Objective evaluation of industrial energy efficiency models for the RSA Section 12L tax incentive

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Abstract

Title: Objective evaluation of industrial energy efficiency models for the RSA Section 12L tax incentive

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The industrial sector is the largest energy consumer in South Africa. There are numerous initiatives that can be implemented in order to reduce the energy intensity of the various industrial processes. Section 12L of the Income Tax Act (1962) allows a significant tax rebate for quantified energy efficiency savings resulting from an energy efficiency initiative. There are, however, strict rules and regulations related to 12L. Applications need to adhere to these rules and regulations in order to receive the allowance.

Previous studies that focussed on Section 12L for industries recommend that multiple models should be developed in order to quantify the energy efficiency savings. These studies, however, do not provide guidance on how to evaluate the various models or how to select the final model. This becomes critical when considering that different models will result in different energy efficiency savings, which has a direct impact on the monetary value associated with 12L.

A need therefore exists to prove that the most appropriate model was chosen between multiple modelling options. The various models should be evaluated to ensure that the final model adheres to the multiple requirements associated with 12L. The evaluation process leading to the selection of the final model should also be transparent in order to increase the confidence of the reported energy efficiency savings and to protect all stakeholders involved.

This dissertation provides a detailed literature study related to the identified problem. Firstly, an overview of the 12L Regulations and Standard, as well as industrial measurement and verification is given. This is done to understand the legal and technical requirements of the 12L tax incentive. Thereafter, literature regarding decision support methods is presented. The generic steps of solving multi-criteria decision problems are also identified. These steps aid in the decision making process between multiple possible solutions which should adhere to multiple conflicting criteria.

The knowledge obtained from literature is used to develop a methodology to evaluate alternative baseline models and objectively select a final modelling option. The methodology consists of three phases: the generation of modelling options, evaluation of the modelling options, and ranking of results and recommending the preferred model.

The methodology was verified by implementing it on three case studies. These case studies considered three different industries (petrochemical, iron and steel, mining). The ranked modelling options showed a 10% to 33% variance in the potential claim value. This significant variance highlights the importance of presenting a transparent and compliant model selection process.

The preferred models recommended by the methodology were finally validated by comparing their result to models developed by an independent, SANAS accredited team. This validation confirms that the methodology addresses the original problem statement by delivering a traceable and objective process of evaluating various modelling options for the Section 12L tax incentive.

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List of abbreviations

Abbreviation	Description
BL	*Baseline*
CMVP	*Certified Measurement and Verification Professional*
EE	*Energy efficiency*
EEI	*Energy efficiency initiative*
ESM	*Energy saving measure*
Et al.	*And others*
GHG	*Greenhouse gas*
i.e.	*That is*
M&V	*Measurement and Verification*
SANAS	*South African National Accreditation System*
SANEDI	*South African National Energy Development Institute*
SANS	*South African National Standard*

List of symbols

Symbol	Description
A	*Multi-criteria evaluation score*
a	*Unweighted evaluation score according to a certain decision criterion*
C	*Criterion weight*
c	*Intercept of regression fit*
df	*Degrees of freedom*
E_s	*Energy savings*
m	*Gradient or slope of regression fit*
R^2	*Coefficient of determination*
$RMSE$	*Root mean squared error*
$SSResid$	*Residual sum of squares*
$SSTo$	*Total sum of squares*
w	*Decision criterion*

1. INTRODUCTION

1.1. Preamble

This chapter will provide the relevant background to justify the need for this study. Firstly, background on industrial energy efficiency will be provided. It is shown that the industrial sector is the largest energy consumer in South Africa. The potential for the implementation of energy efficiency initiatives in the industrial sector will also be highlighted.

Secondly, the problem statement provided will discuss the motivation for the study. Thirdly, the objectives and scope of investigation will be provided; which will give a breakdown of how the problem will be addressed throughout this document.

1.2. Background on industrial energy efficiency

1.2.1 Energy use in South Africa

Greenhouse gas (GHG) emissions are deemed to be the most significant contributor to climate change [1] [2]. According to the *World Bank* [3] South Africa is one of the most intensive GHG emitters per capita, as shown in Figure 1-1. South Africa has therefore committed to reduce its GHG emissions by 32% by 2020 and 42% by 2025 [4]. This was done as part of a global effort to address the risk of climate change and promote sustainable development [2].

