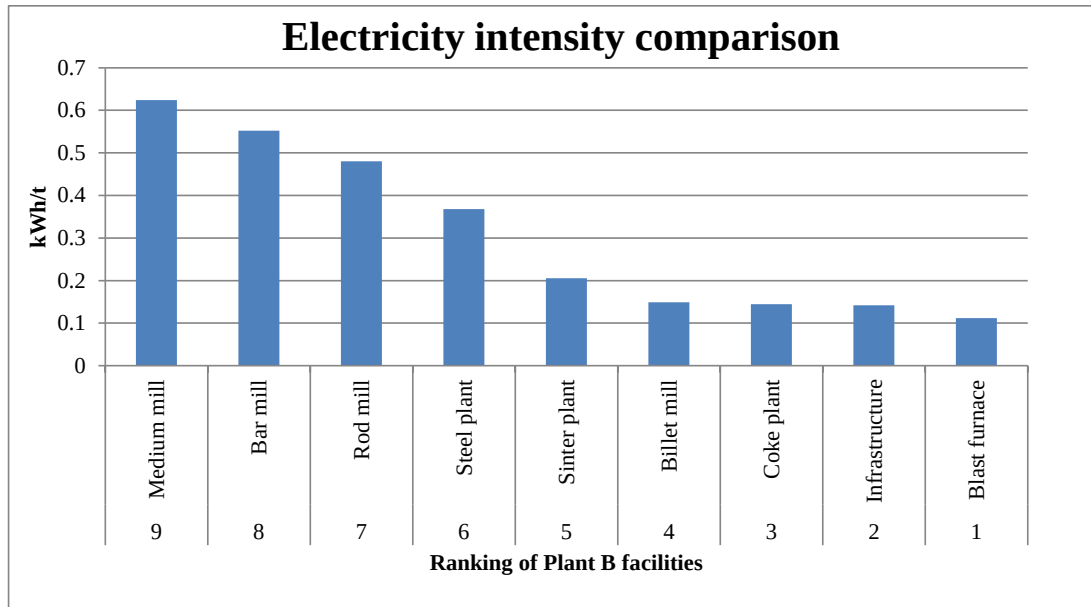


Figure 85: Electricity intensity comparison for Plant B

Complete system parameters and layouts

The parameters for Plant B were also collected on each facility using the approach developed in Chapter 3. The following data is important:

- First level: Holistic data approach:
 - Total facility power, production rate and maintenance schedules.
- Second level: Equipment-specific approach:
 - Data such as fan sizes, running statuses and fan curves.
- Third level: Measurements:
 - Bearing and motor temperatures to identify system constraints.

Although the data was obtained in this step of the framework, the data is only analysed, used and discussed in the system analysis step in Section 4.4.5.

The layouts obtained for the facility during the implementation of the framework were the following:

- PFD;
- Control layouts;

- Electrical layouts; and
- PID.

These can be seen in Appendix E: Plant B – Case Study 2.

Identify initiative for electricity cost reduction through operational changes

The critical evaluation question sets were applied on all the facilities and the results are shown in Table 49. Figure 86 shows the operational change initiative flow.

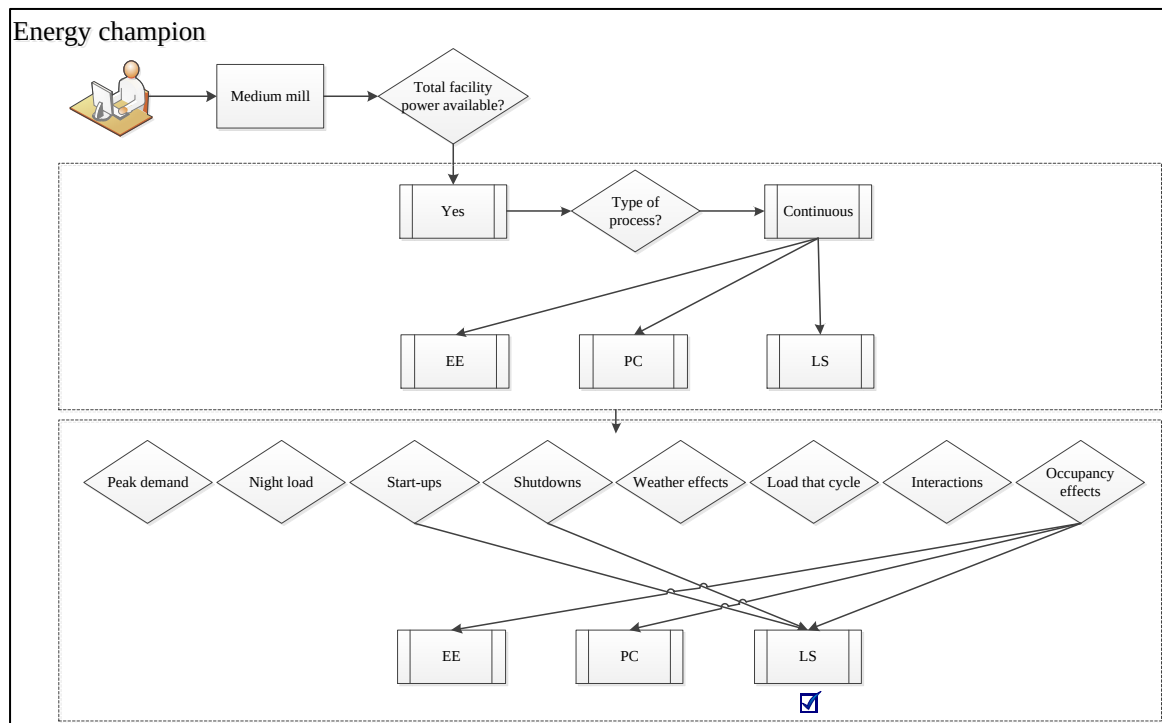


Figure 86: Identification of operational change initiative flow

Table 49: Critical evaluation applied on Plant B facilities

Plant B specific facility	Question Set 1	Question Set 2	Question Set 3	Initiative for model
Medium mill	Yes	EE, PC, LS	EE, LS	LS
Bar mill	Yes	EE, PC, LS	PC, LS	PC
Rod mill	Yes	EE, PC, LS	EE, PC, LS	EE
Steel plant	Yes	EE, PC, LS	EE,	EE
Sinter plant	Yes	EE, PC, LS	PC, LS	LS
Billet mill	Yes	EE, PC, LS	PC, LS	LS
Coke plant	Yes	EE, PC	EE,	EE
Infrastructure	Yes	EE, PC,	PC, LS	LS
Blast furnace	Yes	EE, PC, LS	PC, LS	PC

A 24-hour power profile was compiled for each of the plants which can be seen in Appendix E: Plant B – Case Study 2.

Prioritise the facilities for electricity cost reduction through operational changes

The prioritisation model was applied to the facilities on Plant B to identify and prioritise the facilities for electricity cost reduction initiatives through operational changes.

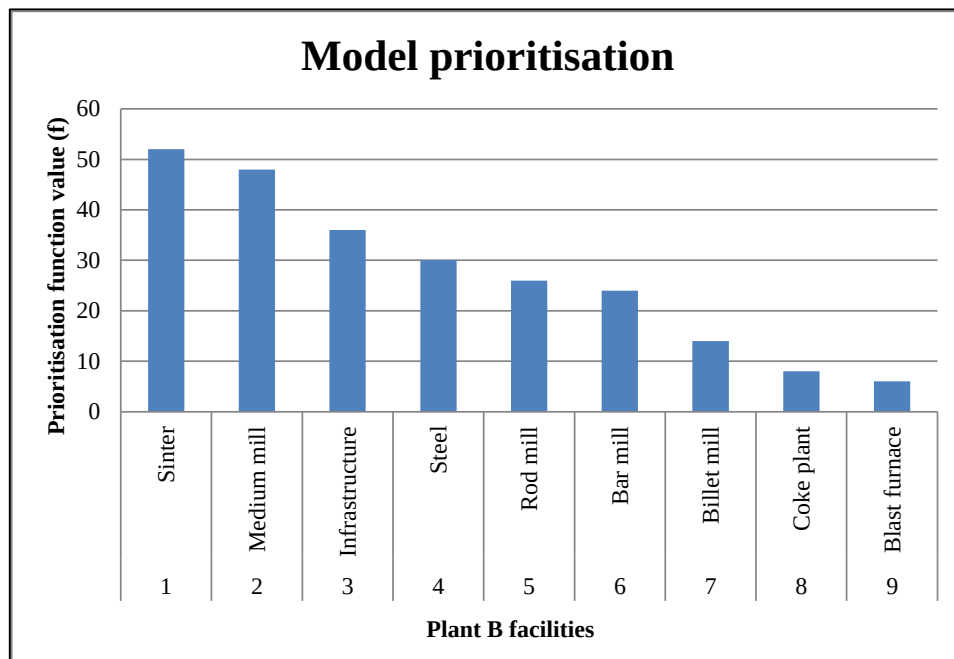


Figure 87: Model output and prioritisation for operational changes

Table 50 gives the results for the model with the prioritisation function. The sinter facility was first and the medium mill second. The sinter facility was prioritised for operational changes to reduce electricity costs. The calculations are shown in Appendix E: Plant B – Case Study 2.

Table 50: Facility identification and prioritisation result for Plant B

Number	Facility	(f)
1	Sinter plant	52
2	Medium mill	48
3	Infrastructure	36
4	Steel plant	30
5	Rod mill	26
6	Bar mill	24
7	Billet mill	14
8	Coke plant	8

In Section 4.4.5, the sinter facility will be analysed first to identify how the operational changes will influence the facility. The initiative is simulated for the specific plant to understand the feasibility of an initiative.

4.4.5 System analysis

Step 8: Do system analysis for project feasibility and implementation – Check

Document the system description and operational data

Sinter is fine iron ore and fine waste material melted together into lumpy material. The sinter is burned in the blast furnace process. Raw materials are transported via conveyors from the stockyard to the different bunkers on the sinter plant. The raw materials are then mixed into the correct ratio according to the sinter specifications.

A 50 mm pre-sintered layer is placed on the sinter strand to protect the strand from burning through and from sinter sticking to the strand. The mixture of raw materials is then spread on top of the pre-sintered layer. The coke in the top layer is ignited with the ignition hood. Two high-powered fans suck air through the burning sinter bed. The sinter falls from the strand onto the sinter crusher. Sinter cakes between 5 mm and 45 mm are transported to the blast furnace. The remaining sinter is transported back to the pre-sintered pile to prepare the new pre-sintered layer.

The average production rate is 300 tonnes per hour, or 7 150 tonnes per day. The daily production record is 8 188 tonnes per day; the monthly production record 202 625 tonnes per month. The blast furnace that uses the produced sinter only requires 5 000 tonnes per day. This means that under normal operations there will be 2 000 t more sinter produced per day. This sinter accumulates on a stockpile that is kept at 15 000 t.

Large motors and fans are the main consumers of electricity at the sinter plant. The motors transfer the sinter across the sinter bed and large fans suck air through the sinter bed. There are two 3.3 MW and two 4.5 MW motors operating the fans for cooling and air drafts respectively. Figure 88 shows the sinter plant layout.

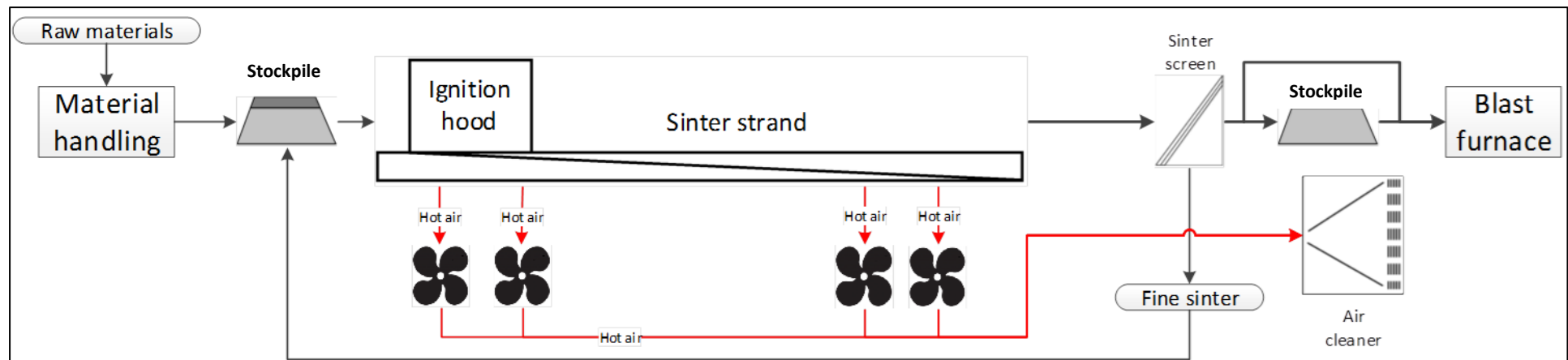


Figure 88: Sinter plant layout

Identify and document the operational constraints

The main operational constraint for the set point facility is the sinter stockpile that always needs to be maintained at 1 500 t. The conditions of the motors for switching on and off during load shifting may also be a constraint. Table 51 summarises the assumptions and information available.

Table 51: Sinter plant operational assumptions

Assumption	Value
Cooling fan power	2.8 MW
Sinter fan power	4.2 MW
Four-fan power	14.5 MW
Two sinter fans; one cooling fan power	11.7 MW
One sinter fan; two cooling fans power	10.1 MW
Four-fan production	6 800–7 200 t/d
Two sinter fans; one cooling fan production	5 800 t/d
One sinter fan; two cooling fan production	4 800 t/d
Blast furnace consumption	6 500 t/d
Ignition hood temperature	950–1 050 °C
Three-fan production cost for July	43.79 R/t
Four-fan production cost for July	46.29 R/t
Maximum stockpile level	32 000 t
Minimum stockpile level	15 000 t
Working shifts	06:30 to 16:00
Maintenance scheduling	Third Wednesday of the month
Maintenance duration	18 hours

Identify all the energy carriers and SEUs in the facility

COG, anthracite, coke breeze, electricity and compressed air are the main energy carriers at the sinter plant. Anthracite and coke breeze constitute approximately 85% of the total energy consumption. These energy carriers are part of the sinter produced by the sinter plant. The sinter plant transforms these energy carriers into sinter cakes that are used in the blast furnace. The small amount of COG used by the sinter plant is burned in the ignition hood to heat and ignite the sinter bed. Large motors and fans are the main consumers of electricity. The motors are used to transfer the sinter across the sinter bed and large fans are used to suck air through the sinter bed.

Identify possible operational change scenarios

Normal sinter plant operation is to run four fans. A possible operational change to reduce electricity costs is to reduce the four-fan operation to a three-fan operation between 06:00 and

19:00 on weekdays. The plant will therefore only run four fans in the night and on weekends. This operational change will result in five fan start-ups per week.

The baseline production for the sinter plant is ~44 900 t per week. It is predicted that with the proposed operational change the production will reduce to 44 892 t per week. This is 94% of the possible production. Table 52 shows the influence of the operational change per day.

Table 52: Operational change scenario calculation

	Power (kWh)	Cost (R)	Production (t)
Monday	306 600	325 393	6 258
Tuesday	306 600	325 393	6 258
Wednesday	306 600	325 393	6 258
Thursday	306 600	325 393	6 258
Friday	306 600	325 393	6 258
Saturday	345 600	197 505	6 800
Sunday	345 600	158 596	6 800
Total	2 224 200	1 983 065	44 892

The baseline was for one month in winter (July). The data was readily available on the plant's SCADA. The baseline values for this strategy can be summarised as:

- Consumption: 9 418.2 MWh;
- Cost: R8 539 087; and
- Production: 189 808 t.

Identify the important measurements for simulation purposes

For this case study, no simulation package was required to calculate the possible savings. A simple Excel calculation was used for the calculations. The variables required to calculate the possible savings are indicated in Table 53.

Table 53: Data required for simulating operational changes

Variable	Unit
Sinter suction fans motors	MWh
Cooling fans motors	MWh
Sinter production	T

Simulate a baseline for the facility and calculate the possible cost savings

The possible electricity cost savings was calculated for one winter month in 2016. It was important that electricity cost was obtained while keeping the sinter stock level above the minimum required level.