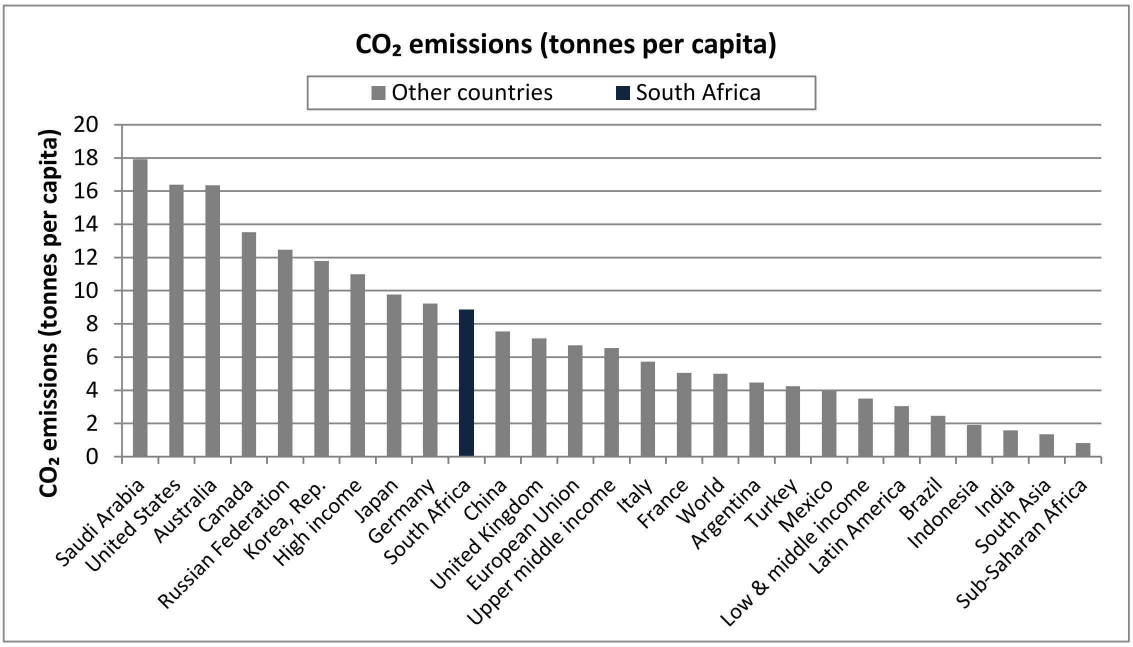

Figure 1-1: National emissions per capita during 2013. Adapted from [3] [5]

Laws, policies and regulations have been implemented to mitigate climate change. In South Africa tax-based directives are prevalently utilised as a strategy to encourage a less carbon intensive economic growth path [1] [4] [6]. The South African government plans to implement carbon tax in an effort to promote the reduction of GHG emissions [1].

The carbon tax will have a significant impact in South Africa since 70% of the country's primary energy sources may be attributed to coal [7]. Investigation of the utilisation of energy in South Africa is therefore a relevant topic to consider.

The end use of energy in South Africa can be divided into various sectorial groupings. This includes various energy sources, such as coal, petroleum products, electricity and gas. There are five main sectors, namely the agricultural, commercial, industrial (including mining), residential and transport sectors [8].

According to the *Digest of South African Energy Statistics 2009* [9] the industrial and mining sector is the largest energy user by contributing to about 40% of South Africa's energy consumption. This is equivalent to approximately 298 TWh of energy per year.

A breakdown of the South African industrial sector's energy consumption is presented in Figure 1-2 [10]. This graph was constructed from the average values from 1992 to 2012 of the South African industry energy balance data, as supplied by the South African Department of Energy.