Table 54: Electricity cost saving calculation results

July 2016		
Strategy: Four-fan operation (evenings and weekends)		
	Baseline	Strategy
Consumption (kWh)	9 418 200	9 418 200
Cost (R)	8 539 087	8 025 744
Production (t)	189 808	189 808
Potential savings (R)		513 343
Four-fan start-ups	1	19

It can be seen from Table 54 that the kWh consumption throughout the month was kept the same as for the baseline. It can be seen in Figure 89 that the sinter stock level stayed within the minimum required amount. It is also clear that with the proposed strategy, the cumulative production over the period of one month stayed the same. It is possible to achieve a R513 343 cost saving with this proposed operational change in a winter month. The downside and operational constraint might be the number of increased fan stoppages and start-ups. It needs to be tested and confirmed that the motor condition would be able to accommodate the extra burden.

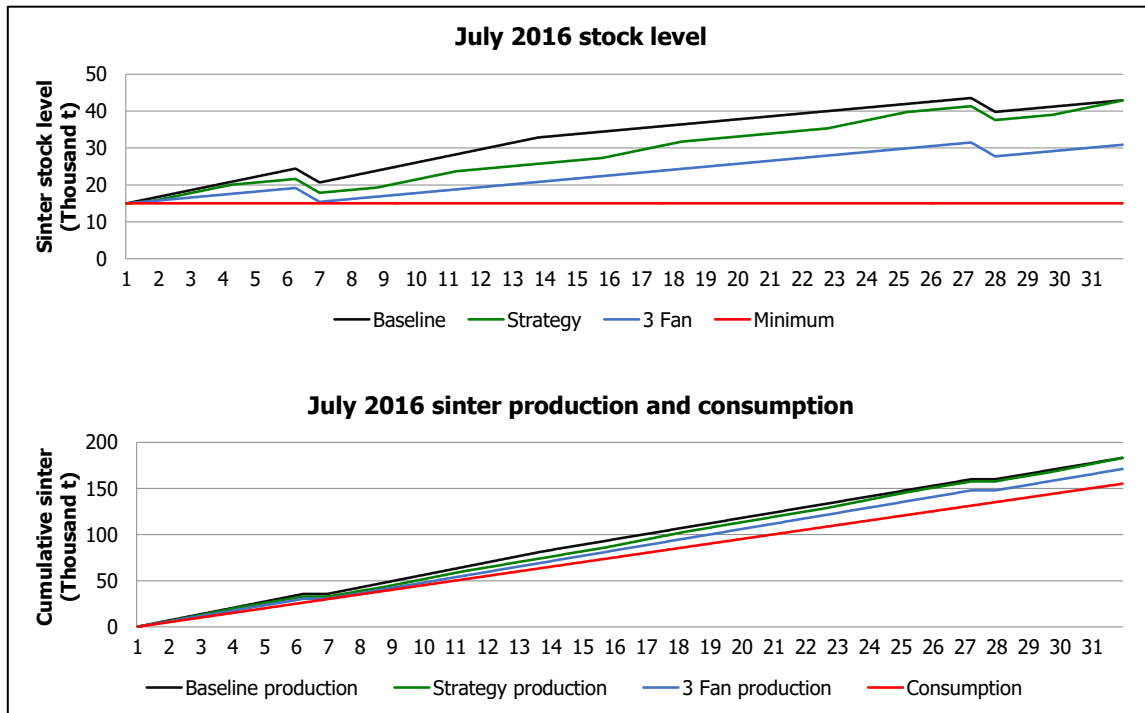


Figure 89: Sinter stock level and cumulative production

Figure 90 shows the power profile for the proposed operational change. On 6 June and 27 June there were routine maintenance stops where all the fans were switched off.

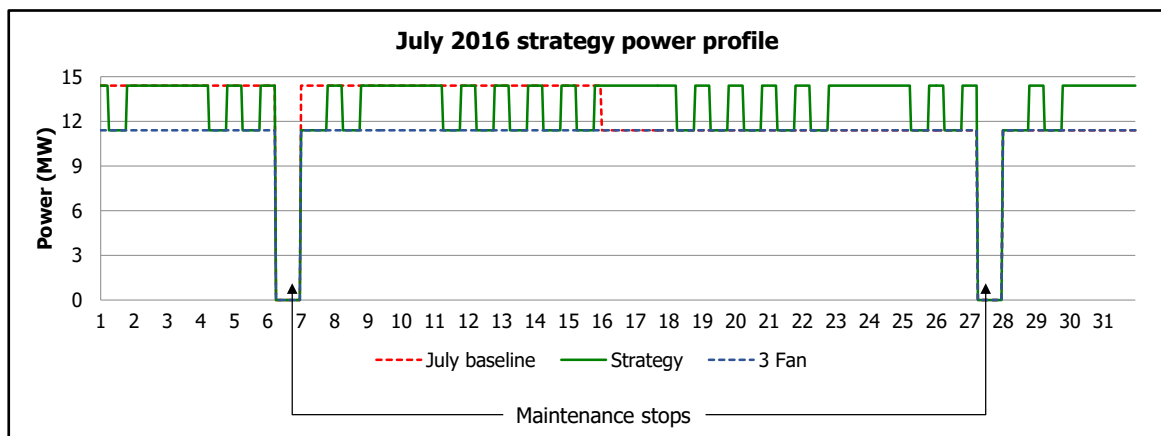


Figure 90: Proposed operational change strategy power profile

Check the feasibility of the project in terms of electricity cost reduction

No infrastructure was required to implement the proposed operational change. This means that no investment capital was required. The project could be submitted to Eskom to apply for DSM funding to do the load shifting project. It was also recommended that an ESCo be engaged to add extra expertise and apply for funding.

Do a detailed project feasibility calculation

The project feasibility was calculated after the system analysis was completed. Table 55 shows that the load shifting project was feasible. Although there was no energy saving, the electricity cost was reduced through operational changes. The sinter facility fans were scheduled to operate outside Eskom peak times. The fan operation was scheduled to the Eskom off-peak periods. R1 050 000 could be saved per annum. Zero capex was spent on the project. The required man years was estimated on plant personnel involvement towards the project. It was estimated that the NPV for the project was R10 300 000 calculated with the project feasibility equation as used with the verification in Section 4.3.

Table 55: Project feasibility result summary

Project description	Operational change to the sinter plant fan operations
Type of savings	Load shifting
Capex	R0
MWh saving	0
GJ saving	0
ZAR saving	R1 050 000
Payback period (years)	0
Implementation time (years)	0.2
Estimated lifetime (years)	10
Required man-years	0.2
NPV	R10 300 000
Man-hour cost	R2 100 000

Step 9: Implement operational change to reduce electricity – Act

The results achieved from applying the framework on Plant B validated the framework. The framework identifies and priorities operational changes to reduce electricity costs.

Document savings

After the investigation and the feasibility calculation, the operational changes could be implemented and tested. At the time of this study, the initiative has not been fully implemented on Plant B yet. Historical data was used to see if actual load shifting would be possible. It was found that Eskom enforced load shifting in 2015. At the time of completion of this study, implementation has not yet taken place. This was due to concerns regarding stops and starts on the fan motors. When variable speed drives are installed, this initiative can be re-investigated. More detailed investigation is therefore required.

Report on findings from the framework and savings obtained

A typical report could be distributed to the specific facility champion to track the electricity cost reduction through the operational changes. A typical report can be seen in Appendix E: Plant B – Case Study 2.

4.5 Conclusion

In Chapter 4, the framework developed was implemented on two separate steel plants. Part of the implementation was to verify and validate the framework. It was found that the framework was validated and that electricity cost could be reduced by applying the framework for operational changes.

Plant A and Plant B, two steel plants in South Africa, were used as case studies. More than R11 million possible savings were identified and already partially achieved.

Chapter 5: Conclusion and recommendations



*Finished product*¹⁹

¹⁹ Tanjin Uniglory International Trade Company, “Colled rolled steel coil,” Tanjin Uniglory International Trade Company, [Online]. Available: <http://www.steelpipemaker.com/2-2-cold-rolled-steel-coil.html>. [Accessed 25 October 2016].

5.1 Introduction

The steelmaking industry in South Africa requires a step-by-step framework for operational changes to reduce electricity costs. In Chapter 5, the work completed in this study is summarised. The recommendations for further research are also discussed and presented for further work to be done in this research area.

5.2 Summary of work completed in this study

The steelmaking industry in South Africa is struggling to remain competitive within local and global markets. Rising electricity costs reduce the profitability margin of steel production. Due to economic growth strain in the global and South African steel industry, steel plants cannot spend capital to reduce electricity using energy efficient equipment.

It was identified that the second-largest contributor to energy costs on South African steel plants is electricity. Although coal is the largest contributor to energy costs, a large percentage of the coal is used directly in the steel production process. It was therefore decided that the focus for energy cost reduction would be on electricity.

Previous studies on energy management and energy cost reduction were considered. The methods employed by these studies were discussed and critically reviewed. The objective was to identify an alternative approach to electricity cost reduction other than large capex projects. It was identified that operational changes with little to no investment costs was a feasible solution.

A study objective was developed and four novel contributions were identified. It was identified that a framework for operational changes to reduce electricity costs was required. The framework developed for this study formed the first novel contribution. The second and third novel contribution addressed the need for an identification and prioritisation model focusing on operational changes.

The identification and prioritisation model guides the user of the framework. The user is guided to the facility where electricity cost savings would be the most likely to be obtained through operational changes. It also considers that cost savings need to be obtained in a short period with little to no capex.

The fourth novel contribution addressed the need for operational analysis. The aim of the operational analysis is to guide an energy champion to identify and implement specific operational changes to reduce electricity costs.

With the study objective known, different energy management strategies, frameworks, funding models and operational changes in industries were studied. In-depth research was done on these aspects to gain knowledge regarding the advantages and disadvantages of each aspect on electricity cost savings in the industry in general, and specifically the steel industry.

For the identification and prioritisation model, a methodology was developed to characterise a steel plant. The facilities on the plant were identified and ranked per total power as well as power intensity. The rankings together with a developed set of critical questions were used in a model to obtain a prioritisation model.

Possible funding models were also used in the model to identify the cost of implementation. Finally, the system analysis part of the framework was developed. With this step in the framework, the prioritised facility was analysed to identify the specific operational change. The feasibility and implementation of the operational change were also incorporated in this step of the framework.

The case studies are two steelmaking plants in South Africa. Both plants form part of the same global steelmaking group. The framework was divided into single elements that were verified separately. All the elements were given specifications to be met by implementing the framework.

The framework was verified using Plant A from Case Study 1. All the elements were successfully verified including:

- The simulation used to model the savings in Section 4.4.4.
- Were electricity costs reduced on the plant?
- Was it required to spend any capital to realise electricity cost savings?
- Is the framework easy-to-use and can savings be realised in a short period of time?
- Could the framework be applied successfully to another plant with different steel products and plant configurations?

A positive result was obtained for all the questions posed for the different elements. An electricity cost saving of R9.9 million was achieved by applying the framework to Plant A by

implementing the identified operational change, which was an energy efficiency project. The compressor plant facility on Plant A was prioritised as the facility for implementation. The low-pressure compressor pressure set point was reduced with 20 kPa. This resulted in a total energy efficiency saving of 1.92 MW.

Plant B was used as Case Study 2 to validate the overall application of the framework. It was identified that the framework satisfied the overall objective. Another operational change initiative was identified to reduce electricity costs. The sinter facility was prioritised for implementing a load shifting initiative. An average evening load shift of 2 MW was identified, which can results in total cost savings of R1 050 000. The electricity costs on both Plant A and Plant B were reduced by applying the framework to implement operational changes.

5.3 Study-specific recommendations

It was shown in the thesis that by applying the framework to South African steel plants, large electricity cost savings can be achieved. It was apparent that by using the framework, electricity cost savings can be identified and the facilities prioritised accordingly.

The more the framework is applied to steelmaking plants, the more operational constraints can be identified. After more applications, these constraints can be incorporated into the framework to improve the quality and accuracy thereof in terms of:

- Correctly identifying operational changes to implement on facilities.
- Correctly prioritising the facilities to implement operational changes.
- Optimising the electricity cost reduction through operational changes.

There are two recommendations applicable to this study specifically:

- Implement identified operational changes on more facilities throughout both case study plants discussed in this thesis.
- Implement the framework on all the steelmaking plants in South Africa.

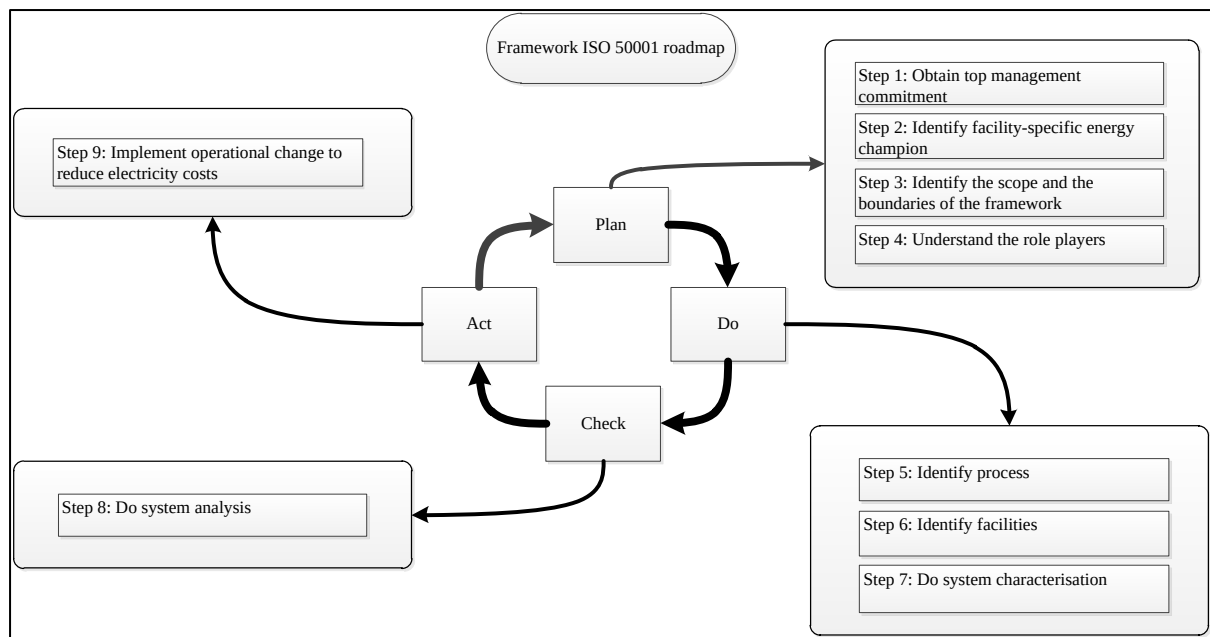
Both recommendations focus on expanding the implementation of operational changes as well as the application of the framework as a whole. There are 22 facilities on Plant A and eight on Plant B where operational changes could possibly be implemented for electricity

cost savings. There are also two more plants from the same steelmaking group where the framework could be applied.

5.4 Recommendations for expansion of study methods

It is recommended that the framework is enhanced to accommodate other energy sources such as gas and coal. Although coal forms part of the steelmaking process, there is potential for energy cost savings. Coal, in the form of coke, is required in the reduction of iron ore. It was identified that gas is the smallest contributor to the total electricity cost on South African steelmaking plants. However, electricity cost savings can be identified and implemented.

It is recommended that the framework, including the identification, prioritisation and analysis steps, is expanded to other industrial sectors such as mining and cement manufacturing. Some of the steps derived from the development of the framework can be applied generically to other industries. The following points discuss the application of the step to other industries:



- Step 1: Obtain top management commitment. This is an important step and needs to be applied to all industries using this framework.
- Step 2: Identify facility-specific energy champion. Depending on the type of industry, this step is generic. If the industry also has many facilities on a plant, this may be applied directly.

- Step 3: Identify the scope and the boundaries of the framework. This is a generic step although the specific framework scope may change for different industries with specific needs and operational constraints.
- Step 4: Understand the role players. This step is important for any industry the framework is applied on. The role players will change depending on the industry. The mining industry has other governmental regulations to adhere to than the steel industry.
- Step 5–7: These three steps focus on identification and prioritisation. It is recommended that these steps be redeveloped for operational changes for the different industries in South Africa.
- Step 8: System analysis is a relatively generic step and can be customised for different industries.
- Step 9: The implementation step will differ from one industry to another. It is recommended that Step 9 needs to be reviewed carefully before applying it to other industries.

It can be concluded that the framework is developed in such a way that it can be applied to other industries with some changes. If the framework is applied to other industries, it can result in major cost savings to improve a plant's overall performance.

Another recommendation is to include carbon tax and the reduction of associated costs. The South African government announced that carbon tax will become mandatory from 2017. It is still to see if it will start in 2017, but provision needs to be made for when it becomes mandatory. Carbon tax adds a large cost component to the cost of a steel plant. When energy efficiency projects are implemented, carbon emissions are reduced. This will prioritise energy efficiency projects before load shifting projects if the cost saving is larger.

5.5 Conclusion

A framework for operational changes to reduce electricity cost was developed in this thesis. Chapter 5 serves as a conclusion and recommendation chapter. A summary of the work completed was discussed first. Recommendations were then made on this study specifically, focusing on what needs to be done to improve the framework. Finally, the expansion of the study methods developed in this study was discussed and recommendations made.

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Appendix A: Energy cost risks

Power Conservation Programme

The increasing demand for electricity left South Africa with an insufficient electricity supply. The Department of Minerals and Energy established the National Electricity Response Team, who then established the Power Conservation Programme. Power rationing studies were considered carefully when this programme was designed [9].

The Power Conservation Programme consists of two subdivisions, namely [9]:

- The Energy Conservation Scheme (ECS): Introduction of mandatory or voluntary price-driven mechanisms; and
- The Electricity Growth Management: Approach on how new connections are managed.

ECS and Electricity Growth Management are closely linked since electricity needs to be available before new connections can be managed. The latest update regarding the ECS is that it is still being developed by Eskom. The latest version is a draft presented in 2011 [60].

This section summarises the implications of the ECS as modelled by Van der Zee [9]. In his study [9], Van der Zee summarised the steps in the ECS as follows:

- Identifying ECS mandatory or voluntary customers;
- Calculating the annual allocated reference consumption;
- Calculating the post-reference loads;
- Identifying investment allocations;
- Calculating and managing annual electricity; and
- Calculating excess electricity usage rates and charges.

Van der Zee derived equations, and from that a graph modelling the price increase in relation to the percentage overconsumed on the allocated amount. Figure 91 represents the ECS cost increase graph.

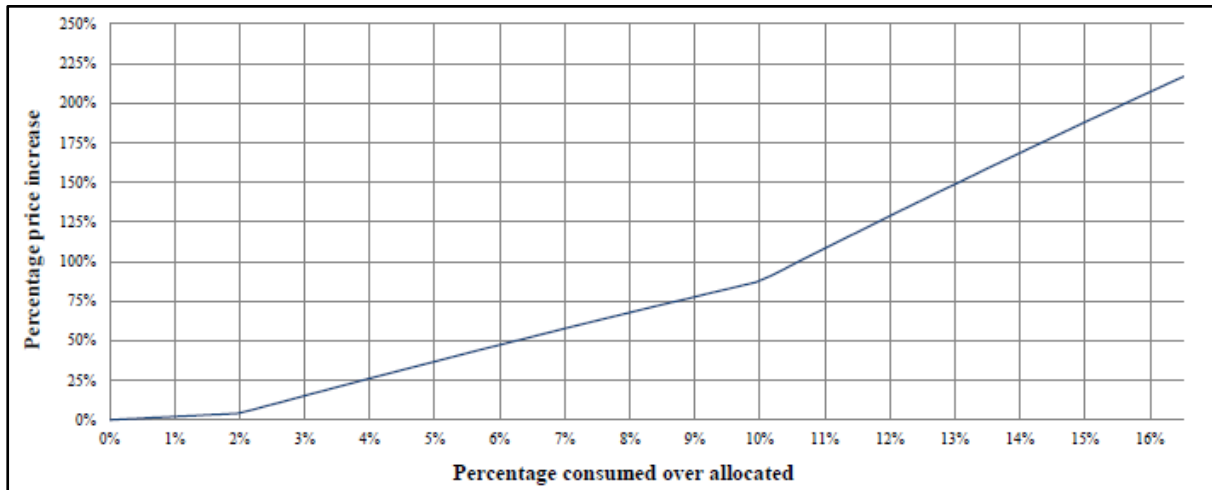


Figure 91: Electricity cost increase relative to overconsumption [9]

Van der Zee [9] modelled a scenario for a mining company to indicate the additional ECS charges if the monthly electricity was allocated by default, and no phasing was performed. It is shown in Figure 92 that that ECS charges could have resulted in an annual price increase of 50% [9].

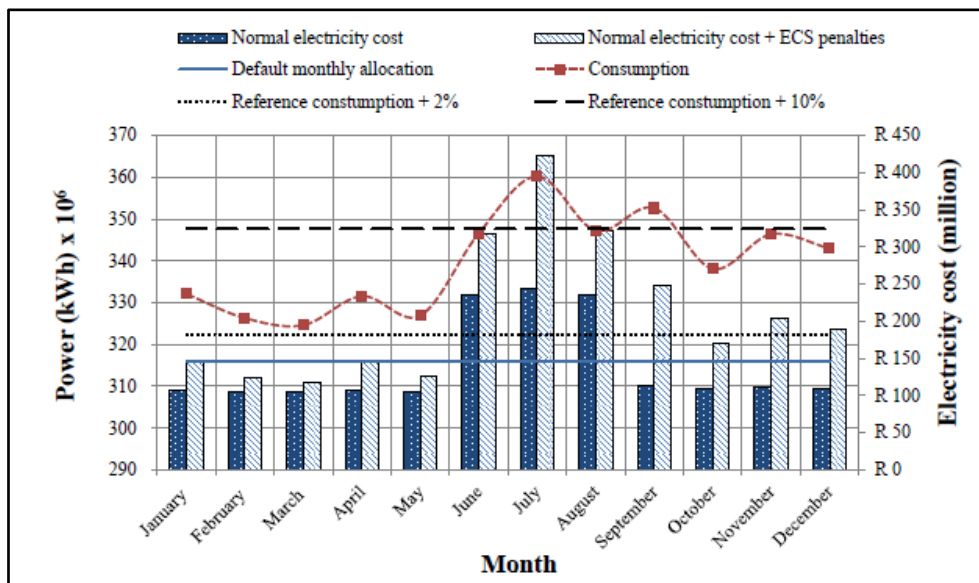


Figure 92: ECS price increase with default monthly allocation [9]

Van der Zee [9] summarised other risks associated with the ECS:

- It is a lengthy regulatory process;
- Economic challenges due to customers' inability to achieve savings overnight; and
- Operational complexities due to the lack of standardisation.

Van der Zee [9] formulated mitigation strategies from the ECS rules and literature [9]:

- An effort should be made to operate below or close to the reference consumption values.
- Production and electricity costs for mines in the mining group should be evaluated on a regular basis.
- Planning and allocation play an important part to prevent costly excess charges.
- Equipment should be installed to monitor consumption on all parts of the mines to quantify potential ECS penalties.
- DSM projects and the funding available can aid with energy efficiency on the plant.
- Each electricity-consuming section should be responsible and independent from the process.
- Competent and trained personnel should be made responsible for managing electricity usage.

There are benefits of being compliant to the ECS [9]:

- Lower electricity bill from lowering demand;
- Reduced rate of increasing electricity prices;
- Reduced carbon footprint and environmental effect;
- Reduced risk of load shedding from the additional spare capacity now available;
- Lower future electricity rates; and
- Income generated by trading allocated electricity.

Carbon tax

Carbon dioxide, with the chemical formula of CO₂, is the primary greenhouse gas that is emitted through human activity on earth. The United States Environmental Protection Agency states that in 2014, CO₂ accounted for 80.9% of all greenhouse gas emissions from human activity in the US [61].

Human activities alter the carbon cycle by adding more CO₂ to the atmosphere as well as influencing the natural sinks on the earth. The natural sinks include forests that remove CO₂ from the atmosphere [61].

The human activity mainly responsible for CO₂ emissions is the combustion of fossil fuels. Fossil fuels include coal, natural gas and oil. These fossil fuels are combusted mainly for energy and transportation. The main sources can be described as follows [61]:

- Electricity: The combustion of fossil fuel to generate electricity is the largest source of CO₂. The type of fossil fuel combusted to generate electricity emit different amounts of CO₂. The burning of coal will produce more CO₂ than natural gas or oil.
- Transportation: Combustion of fossil fuels to transport goods and people is a large contributor to carbon emissions. The fossil fuels include gasoline and diesel.
- Industry: A large number of industrial processes emit CO₂ through the combustion of fossil fuels. Chemical reactions in processes can also cause carbon emission levels to be high. These processes include cement, iron and steel production.

The most important greenhouse gases with global warming potential are shown in Table 56.

Table 56: Global warming potential of greenhouse gases [62]

Gas	Source	Global warming potential
Carbon dioxide (CO ₂)	Biomass respiration and burning, land-use change, energy, transport, industry, etc.	1
Methane (CH ₄)	Energy, landfills, ruminants, waste treatment, rice agriculture, biomass burning, etc.	21
Nitrous oxide (N ₂ O)	Transport, industry, livestock and feed, biomass burning, etc.	310
Hydrofluorocarbons (HFCs)	Refrigeration and air-conditioning industries, firefighting agents.	140–11 700
Perfluorocarbons (PFCs)	Electronics industry processes.	6500–9200
Sulphur hexafluoride (SF ₆)	Dielectric gas for high voltage applications.	23 900

The United Nation Framework Convention on Climate Change (UNFCCC) was established in 1992. The Kyoto Protocol, which extends the 1992 UNFCCC, was established between three parties that set a binding obligation for countries to reduce greenhouse gas emissions on average 5.2% below their 1990 levels. 38 countries agreed to take part of which 27 countries were industrialised countries and 11 non-industrialised countries [9].

South Africa forms part of a group of developing countries that are not obliged to reduce emissions. However, South Africa has made several announcements that it would reduce its

greenhouse gas emissions. A carbon tax is proposed by the South African government to mitigate the climate effect of greenhouse gas emissions [9].

The National Treasury of South Africa published the Carbon Tax Bill for public comment on 2 November 2015. According to this bill, South Africa is committed to reduce greenhouse gas emission by 42% by 2025. This figure is outlined in South Africa's Intended Nationally Determined Contributions, which were submitted to the UNFCCC in Paris [63].

The 2015 release is the next step in the consultation process that has been conducted over a five-year period. It considers all the comments received in writing from workshops and stakeholders. The revised Carbon Tax Bill includes:

- A 60% tax-free threshold during the first phase of carbon tax from the date of implementation to 2020.
- An additional 10% tax-free allowance for process emissions.
- A tax-free allowance for trade-exposed sectors up to 10%.
- Recognition for early actions to reduce emission.
- A carbon off-set tax-free allowance from 5% to 10%.
- Recognising the role of carbon budgets.
- Combined effect capped at 95%.
- An initial carbon tax rate of R120 per tonne CO₂ will apply. Taking the tax-free threshold into account, this results to effective carbon tax rate of between R6 and R48 per tonne CO₂.

Van der Zee [9] states that a customer can expect a price increase of 6% if assumed that the tax is only paid for the last 40% consumed.

There are several methods for reducing greenhouse gas emissions. One of the models is the Clean Development Mechanism (CDM), which is defined under Article 12 of the Kyoto Protocol. This model allows developing countries to receive funding for carbon-reducing projects. The funds are received from already industrialised countries and they receive Certified Emissions Reductions (CERs). This is per CDM rules. The CERs received can be traded or used to obtain reduction targets under the Kyoto Protocol [9].

Van der Zee [9] states that the uptake of CDM projects has been slow and this can be due to the following hurdles:

- DSM projects have a negative impact on the implementation of CDM projects;
- It is difficult to obtain finance for CDM projects ; and
- New baseline and methodologies to monitor CDM projects need to be developed and approved.

The cost involved with registering and taking part in the CDM model is not viable with the current low prices for CERs.

Appendix B: Energy management

This section includes more case studies on EnMS in general as well as on ISO 50001 energy management in particular.

ISO energy management in the industry (continued from Section 2.3.3)

Case Study 2

Javied, Rackow and Francke [64] found that energy management in industrial companies is not only a technical task, but also an interface function. In addition to operational energy flow, there are business administration, technology and law. Javied et al. [64] define in their study that energy management can be operated within the basis of standards and guidelines but following different paths [64].

Javied et al. [64] considered several boundaries that could prevent a company from implementing a sufficient EnMS. Javied et al. [64] incorporated these boundaries and obstacles in the chosen energy management approach. The following obstacles are identified [64]:

- A lack of energy awareness;
- The need for energy management;
- A lack of knowledge; and
- A lack of motivation.

Javied et al. [64] designed a multi-stage model since the approach should be suitable to all industrial enterprises. The designed model is shown in Figure 93.

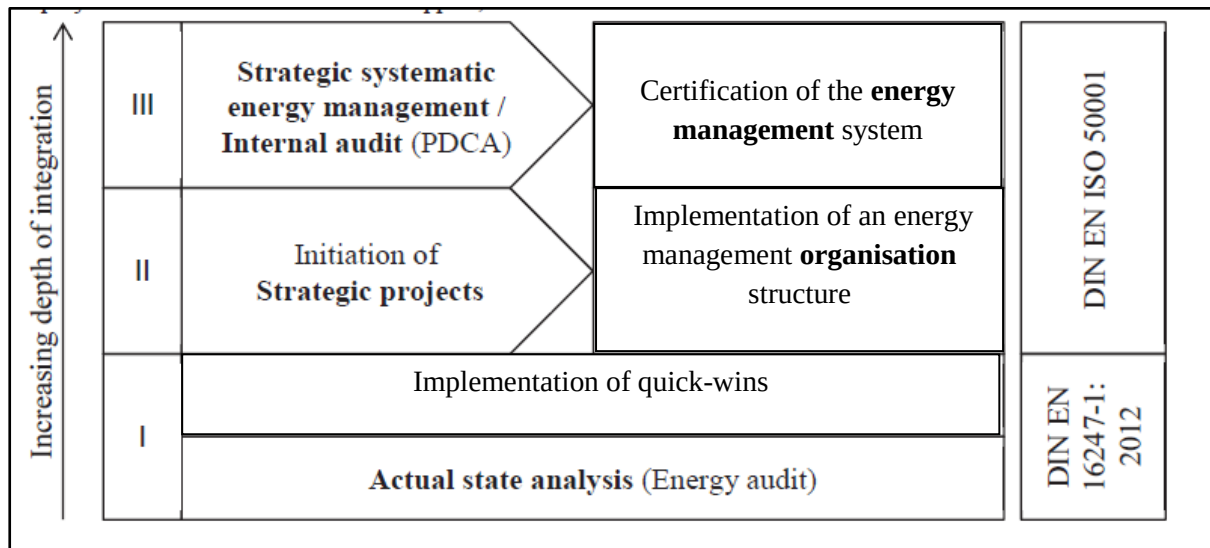


Figure 93: Multi-stage energy management implementation model [64]

The first phase starts with a general analysis of the current energy situation. This first phase can be done practically with an energy audit. The second phase is based on the energy audit findings. In this stage, the quick-wins identified in Phase 1 are included. These benefits can be achieved quickly with little effort and low capex. These two phases are included in Stage 1 [64].

Javied et al. [64] define Stage 2 as the start of implementation with the setting of a goal and the naming of an energy management strategy. Stage 3 is needed for the sustainable implementation of an EnMS. In Stage 2, an energy management process is developed and implemented. In Stage 3, the internal audit and energy management process is checked for efficiency and effectiveness. The report is then presented to the top management in the organisation. The process can then be optimised [64].