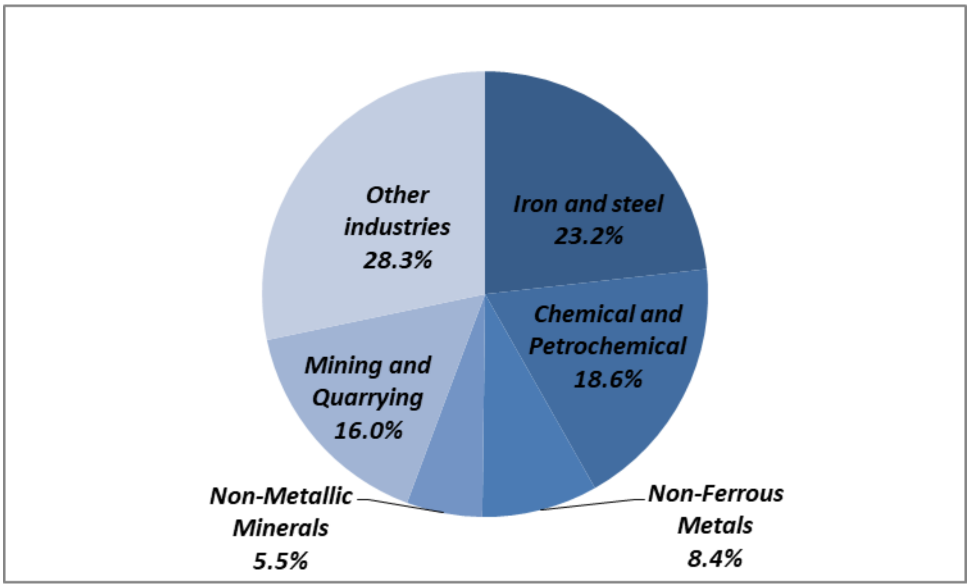

Figure 1-2: Non-renewable energy consumption per industry. Adapted from [10]

Figure 1-2 shows that the three largest energy consuming industries in South Africa consist of the iron and steel, chemical and petrochemical, and mining and quarrying industries. The largest energy consumer in the industrial sector is the iron and steel sub-sector (23.2%). This is closely followed by the chemical and petrochemical sub-sector (18.6%), as well as the mining and quarrying sub-sector (16.0%).

1.2.2 Energy efficiency potential in the industrial sector

The previous section identified the industrial sector as the largest energy consuming sector in South Africa. It was further identified that the chemical and petrochemical, the iron and steel, and the mining and quarrying sub-sectors are the main energy consumers in industry. In this section the potential for energy efficiency (EE) improvements in the three industrial sub-sectors will be investigated.

Chemical and petrochemical industry

Worrell & Galitsky [11] identified the key areas for EE improvement for petroleum refineries. These areas were utilities, fired heaters, process optimisation, heat exchangers, motor and motor applications, and other areas. The percentages of total energy saving opportunities for each of the key areas are shown in Figure 1-3.

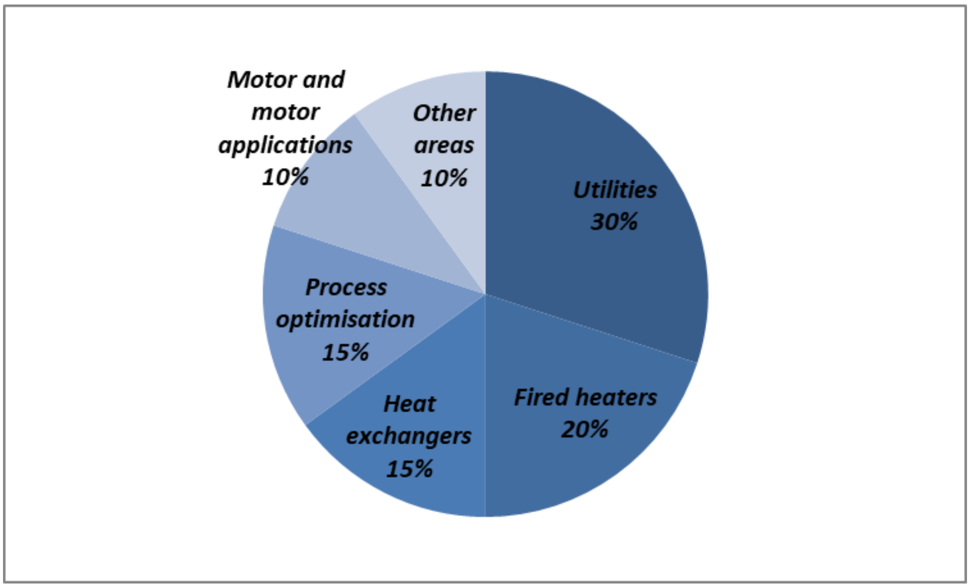

Figure 1-3: Energy efficiency potential in chemical and petrochemical industry. Adapted from [11]

Bergh [12] investigated the drivers, barriers and opportunities of EE in the South African crude oil refining industry. Furthermore, *Bergh* [12] also identified short to medium term as well as long term opportunities for EE improvement in refineries. These opportunities are summarised in Table 1-1.