Javied et al. [64] also developed an organisational model. The model is based on the ISO 50001 PDCA cycle. In the model, roles are defined in the EnMS. Depending on the size of the organisation, an energy management core team may be needed to assist the energy manager. This core team needs to provide the necessary resources and support for energy management. Figure 94 is the flow of the organisational model based on the ISO 50001 energy management standard [64].

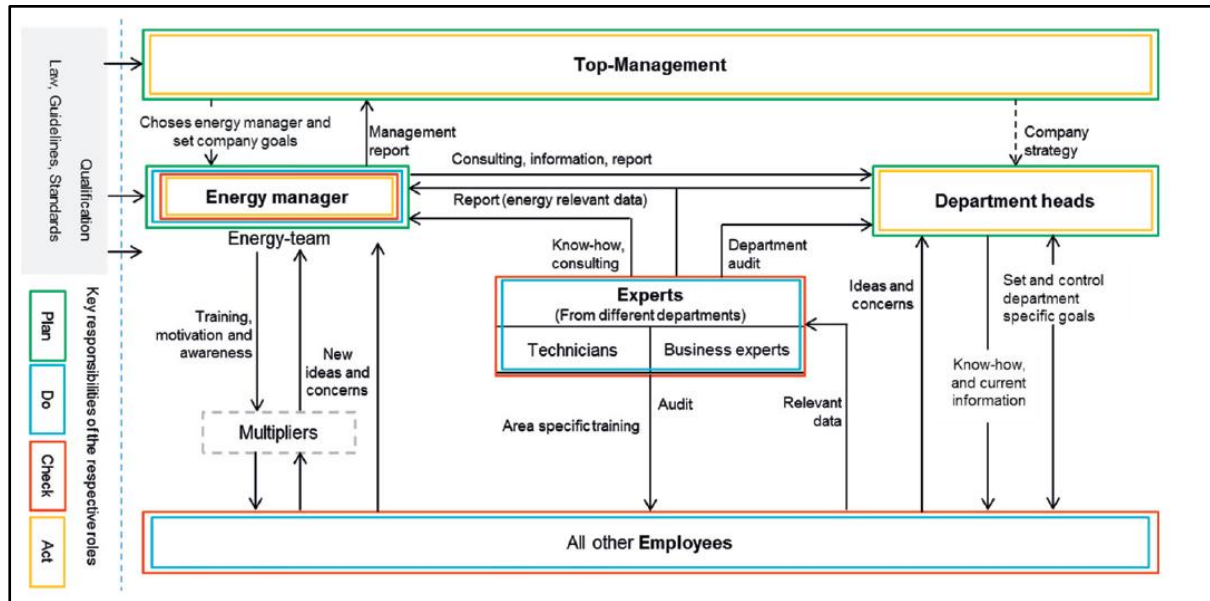


Figure 94: Advanced organizational model based on ISO 50001 [64]

Javied et al. [64] state that one of the most important tasks for an energy manager is to define and identify the EnPIs together with the energy team. The EnPIs can be used to benchmark the energy and the control of the energy flow in the organisation. The EnPIs may differ from company to company, and therefore have to be chosen wisely [64].

Javied et al. [64] conclude that through the proposed organisational structure, a PDCA cycle can be realised for sustainable and continuous improvement. Another benefit is that the company can qualify for ISO 50001 certification [64].

Case Study 3

Dzene et al. [65] developed a research paper focusing on the assessment of municipalities applying ISO 50001. There are several energy management schemes and organisational models. The option resides with the municipality to choose the correct system structure [65].

Dzene et al. [65] state that it is commonly observed that there is a lack in the analysis of energy production and consumption data. Often there are not metering devices in municipal buildings. It is crucial to establish a reliable data collection system. Metering is critical to account for produced and consumed energy. With measuring it is possible to achieve energy savings of up to 10% [65].

Dzene et al. [65] define the four main stages of energy managements as follows [65]:

- System development – Plan;
- Data collection – Do;
- Data analysis – Check; and
- Conclusions and change of action – Act.

If a centralised energy monitoring can take place in municipalities, it is possible to reduce energy consumption. The developed methodology by Dzene et al. [65] is implemented in Saldus Municipality in Courland, Latvia. Results are quantified in terms of the energy indicators able to use procedures described in ISO 50001 [65].

For the sustainable energy action plan, Dzene et al. [65] found that ISO 50001 procedures are important. It was found that the most important step for adopting the ISO 50001 strategy is to officially decide to implement the international standard [65].

Case Study 4

Tutterow [66] conducted a study on ISO 50001 implementation, case studies, and the lessons learned from these studies. The first case study for ISO 50001 energy management was implemented on Veriform Inc. Veriform Inc. is a metal-fabricating company in Cambridge, Ontario. Veriform Inc. is described as a small company in accordance to manufacturing industry standards. The company implemented ISO 50001 as part of their sustainability programme in 2006. Since the implementation, the company has grown 145% while reducing their energy consumption with 58%. With the energy savings, the company also reduced their carbon footprint with 65% [66].

Veriform Inc. received ISO 50001 certification in 2013. Tutterow [66] reports that the success with ISO 50001 started with the energy champion. He created awareness towards energy within the company and shared the responsibilities with staff to make up an energy management team. Veriform Inc. reported a payback of less than six months [66].

Veriform Inc. benefited because they were a small firm and they already had [66]:

- Metering and monitoring systems in place;
- Internal staff with previous ISO experience;
- A relationship with a third-party auditor; and
- A level awareness and understanding of energy management.

The company reported a saving of US\$100 000 in energy savings for one year, mostly electricity savings [66].

Case Study 5

Van Heerden, Vosloo and Kleingeld [67] conducted a study on improving DSM project implementation and sustainability through ISO standards. ESCos assist South Africa's leading electricity utility provider, Eskom, and manage energy around South Africa. DSM projects provide cost savings to clients and demand reduction on the Eskom grid during high electricity demand periods. Van Heerden et al. [67] state that there is a need for a sustainable EnMS within these DSM projects [67].

Van Heerden et al. [67] designed an EnMS for these types of project to achieve the maximum energy performance. Van Heerden et al. [67] combined three ISO standards to design a framework. The use of the PDCA cycle was evident in the study. The proposed EnMS developed by Van Heerden et al. [67] was implemented on five different mines. Figure 95 shows the DSM process steps. The electricity cost saving obtained by implementing the EnMS-incorporated DMS projects resulted in R18 million [67].

Van Heerden et al. [67] conclude that an EnMS indicates that a continually controlled framework can improve the DSM project implementation quality and sustainability [67].

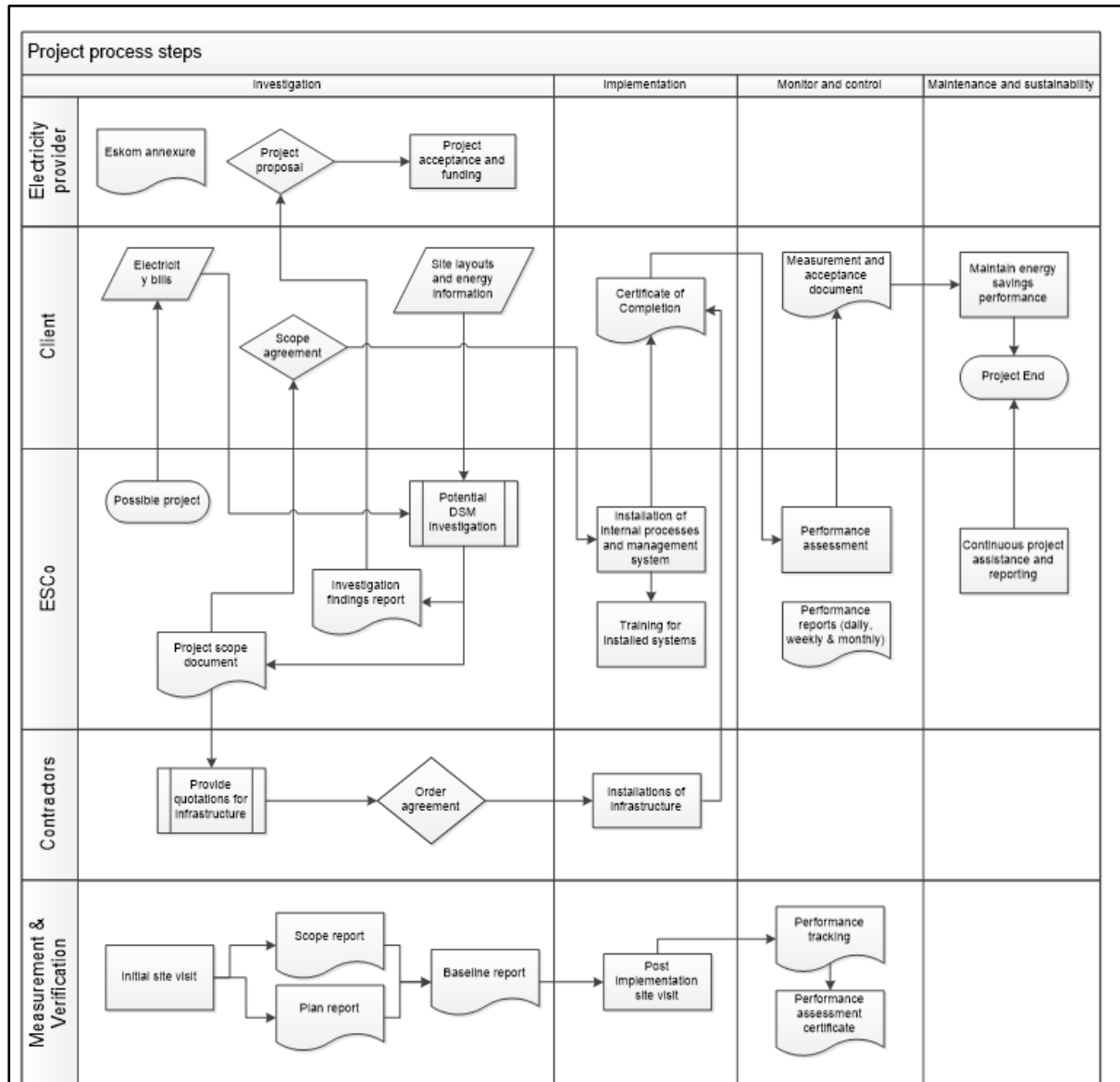


Figure 95: DSM process steps and the accompanied stakeholders [67]

Appendix C: PDCA cycle

This section focuses on the PDCA cycle as part of EnMS for the new framework to reduce electricity costs.

C. 1. Plan: Energy management planning

The fundamentals of energy management planning can be divided into two major categories, namely:

- Drivers; and
- Barriers.

Barriers are the mechanisms or obstacles that prevent or hinder the implementation of energy management [68]. Drivers in turn are the ‘motivation’ to overcome these barrier or obstacles that prevent the implementation of an EnMS [69].

Waldemarsson [70] published a study on energy and production planning for process industry supply chains. Waldemarsson [70] state that it is important in terms of profitability to use the energy system correctly by doing appropriate energy planning. Waldemarsson [70] discusses and reviews three papers and identifies that the process industry is energy intensive. Waldemarsson [70] states that it is important to manage energy, and to integrate energy planning into optimisation models and systems [70].

Waldemarsson [70] states that making energy available in the correct quantity and quality is key in optimisation modelling for the process industry. Also, recovering residual heat is important. Controlling starting and stopping of processes, if batch processes are present, is important and needs to be incorporated in the optimisation decisions [70].

Waldemarsson [70] publishes that cost savings can be achieved through optimising production planning. This can be achieved practically by rescheduling production from the Eskom peak time to the Eskom off-peak times. Waldemarsson [70] identifies two major barriers in energy planning for the process industry, namely [70] :

- Lack of responsible energy managers; and
- Poor energy planning.

These two factors lead to underinvestment towards energy and lack of energy planning incorporated into decision-making processes within companies [70].

Trianni, Cagno and Farnè [69] published a study on barriers, drivers and decision-making processes for industrial energy efficiency. Trianni et al. [69] investigated empirical studies on barriers and drivers for industrial energy management. Trianni et al. [69] developed a taxonomic classification on the barriers and drivers. Market research was done and case studies integrated to a total of 1 467 small to medium enterprises included in the study discussed. Interviews were held with firms and a three-phase questionnaire was used [69]:

- Phase 1 (person responsible for energy): General description of enterprise including processes in place and type of product manufactured.
- Phase 2: His/her view about barriers for the implementation of EnMS.
- Phase 3: Identification of drivers for energy efficiency.

Cagno et al. [71] developed an approach to overcome the barriers to energy efficiency and energy management. They developed this structure approach in a specific sequenced order as seen in Figure 96. The recommended procedures to overcome each barrier are explained below each step [71].

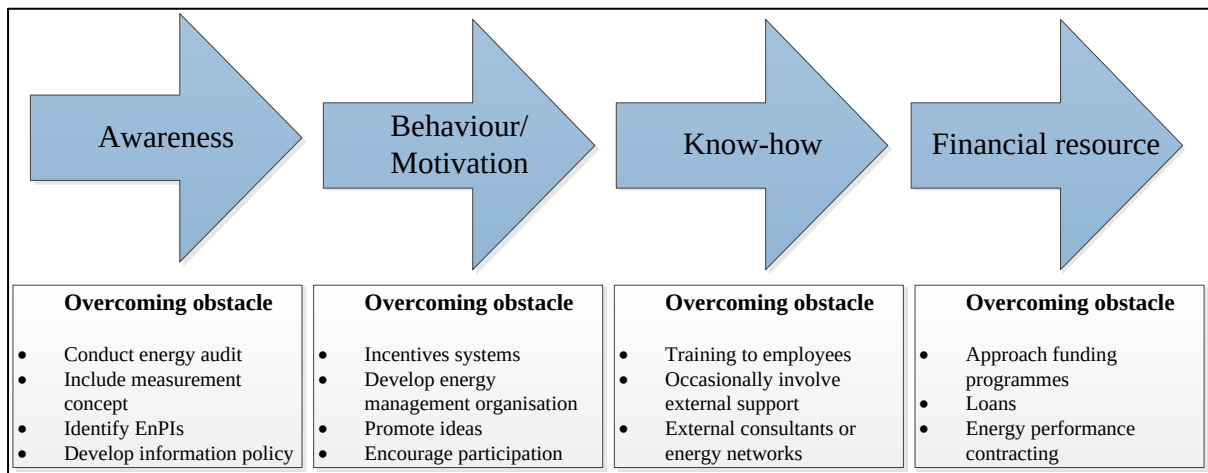


Figure 96: Sequential structured approach to overcome energy management barriers [71]

C. 2. Do: Execution

Sintering

The sinter plant forms part of the ironmaking section of the steelmaking facility. It serves the purpose of sintering fine ore particles and ferrous material reverted together into a porous clinker. The sintering improves the permeability of the blast furnace burden and improves the reduction process. Coke breeze is used as ignition fuel for the sinter bed moving on a strand. Gas burners ignite the coke in the top layer on the strand. Air is drawn through the sinter feed on the strand. The moving air causes the combustion to proceed through the entire layer. Temperature is typically between 1 300–1 480 °C [72].

The typical energy use due to fuel consumption, electricity consumption and net primary energy for the sinter plant are [72]:

- Fuel = 410.3 kWh/t;
- Electricity = 26 kWh/t; and
- Primary = 468.9 kWh/t.

Recover heat from sinter cooler

There are two places where heat can be recovered:

- From the main exhaust fans; and
- From the sinter cooling air.

It was found in the study published by New Energy and Industrial Technology Development Organization [73] that 0.25 GJ/t sinter can be recovered with steam generation using a waste heat boiler.

Reduce air leakage

Repairing air leaks and reducing the leakages can reduce the electricity use of the fans by an average of up to 14 MJ/t as reported by Zandi, Martinez-Pacheco and Fray [72]. The only downside to this initiative is that it might require an investment for repairing equipment and leaks.

Use waste fuels for the sinter plant operation

Sludge and dust from waste gas treatment devices can be recovered. It can then be used to reduce the use of gas in the burner. This needs very careful monitoring of the combustion process [74].

The saving coupled with the initiative depend on the composition and the quantity of the lubricants and efficiency of the waste gas recovery system [74].

Increase bed depth

Lower fuel consumption is a direct effect of an increased bed depth. It also results in improved product quality and may also promote a slight increase in productivity. Increased bed depth can result in a saving of 0.3 tonne coke per kilotonne sinter produced, and an electricity saving of 0.05 kWh/t sinter [72].

Improve charging method

Limonite, otherwise known as brown iron ore, decreases productivity in the sintering process. The ore combines with water and has a coarse particle size. This problem can be overcome by using a drum chute with a segregation slit wire, which controls the particle size distribution [72].

Improve ignition oven efficiency

The ignition energy can be minimised by 30% using a slit-like burner tile [72].

Coke-making

Coke is needed for blast furnace operation. Table 57 summarises the major energy saving measures that can be implemented at the coke-making facility on a steel plant.

Table 57: Coke-making energy efficiency measures

Energy saving measure	Description	Resource
Coal moisture control	Reduces the carbonisation heat. Improves the quality and productivity.	[73] [75]
VSD COG compressors	Smooth out varying COG. Reduce compression energy.	[76]
Coke dry quenching	Alternative to wet quenching. Recovers sensible heat of the high temperature coke.	[61]
Programmed heat	Instead of constant heating of coke, programmed heating enables optimisation of fuel gas to the coke ovens.	[70]

Energy saving measure	Description	Resource
Single-chamber systems	Use preheated coal. Reactor is separated by controlled modules. Allow for thinner heating walls and better heat transfer.	[77]
Non-recovery coke ovens	Coke oven slag and other by-products released are combusted within the oven. Offer the possibility for heat recovery and cogeneration.	[77]
COG	COG has low calorific value and is a by-product of the coke-making process. COG gas can be used for heat recovery, oxidation and direct combustion in processes.	[78]

Blast furnace

In the blast furnace, iron oxides are reduced to obtain iron. The iron is then melted and form liquid iron (pig iron). The blast furnace is a very energy-intensive process. One of the main drives in energy efficiency for the blast furnace is replacing coke with other hydrocarbon sources. Table 58 summarises the most important energy efficiency measures that can be implemented on a blast furnace.

Table 58: Blast furnace energy efficiency measures

Energy saving measure	Description	Resource
Improved blast furnace control	Improvement of process control can lead to energy efficiency. Implementation of a closed-loop blast furnace automated control system can result in energy efficiency.	[19]
Injection of natural gas	Allows reduction in coke production. Requires large capital investment for special equipment.	[19]
PCI	PCI saves part of the coke production. Fine coal is blown into the blast furnace as carbon source.	[61]
Injection of oil	Waste oil or heavy fuel can be injected into the blast furnace. 1 tonne of oil can replace 1.2 tonnes of coke.	[61]
Injection of plastic waste	Allows for reduction on coke production. Plastic waste has higher heating values than coal.	[19]
COG and BOF injection	COG and BOF gas can be injected into the blast furnace. The thermochemical conditions of the blast furnace limit the replacement rate of COG to 1 tonne of gas for 0.98 tonne of coal.	[19]
Top-pressure recovery turbine	Blast furnace top gases can be used to drive a turbine generator.	[19]
BFG recovery	BFG can be cleaned and stored in gas holders to be used as alternative fuel or in a gas turbine.	[19]
Slag heat recovery	A safe and reliable energy efficient system has not been developed yet, but if developed, can result in energy saving.	[19]

Energy saving measure	Description	Resource
Top gas recycling	Blast furnace performance can be improved with the recirculation of the reducing gas components (CO and H ₂).	[61]

Hot blast stove measures

Hot blast stoves heat the compressed air before the temperature control station that regulates the hot blast air into the blast furnace. Table 59 summarises the energy efficiency measures for the hot blast stoves.

Table 59: Hot blast stoves energy efficiency measures

Energy saving measure	Description	Resource
Improved hot stove control	Automating the control on the hot stoves can result in reduced energy consumption.	[61]
Preheating of hot stove fuel	The heat of the flue gases from the hot stoves can be recovered to preheat the combustion air of the stoves. This results in reduced energy consumption.	[61]
Improvement of combustion in the hot stoves	More efficient burner in the hot blast stoves can result in improvement of combustion and can lead to energy savings.	[61]

Steelmaking BOF

After pig iron production has taken place at the blast furnaces, the steelmaking process takes place in either a BOF or an EAF. For this study, only the BOF will be discussed since EAFs are no longer used in South Africa due to high electricity costs. Table 60 summarises the most important BOF energy efficiency improvement measures.

Table 60: BOF energy efficiency improvement measures

Energy saving measure	Description	Resource
Improvement of process control and monitoring	Monitoring systems increase process control and can lead to better productivity and energy savings. Process optimisation can take place with acquired monitored data.	[79]
Ladle preheating	Reduction of losses through lids and radiation. Installing temperature controls and hoods on the ladles can lead to energy savings.	[79]
VSDs on ventilation fans	Air quality is controlled by large fans. Because the BOF is a batch process, flue gases vary over time. With VSDs installed, fans can match demand and not run full all the time. This can result in energy savings.	[79]

Energy saving measure	Description	Resource
Recovery of BOF gas and sensible heat	Recovering of BOF gas can be the most energy saving opportunity. This can result in the BOF being a net energy producer. The off-gas sensible heat can be recovered in waste heat boiler to generate high-pressure steam.	[79]

Casting

Casting follows the steelmaking process and results in a series of semi-finished steel products including slabs, blooms or billets. Continuous casting is the most common method of casting. Table 61 summarises the important energy efficiency improvement measures for the casting plant as part of the integrated steelworks.

Table 61: Casting energy efficiency improvement measures

Energy saving measure	Description	Resource
Ladle preheating	Reduction of losses through lids and radiation. Installing temperature controls and hoods on the ladles can lead to energy savings.	[79]
Tundish heating	With the heating of the tundish, it reduces the heat loss of molten steel and avoids degeneration of refractory due to thermal shocks.	[61]
Integrated casting and rolling	If direct rolling can be applied, the casted slab is rolled directly into the shape required in the hot strip mill and connected to the mill. This saves on handling cost and energy costs.	[19]

Hot rolling

The reheating furnace is the most important part of the hot rolling operation. This is also the most energy-intensive process.

Table 62: Hot rolling energy efficiency improvement measures

Energy saving measure	Description	Resource
Proper reheating temperature	It is important to choose the reheating temperature of semi-finished products carefully. A reduction of 100 °C can result in a fuel decrease of 10%. A systems approach should be used to investigate, since the lowering of temperature may influence the load on the electric drive motors.	[79]
Process control on hot strip mill	Control on the process can save energy and increase productivity. Reduced rejection of products will take place and indirectly lead to energy savings.	[51]

Energy saving measure	Description	Resource
Avoiding overload of reheat furnace	The risk with overloading the furnace is excessive stack temperatures. An overloaded furnace runs colder than optimal. This results in a higher than usual fuel rate to the burners.	[51]
Flameless burners	Air preheating is widely used to enhance furnace efficiency. Flameless air fuel combustion uses the techniques of using air to oxidise. The flame is then invisible.	[51]
Regenerative burners	Regenerator is rechargeable heat storage batteries. The exhaust gases are stored in a medium till maximum temperature is reached and the heat is used for preheating.	[51]
VSDs on combustion air fans	Depending on the load factor of the furnace, VSDs can control the oxygen level, especially during load fluctuations.	[19]
Hot charging	If the charging of the slabs into the reheating furnace can take place at an elevated temperature, an energy saving will occur. This initiative depends on the distance between the casters and the reheating furnace.	[76]
Insulation of reheat furnace	Lower heat losses in the furnace can be obtained using ceramic low-thermal insulation materials. The savings can be up to 5%.	[76]
Heat recovery to the product	The slab charge can be preheated with the exhaust gas leaving the high temperature part of the process.	[76]
Cooling water waste heat recovery	Waste heat can be recovered from cooling water used at the hot strip mill. An absorption heat pump can be installed.	[76]

Cold rolling and finishing product

Cold rolling is referred to when the temperature of the metal is below its recrystallization temperature when rolled. The rolling therefore takes place in a temperature controlled environment. Table 63 include the cold rolling energy efficiency improvement measures.

Table 63: Cold rolling and finishing product energy efficiency improvement measures

Energy saving measure	Description	Resource
Reduced steam use in the acid pickling plant	A system of lids and floating balls can reduce the steam use by about 17%.	[61]
Automated monitoring and targeting system	An automated monitoring and targeting system at the cold strip mill can reduce power demand and reduce effluents.	[19]
Continuous annealing	Continuous annealing furnaces make it possible to combine batch annealing into one line. Productivity improvement can lead to energy savings.	[19]

Energy saving measure	Description	Resource
Inter-electrode insulation in electrolytic pickling line	The efficiency of the steel pickling process can be improved reducing inter-electrode short circuit current with inter-electrode isolation.	[19]
Reducing losses on annealing line	With the installation of heat recovery systems on the annealing line, heat losses can be reduced.	[19]

There are numerous ways to reduce the primary energy efficiency of the steel production process. The reduction in CO₂ emissions can be determined by multiplying the reduction in energy with the CO₂ emissions factor.

All these energy efficiency measures listed in Table 57 to Table 63 are important for the implementation of an EnMS. These measures can be incorporated into one comprehensive energy management model.

Engineering works

Engineering works include the following:

- Steam systems;
- Motor systems;
- Pump systems;
- Fan systems; and
- Compressed air systems.

Each of these systems is integrated and needs to be studied carefully as individual systems. It, however, forms part of the steelmaking process.

Maintenance

Groenewald, Kleingeld and Vosloo [80] developed a performance-centred maintenance (PCM) strategy for industrial DSM projects. The study done by Groenewald et al. [80] focused only on the mining sector. It is stated that underperformance of industrial DSM projects is often because of a lack of proper maintenance and practices. This can result in lost electricity cost savings opportunities [80].

Groenewald et al. [80] pose a solution to the problem in the form of PCM. PCM is based on the PDCA cycle and is therefore relevant to this thesis. Groenewald et al. [80] divide the PCM into six different types of maintenance, namely [80]:

- Breakdown maintenance;
- Corrective maintenance;
- Preventative maintenance;
- Time-based maintenance;
- Condition-based maintenance; and
- Reliability-centred maintenance.

Figure 97 shows the PCM strategy in accordance with the PDCA cycle as part of the ISO 50001 standard. Groenewald et al. [80] found that applying the PCM strategy could result in an increased performance of 70% when applied to underperforming DSM projects on mines [80].

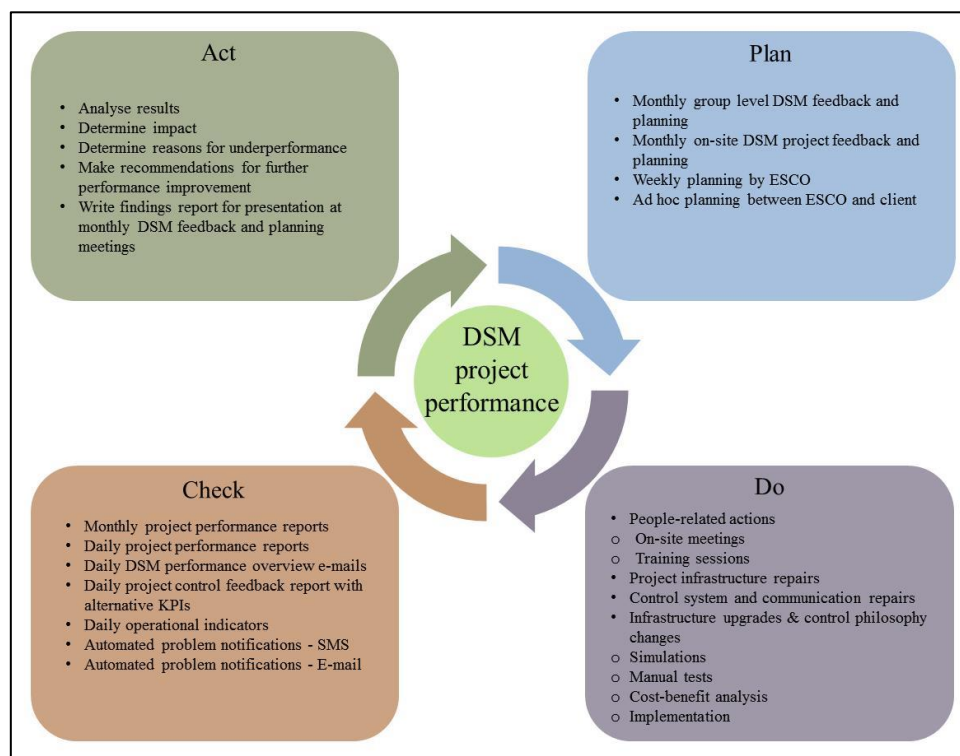


Figure 97: PCM strategy [80]

Process optimisation

As previously mentioned, the steel manufacturing industry is a very competitive industry. Each company needs to enhance its competitive edge. In a report, Schneider Electric emphasises that steel production is a highly energy-intensive process [81].

Schneider Electric [82] states that it is important to optimise processes to obtain energy efficiency. Optimising processes not only reduces energy, but also reduces production costs and increases their competitive edge. It also contributes to lowering CO₂ emissions [82].

Energy-specific consumption can be reduced with the following [82]:

- EnMS;
- Power, control and energy efficient equipment;
- High-efficiency drives, motor monitoring and control; and
- Process and production optimisation.

C. 3. Check: M&V and reporting

M&V has been developed to accurately and efficiently calculate the impact of an energy saving intervention on a specific application. There are procedures developed within the M&V framework. These procedures are developed to mitigate the challenge of an accurate and efficient calculation. With M&V, the parties involved receive a credible view on the impact of energy management. Incorporating M&V into an EnMS is important and cannot be neglected. It also forms part of the ISO 50001 standards [34].

There are several reasons to look at your energy consumption in retrospect [83]:

- Energy consumption improvement;
- Trends in energy usage;
- Energy predictions according to trends;
- Areas where energy might be wasted;
- Benchmarking of energy use; and
- Development of performance targets.

The M&V process includes measuring of processes. Therefore, metering is of a high importance. The key characteristics of the system need to be measured to determine energy

performance against the energy policy and objectives set out to achieve. The results obtained are then reported [34].

Reporting

Reporting is stated by many as one of the most important aspects in energy management to ensure sustainable and continuous performance of implemented initiatives [9].

The main focus of Van der Zee's study was to model the electricity risks and opportunities in the gold mining industry. To aid in monitoring the risks and opportunities, Van der Zee developed an electrical energy reporting procedure for gold [9].

Although Van der Zee regards the reporting procedure as comprehensive, the author is of the opinion there are other important aspects that need to be incorporated. In particular, Groenewald and Fockema mention the need for reporting on condition monitoring and system operating parameters [80], [84].

With slight modifications and integration with automated systems, it would be ideal to incorporate the reporting procedure within an IEMS for the gold mining industry. Reporting procedures would enable mine personnel to respond to important aspects of the IEMS and address nonconformities as specified by the ISO 50001. [9]

C. 4. Act: Optimising energy management

This final step of the cycle focuses on improving the implementation procedures continuously. From a financial point of view, it means improving the cost savings from reducing electricity costs through operational changes. [85]

Continually optimising the implementation of cost saving strategies will ensure a year-on-year improvement of energy performance as well as cost reduction. This will also ensure increased profitability during difficult times in the industry. [85]

Appendix D: Plant A – Case Study 1

Top plant management commitment

PLANT A & PLANT B

Energy manager |

This individual is appointed by the Top Management representative due to their appropriate skills and competence. This individual has other responsibilities within the organisation however the individual also has a lot of responsibility and authority pertaining to the ISO500001.

Roles and responsibilities	Objectives
• Ensure the EnMS is established, implemented, maintained and continually improved in accordance with the International Standard. • Identify persons in support of energy management that he/she will work with. • Report to Top management on energy performance and on the EnMS performance. • Ensure energy management activities' planning is designed in support of the organization's policy. • Define and communicate responsibilities and authorities in order to facilitate effective energy management. • Determine criteria and methods needed to ensure both the operation and control of EnMS is effective. • Promote awareness of the energy policy and objectives at all levels of the organization. • Identify and document all legal and other requirements applicable to the organization's use of energy. • Complete energy review steps • Document all proceedings with regards to the EnMS and energy performance • Manage energy, equipment and services	• Ensure new projects are energy efficient. • Monitor and take action related to energy metrics • Manage corrective and preventative actions related to EnMS and non-conformities.