Table 1-1: Energy efficiency potential in chemical and petrochemical industry. Adapted from [12]

Focus area	Description
Short to medium term EE opportunities	- Energy management - House-keeping, maintenance and operational best practices - Monitoring overall performance - Utility system improvements - Fuel-gas systems - Steam systems - Power recovery - Cooling water systems - Heat integration and fouling mitigation - Combustion efficiency in process heaters/boilers - Distillation - Fluid catalytic cracker - Cogeneration - Gasification - Hydrogen management - Advanced process control - Electric motor systems (e.g. pumps, compressors, fans, etc.)
Long term EE opportunities	- Distillation - Hydrogen recovery - Hydro treating

Iron and steel industry

Worrel et al. [13] specified numerous EE measures applicable to the iron and steel industry. *Hasanbeige et al.* [14] identified twenty five of these measures as the most relevant to the industry with respect to applicability and significance of the achieved energy savings. Table 1-2 provides a summary of the EE measures according to the various sections associated with the iron and steel industry [15].

Table 1-2: Energy efficiency potential in the iron and steel industry. Adapted from [15]

Focus area	Description
Sintering	- Heat recovery from sinter cooler - Increased bed depth
Coke making	- Coal moisture control - Coke dry quenching
Blast furnace	- Injection of pulverized coal in blast furnace - Injection of coke oven gas in blast furnace - Top-pressure recovery turbines - Recovery of blast furnace gas
Direct reduced iron	- Use of iron ore in direct reduced iron kiln - Install variable frequency drive on kiln cooler drives - Properly sized blowers
Basic oxygen furnace	- Recovery of basic oxygen furnace gas and sensible heat
Electric arc furnace	- Scrap preheating
Casting and refining	- Integrated casting and rolling (strip casting)
Hot rolling	- Recuperative or regenerative burner - Process control in hot strip mill - Waste heat recovery from cooling water
Cold rolling	- Heat recovery on the annealing line - Automated monitoring and targeting systems
General measures	- Preventative maintenance in integrated steel mills - Preventative maintenance in electric arc furnace plants - Energy monitoring and management systems in integrated steel mills - Energy monitoring and management in electric arc furnace plants - Variable speed drives for flue gas control, pumps, fans in integrated steel mills - Cogeneration for the use of untapped coke oven gas, blast furnace gas, and basic oxygen furnace gas in integrated steel mills

Mining industry

The mining sector can be split into two areas of focus, namely production and services. Production refers to the mining of ore, while services refer to the auxiliary systems needed and used during mining. The auxiliary systems include compressed air, hoisting, pumping, ventilation and refrigeration [16].

The auxiliary systems contribute to 61% of the mining sector's electricity consumption [16]. The other 39% may be attributed to the processing plants, mining processes, office buildings, hostels and other electricity consumers in the sector. The potential for electrical savings on the auxiliary systems has extensively been investigated in literature [17] [18] [19]. Table 1-3 summarises potential areas for EE improvement in the various auxiliary systems of the mining industry [16].

Table 1-3: Energy efficiency potential in the mining industry. Adapted from [16]

Focus area	Description
Compressed air network	- Compressor control - Surface/ underground distribution control - Replace pneumatic applications - Fix air leaks
Pumping	- Replace inefficient pumps - Recondition inefficient pumps
Refrigeration	- Maintenance - Cleaning of tubes for better heat exchange - Implementing energy recovery systems (e.g. turbines and three-pipe systems) - Water system optimisation - Cooling auxiliaries optimisation
Ventilation	- Booster fans opportunities: ▪ Utilisation of more efficient fans ▪ Reduce amount of booster fans - Main fans opportunities: ▪ Improve fan control (e.g. reduce fan speed, pre-rotation of inlet air, or damping of fan outlet) ▪ Replace blades with carbon fibre blades

Summary of industrial energy efficiency potential

From the above mentioned possible initiatives, it can be seen that there are a substantial number of EE opportunities available in all three of the largest energy consuming industries within South Africa. Implementation of these initiatives could lead to significant EE savings. Over the eleven year period from 2000 to 2011 a compounded annual decrease of 2.1% could have been obtained due to EE in the industrial sector [8]. This energy saving of 2.1% in the industrial sector would have been equivalent to approximately 6.3 TWh of EE savings per year.