I, as the energy manager, hereby confirm that I am aware of the roles and responsibilities of this position.

PROFESSIONAL SUMMARY

- Summary of the appointed energy manager

Figure 98: Typical energy manager appointment letter

System characterisation

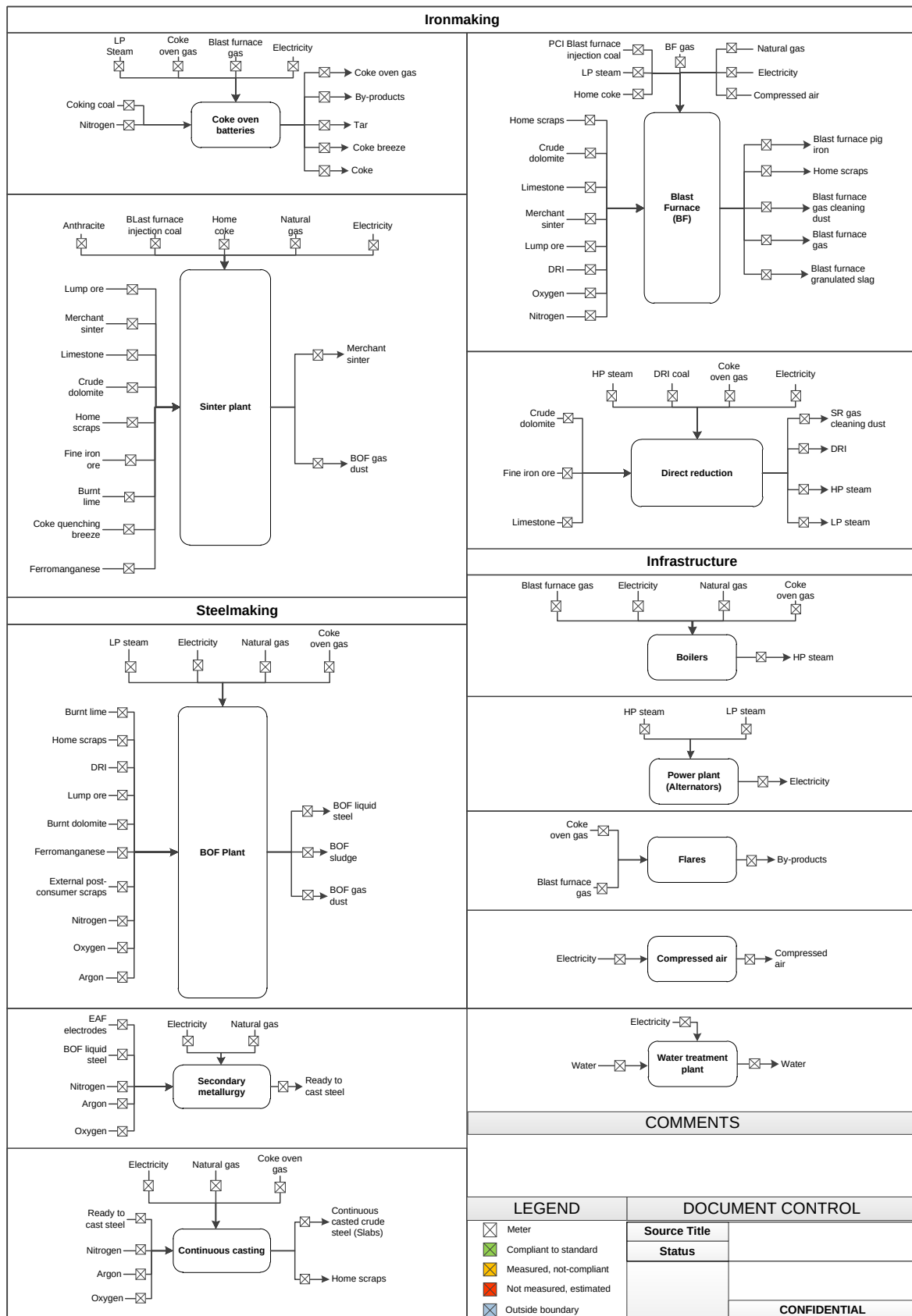


Figure 99: Plant A facility black-box analysis

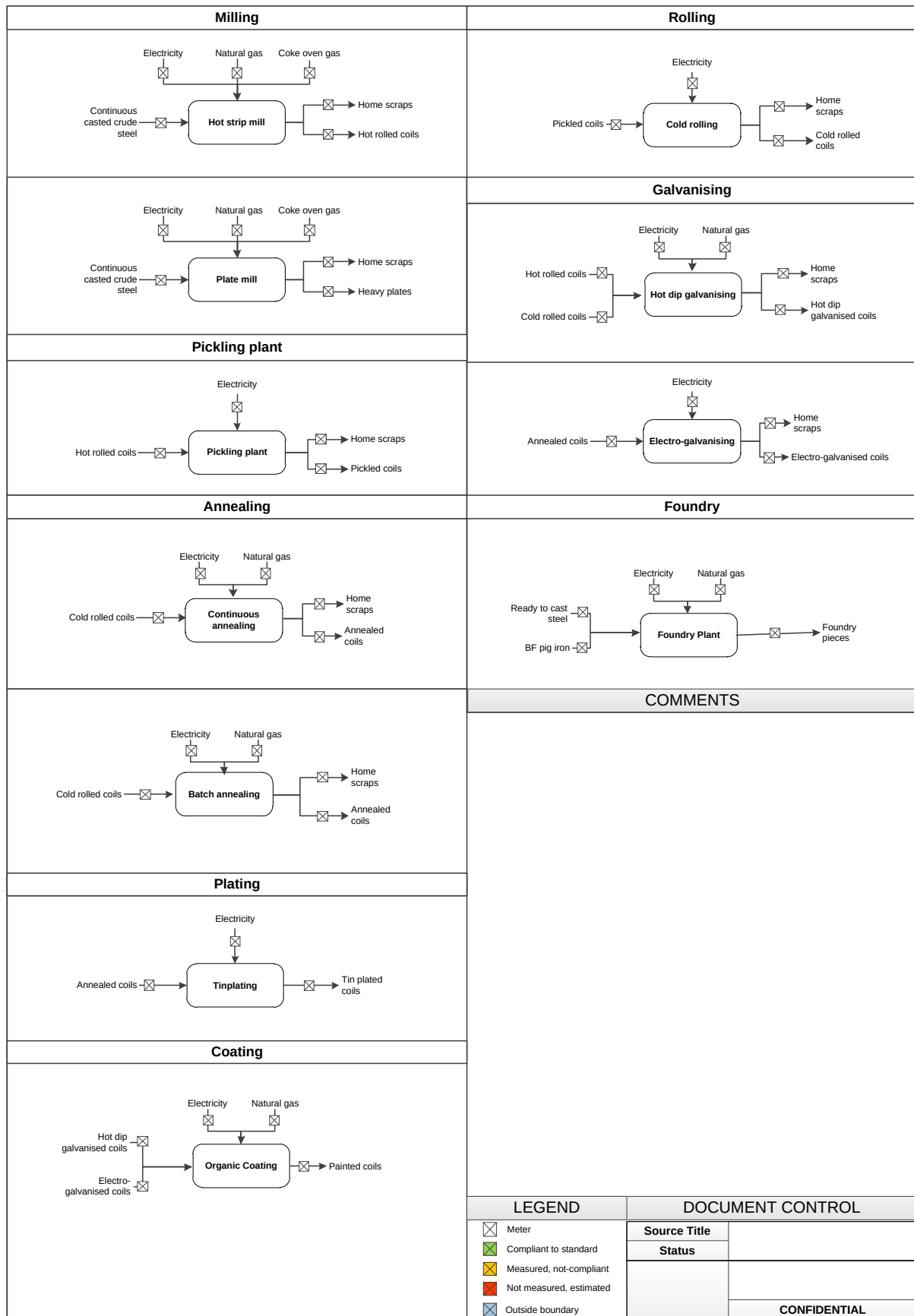


Figure 100: Plant A facility black-box analysis continued

Appendix D: Plant A – Case Study 1

Process number	Process name	electricity		HP Steam		LP Steam		Steam		Compressed air		Natural gas		Home coke		Coking coal		Anthracite		Injection coal		Smelting		Total coal		Blast furnace gas		Coke oven gas	
		INPUT	OUTPUT	INPUT	OUTPUT	INPUT	OUTPUT	INPUT	OUTPUT	INPUT	OUTPUT	INPUT	OUTPUT	INPUT	OUTPUT	INPUT	OUTPUT	INPUT	OUTPUT	INPUT	OUTPUT	INPUT	OUTPUT	INPUT	OUTPUT	INPUT	OUTPUT	INPUT	OUTPUT
1	Coke plant	37,432			0	338,909		338,909	0					858,388		1,157,486								1,157,486	858,388	2,248,080		1,083,061	5,798,507
2	Sinter Plant	147,282						0	0			153,016		127,319				15,134						142,453				0	
3	Blast Furnace	107,914				54,339		54,339	0	2,502,100		210,951		1,039,472				0		292,132				1,331,604	5,400,201	13,835,039			
4	Direct Reduction	54,016	38,397	155,135	301,044		260,163	155,135	561,207													474,699						22,221	
5	BOF Plant	80,421				10,538		10,538	0																			118,792	
6	Secondary metallurgy	57,555						0	0																				
7	Continuous casting	27,303						0	0																				
8	Hot Strip Mill	197,096				11,122		11,122	0			1,461,714																2,172,921	
9	Plate Mill	24,346						0	0			118,526																681,696	
10	Pickling Plant	21,198				65,871		65,871	0			0																	
11	Cold rolling	72,608				54,857		54,857	0																				
12	Continuous Annealing	69,234				30,106		30,106	0																				
13	Batch Annealing	15,431						0	0																				
14	Hot dip galvanising	57,517				1,427		1,427	0																				
15	Electro galvanising	14,148				2,057		2,057	0																				
16	Tinplating	28,548				48,452		48,452	0																				
17	Organic coating	6,372				14,078		14,078	0																				
18	Foundry Plant	4,404						0	0																				
19	Power Plant		131,737	644,704		57,396		702,100	0																				
20	Boilers	2,508		221,458	1,410,576		0	221,458	1,410,576			381,694													4,108,596		1,172,677		
21	Compressed Air Plant	370,849						0	0	3,980,200																			
22	Water Treatment Plant	25,608				186,161		186,161	0																				
23	Internal Transports							0	0																				
24	Buildings	6,682						0	0																				
25	Others	15,918				69,683		69,683	0			291,520																	
26	Flares					5,490		5,490	0																	2,078,162		526,635	

Figure 101: Plant A energy input-output data in GJ

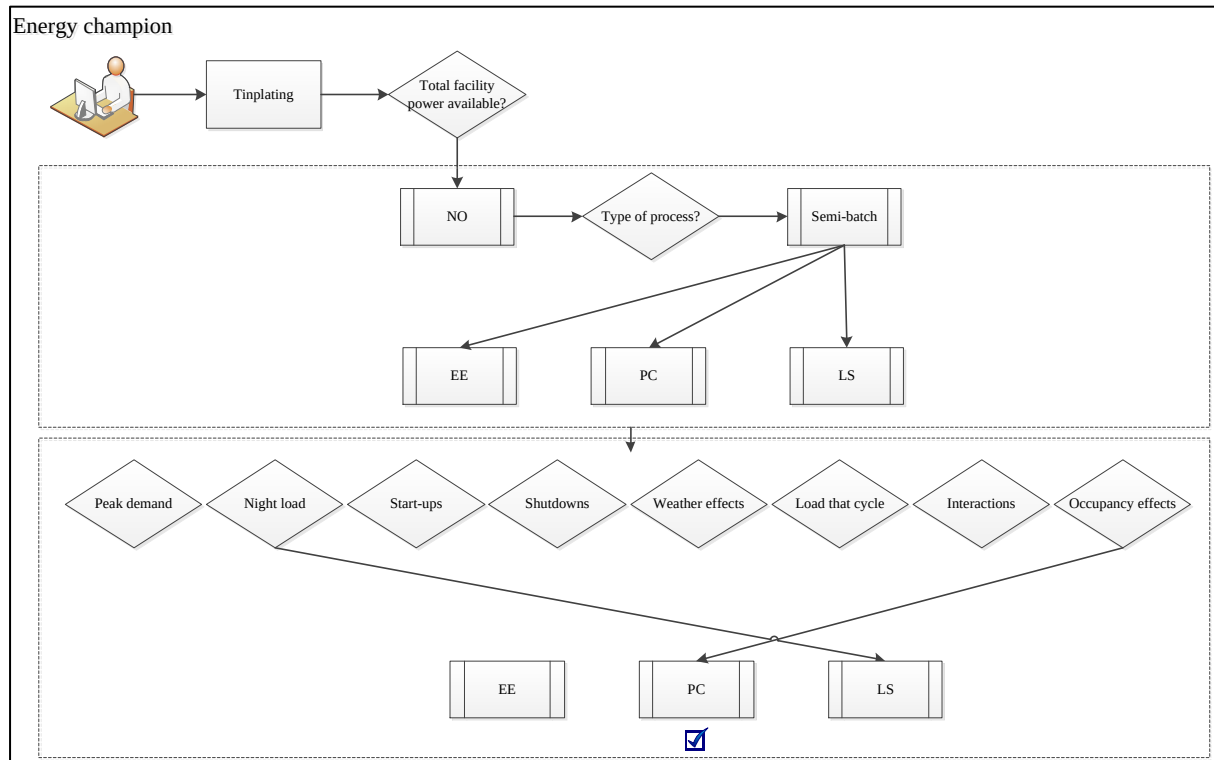


Figure 102: Tinplating operational change identification flow

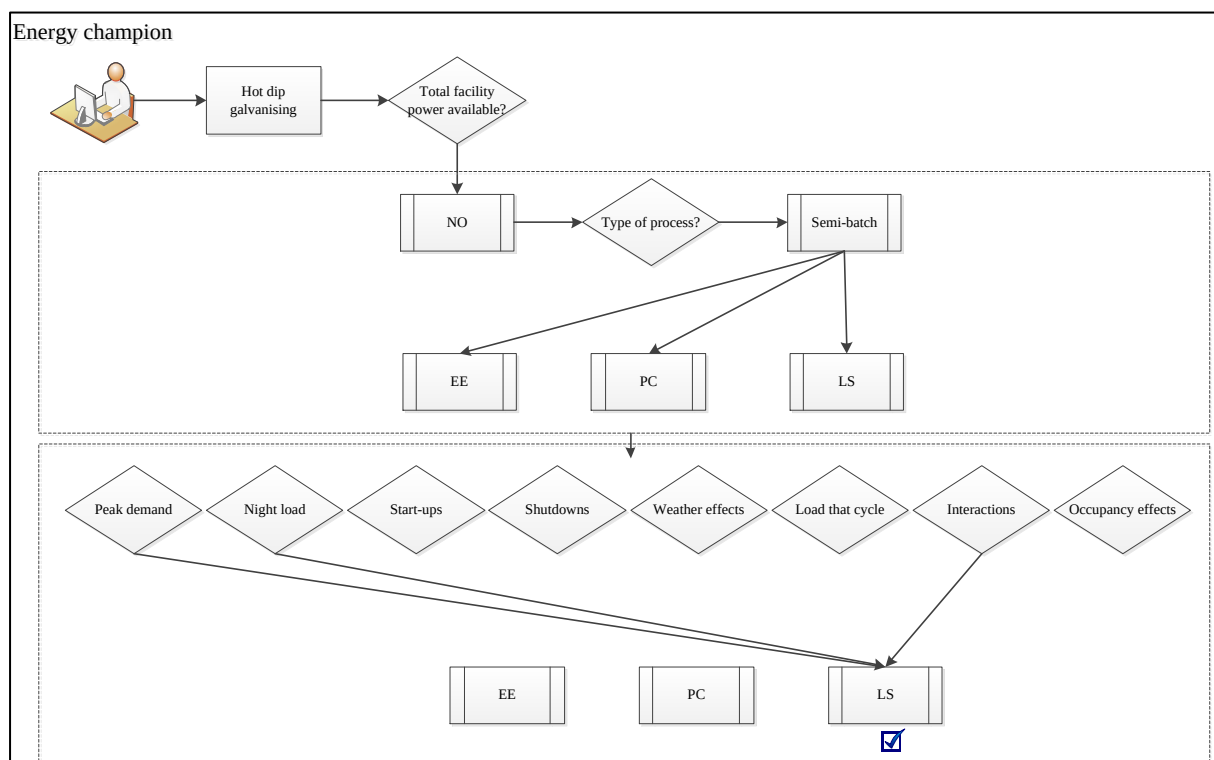


Figure 103: Hot dip galvanising operational change identification flow

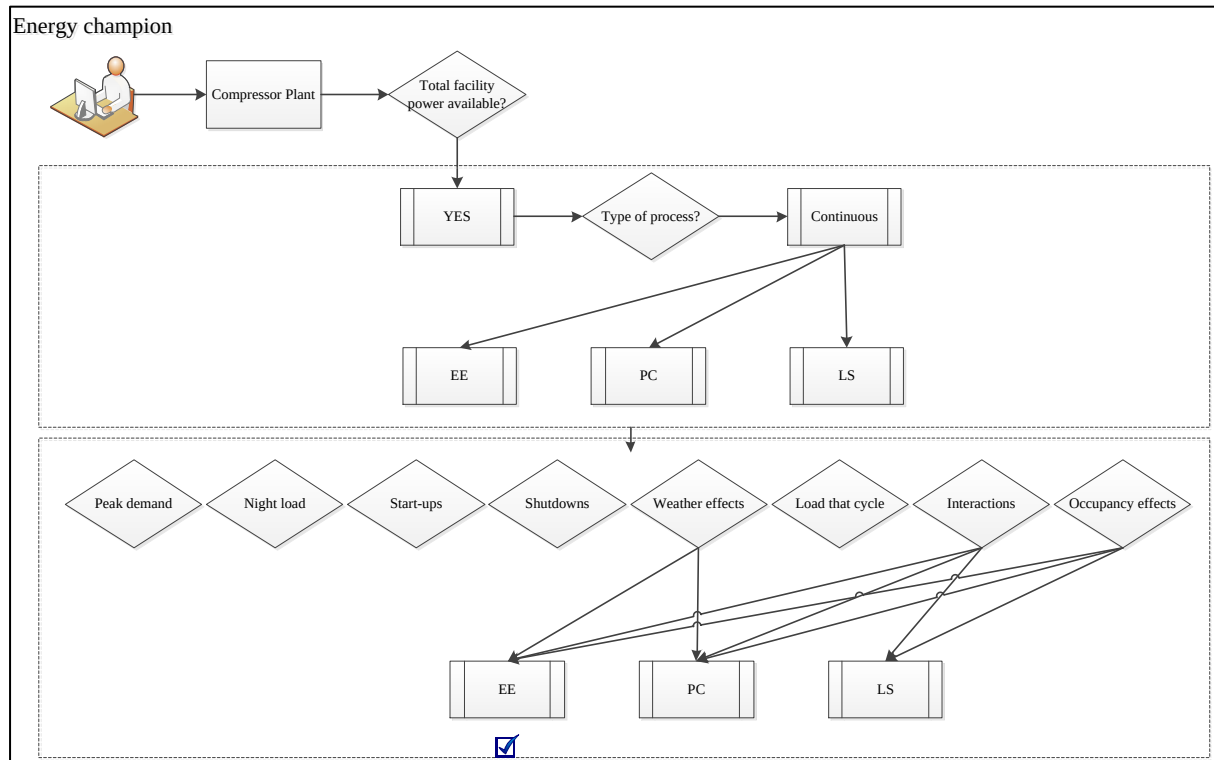


Figure 104: Compressor plant operational change identification flow

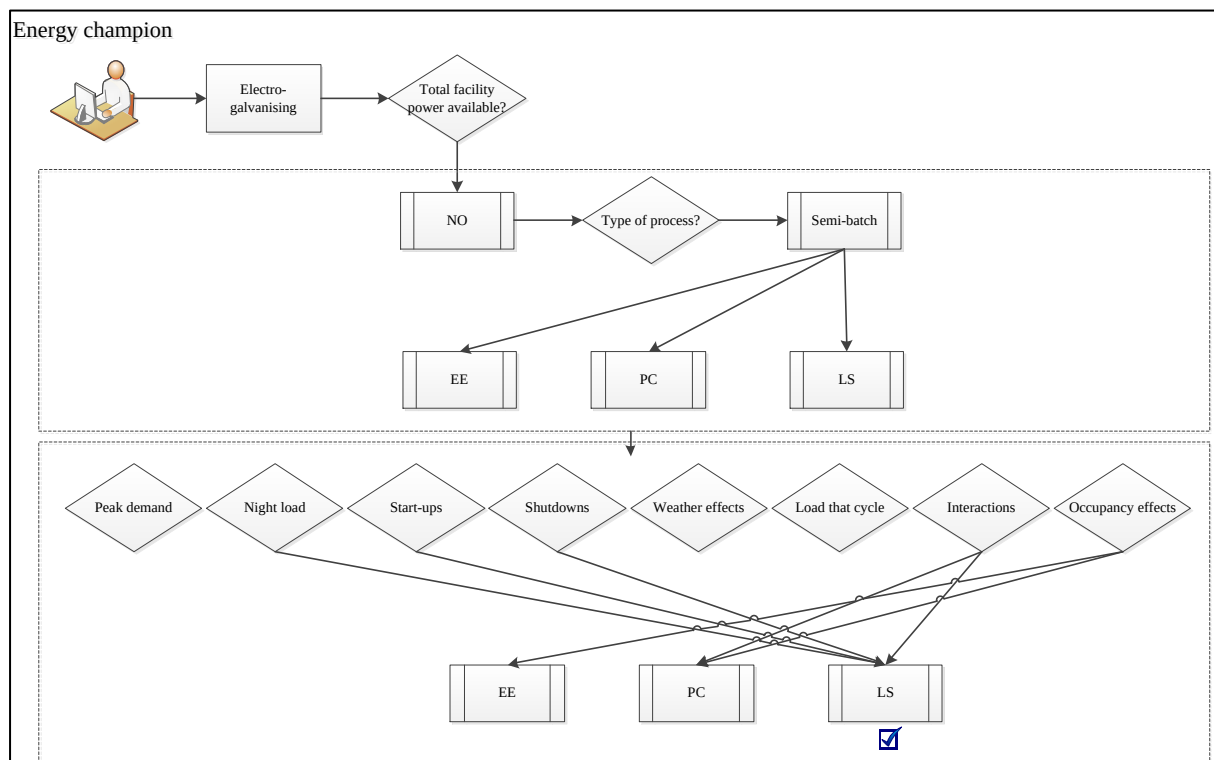


Figure 105: Electro-galvanising operational change identification flow

Table 64: Plant A total power facility ranking

Ranking	Plant A facility	kW
26	Compressor plant	42 922
25	Hot strip mill	22 812
24	Sinter	17 047
23	Blast furnace	12 490
22	BOF	9 308
21	Cold rolling	8 404
20	Continuous annealing	8 013
19	Secondary metallurgy	6 661
18	Hot dip galvanising	6 657
17	Direct reduction	6 252
16	Coke	4 332
15	Tinplate	3 304
14	Continuous casting	3 160
13	Water treatment plant	2 964
12	Plate mills	2 818
11	Pickling plant	2 453
10	Others	1 842
9	Batch annealing	1 786
8	Electro-galvanising	1 638
7	Buildings	773
6	Organic coating	737
5	Foundry plant	510
4	Boilers	290
3	Transport	0
2	Flares	0
1	Power plant	0

Table 65: Plant A facility intensity ranking

Ranking	Plant A facility	Intensity
26	Foundry plant	2.07
25	Tinplate	1.48
24	Hot dip galvanising	0.49
23	Compressor plant	0.46
22	Electro-galvanising	0.39
21	Continuous annealing	0.29
20	Batch annealing	0.15
19	Cold rolling	0.12
18	Hot strip mill	0.09
17	Direct reduction	0.09
16	Blast furnace	0.08
15	Sinter	0.06
14	Secondary metallurgy	0.04
13	Pickling plant	0.03

Ranking	Plant A facility	Intensity
12	Continuous casting	0.02
11	BOF	0.01
10	Water treatment plant	0.01
9	Plate mills	0.01
8	Buildings	0.006
7	Organic coating	0.006
6	Coke	0.004
5	Others	0.003
4	Boilers	0
3	Transport	0
2	Flares	0
1	Power plant	0

Table 66: Plant A prioritisation ranking

Ranking	Plant A facility	Function value
1	Compressor plant	294
2	Sinter	195
3	Hot strip mill	172
4	Hot dip galvanising	168
5	Continuous annealing	164
6	Cold rolling	160
7	Tinplate	160
8	BOF	132
9	Electro-galvanising	120
10	Pickling plant	96
11	Plate mills	84
12	blast furnace	78
13	Direct reduction	68
14	Secondary metallurgy	66
15	Foundry plant	62
16	Batch annealing	58
17	Continuous casting	52
18	Organic coating	52
19	Coke	44
20	Buildings	30
21	Water treatment plant	0
22	Others	0
23	Boilers	0
24	Transport	0
25	Flares	0
26	Power plant	0

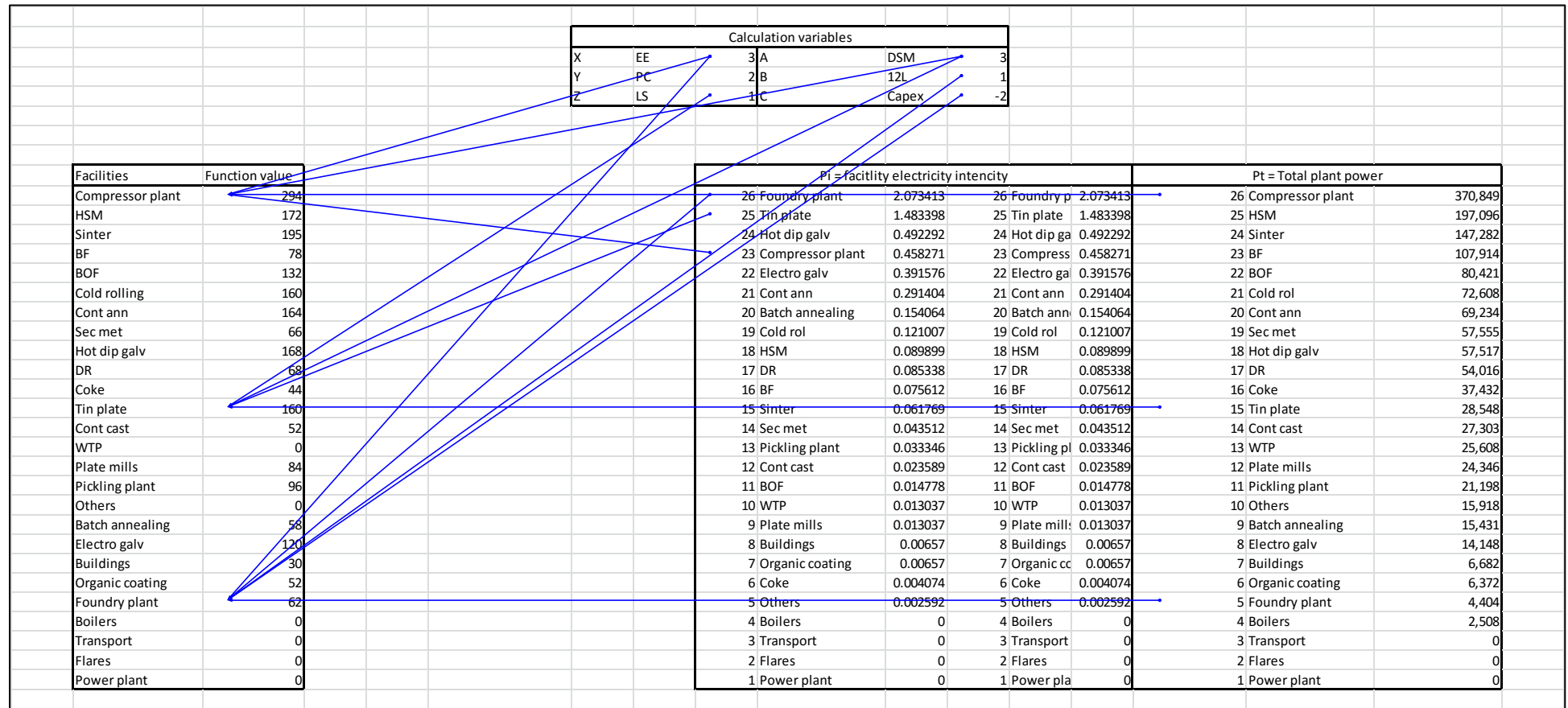


Figure 106: Prioritisation model calculation example for three facilities

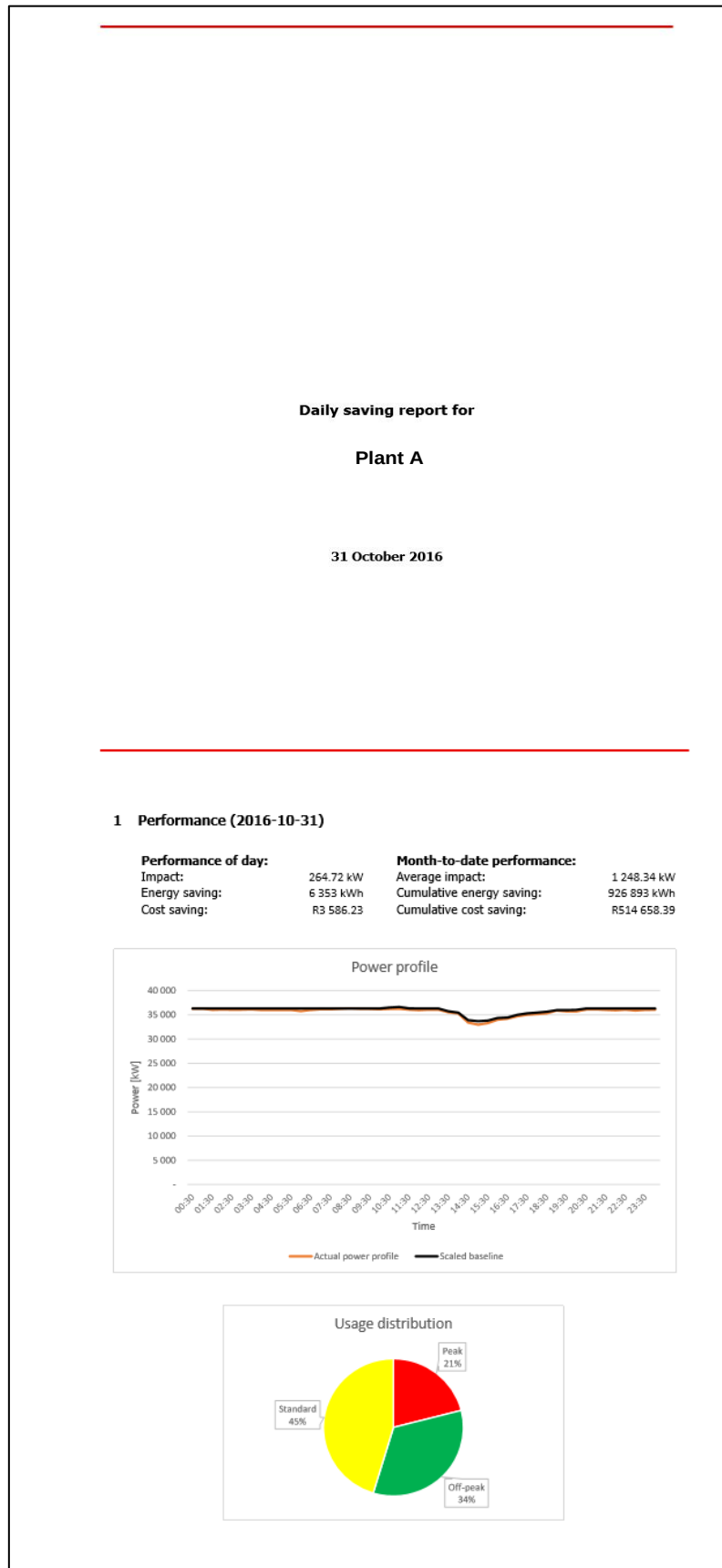


Figure 107: Example of savings report for Plant A compressor plant facility

Appendix E: Plant B – Case Study 2

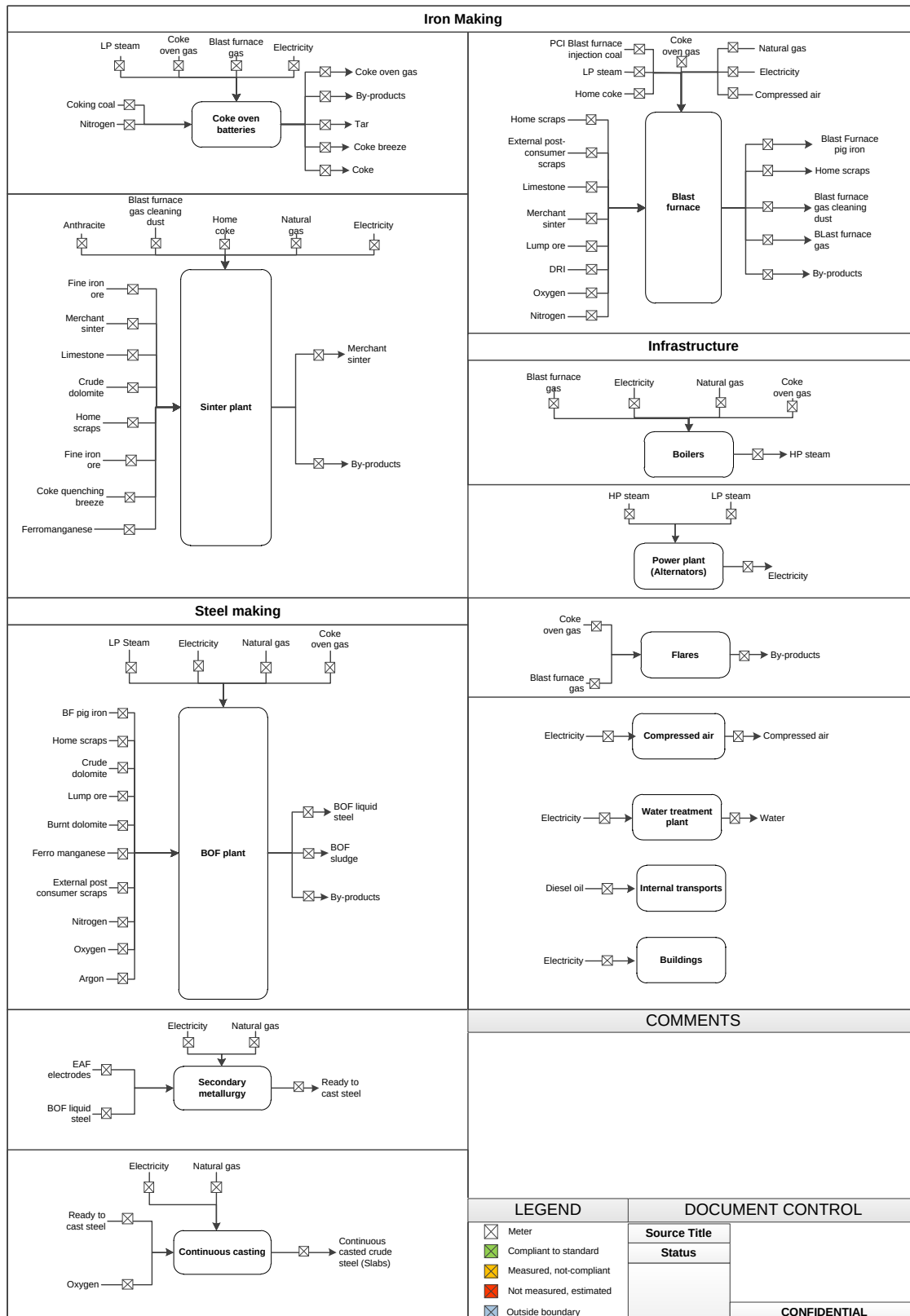


Figure 108: Plant B facility black-box analysis

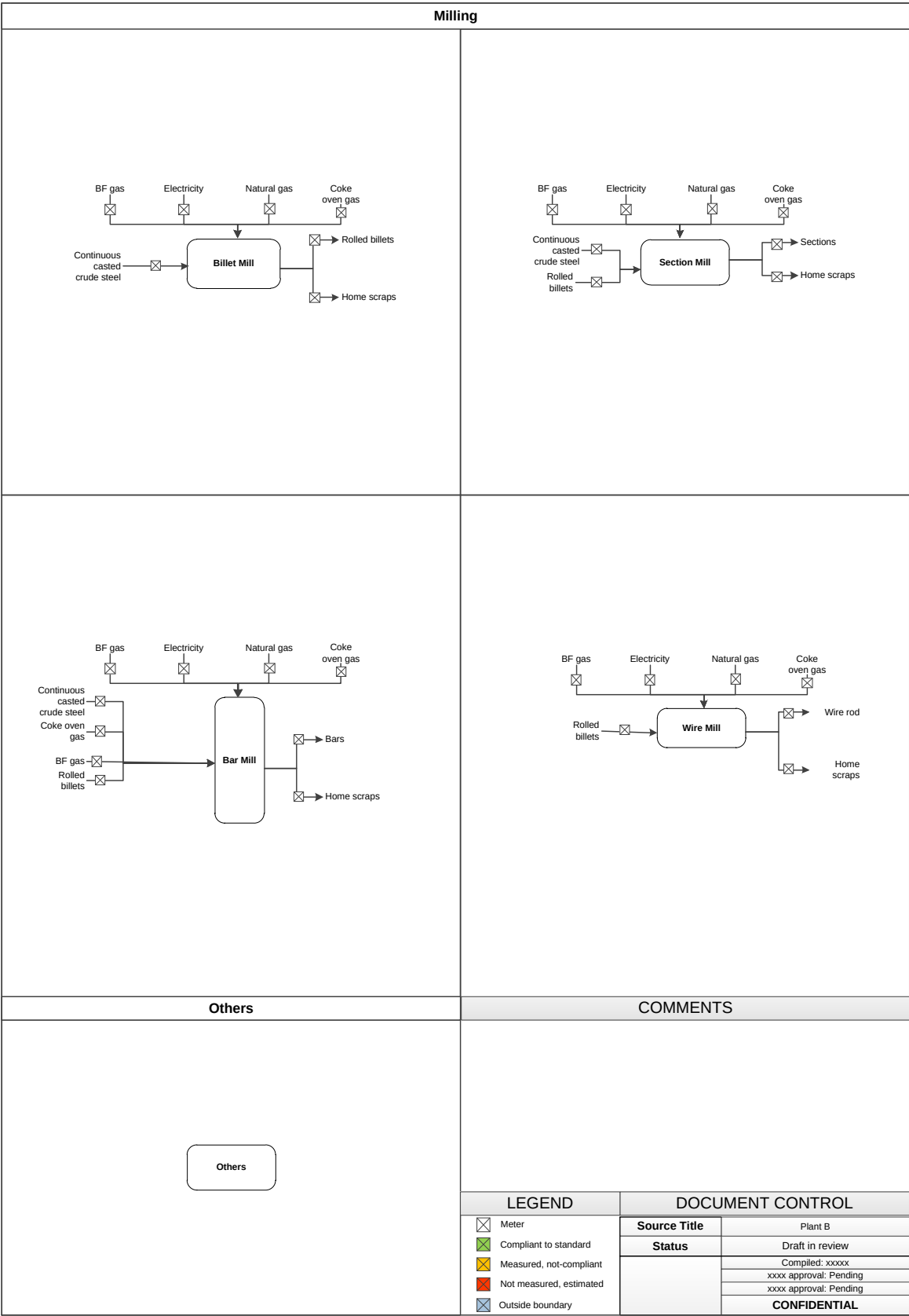


Figure 109: Plant B facility black-box analysis (continued)

Table 67: Plant B facility power ranking

Ranking	Facility	Power (kW)
9	Steel plant	34 971
8	Sinter plant	26 031
7	Infrastructure	18 817
6	Rod mill	18 383
5	Medium mill	12 697
4	Bar mill	11 343
3	Billet mill	11 086
2	Blast furnace	10 881
1	Coke plant	9 215

Table 68: Plant B facility intensity ranking

Ranking	Facility	Intensity
9	Medium mill	0.624
8	Bar mill	0.552
7	Rod mill	0.481
6	Steel plant	0.368
5	Sinter plant	0.206
4	Billet mill	0.149
3	Coke plant	0.144
2	Infrastructure	0.142
1	Blast furnace	0.112

Table 69: Plant B prioritisation ranking

Ranking	Facility	Function value
1	Sinter	52
2	Medium mill	48
3	Infrastructure	36
4	Steel	30
5	Rod mill	26
6	Bar mill	24
7	Billet mill	14
8	Coke plant	8
9	Blast furnace	6

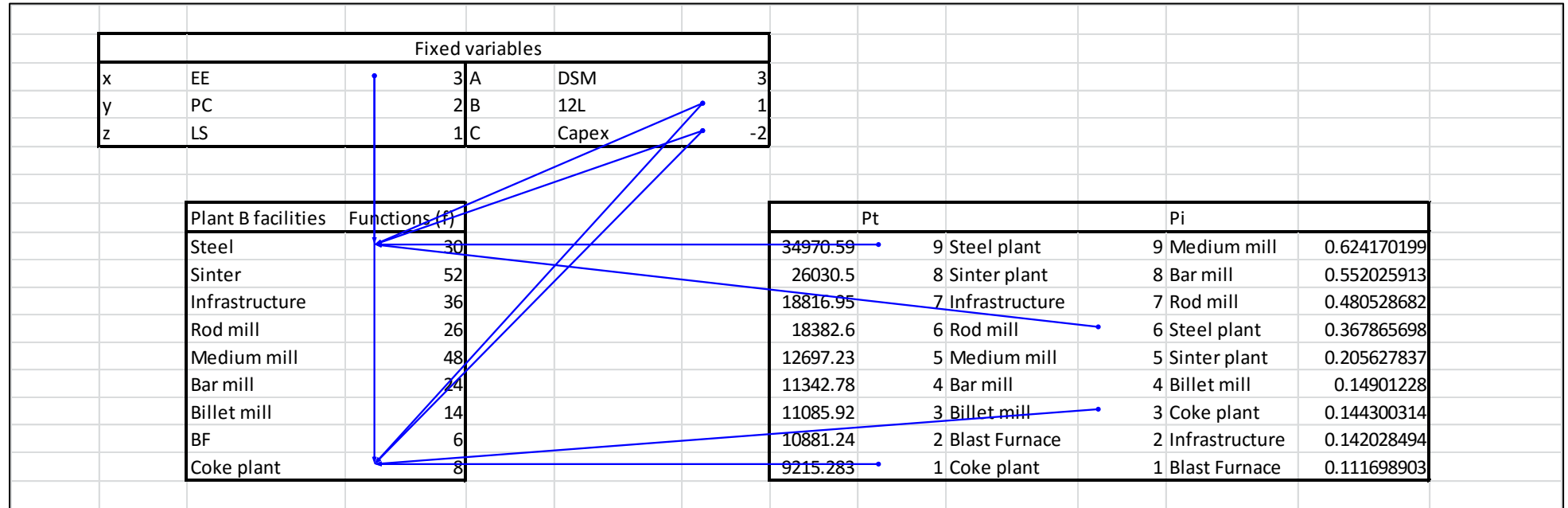


Figure 110: Prioritisation model calculation example for two facilities

Electricity consumption weekly report

Table 1-1: Weekly performance summary

Weekly electricity savings 06 Jun 2016 - 12 Jun 2016	
Consumption (kWh)	45,249.53
Cost	R 126,200.95

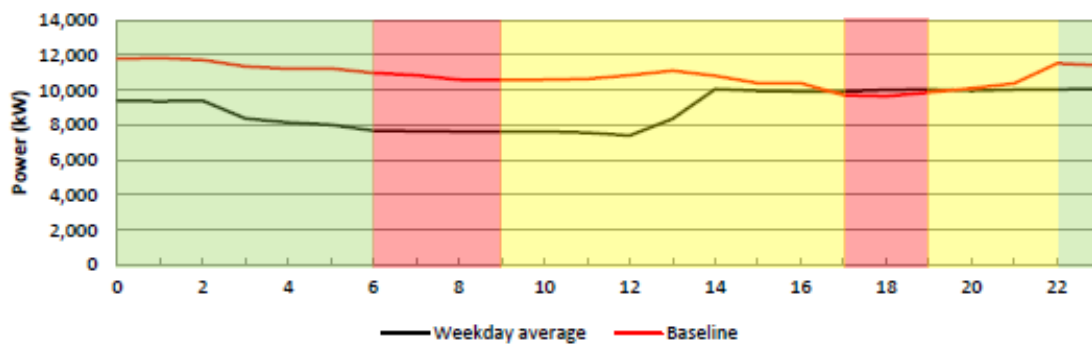


Figure 1-1: Average weekday performance profile

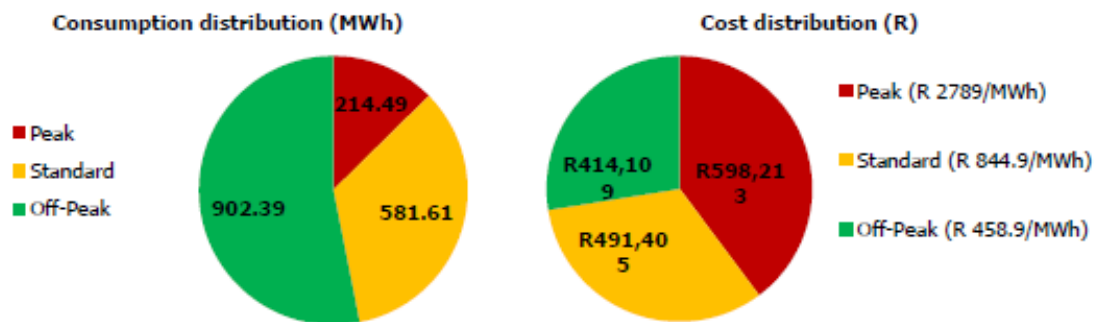


Figure 2-1: Weekly electricity distributions

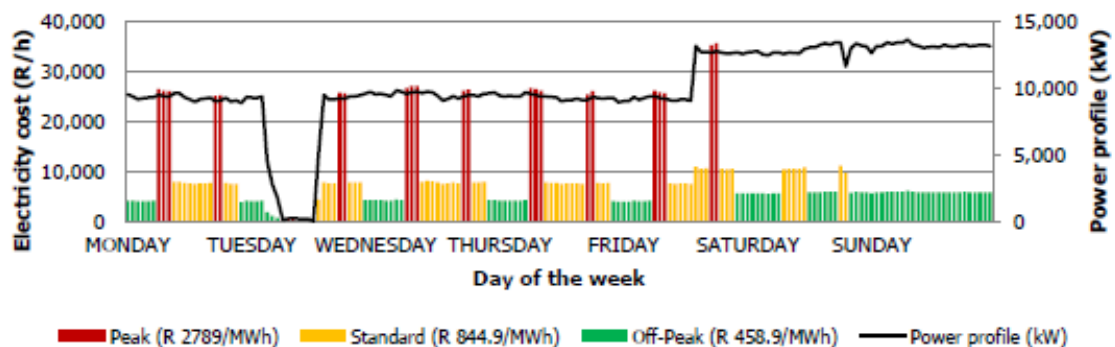


Figure 3-1: Weekly electricity expenditure

Figure 111: Possible report for Plant B