Despite the significant potential of EE in industry, there are a number of barriers associated with the implementation of energy efficiency initiatives (EEI) in industry [10] [20]. In a study done by *Fawkes* [20] five reasons for the resistance to the implementation of EEI in South Africa were identified. These reasons include attitude, resistance to change, rather focussing on high cost of raw materials and labour than that of energy, lack of capital and investors' uncertainty regarding the future (e.g. payback periods) [20] [21].

The South African government acknowledges that considerable investment is required to implement energy efficiency initiatives [22]. Therefore, the government has introduced financial incentives to encourage the implementation of EEI's [10]. The flagship government incentive is Section 12L of the Income Tax Act which was proposed by the National Treasury in the 2009 Taxation Laws Amendment Act [10] [22] [23] [24]. This incentive is discussed in more detail in the next section.

1.2.3 Section 12L of the Income Tax Act

In essence, the idea of Section 12L is that the more energy is saved, the less tax is paid [22]. According to Section 12L of the Income Tax Act (1962), a tax deduction allowance is awarded to tax payers for quantified EE savings [24]. Initially the allowance was 45c per verified kWh of EE savings; however since March 2015 this amount has been increased to 95c/kWh [25].

In the previous section, the example was given that if an energy saving of 2.1% took place in the industrial sector it would be equivalent to approximately 6.3 TWh of energy savings. The tax allowance certificate value with respect to 12L for this energy savings is equal to R 5.9 billion. This indicates that 12L can be a significant source of funding for EE in South Africa.

There are, however, a number of challenges associated with the incentive [22]. This becomes evident when considering that in 2016 there were 108 12L applications registered; while only 14 certificates were successfully issued [26]. A key challenge is to accurately calculate, and verify, the achieved energy savings while adhering to the strict rules and regulations, as stated in the 12L Regulations [5] [6] [27]. This challenge is a significant concern as the calculated energy savings have a direct impact on the 12L tax allowance certificate value [5] [27].

The 12L regulatory structure stipulates that the quantified EE savings must be verified by an independent, SANAS accredited measurement and verification (M&V) body [5] [6] [28] [29]. This is done with the aim of mitigating the concerns associated with the incentive. Furthermore, the M&V process is required to be traceable, accurate and transparent to ensure the protection of all stakeholders involved [5] [28]. The M&V practice will thus form a crucial part in the practical application of 12L.

1.2.4 Previous research

Energy efficiency savings refer to the absence in energy usage after the implementation of an EEI [30]. Since the absence of energy usage cannot be directly measured, baseline models are used to predict what the energy consumption would have been in the performance assessment if the EEI was not implemented [5] [30]. The baseline and performance assessment periods refer to the periods before and after the implementation of an EEI.

Energy efficiency savings are then determined as the difference between the measured energy consumption during the baseline and performance assessment periods. It is therefore crucial that the developed baseline model is representative of the “business as usual” scenario in order to accurately quantify the achieved EE savings [5] [30].

The EE savings can be calculated for different measurement boundaries on a facility. This includes considering the whole facility or only a portion of the facility to evaluate and assess the EE savings. The selected measurement boundary should however encapsulate the effect of the EEI [30].

Janse van Rensburg [10] undertook a study that focussed on structuring mining data for the Section 12L tax incentive. In the study a methodology was provided to select a measurement boundary. This was done by identifying all of the available measurement boundary options and recommending suggestions to take into consideration when selecting the final measurement boundary.

Within the selected measurement boundary an accurate dataset must be compiled. This dataset may consist of either all of the parameters associated with the energy system, or only the significant energy governing parameters [30].

The data used to construct the dataset should be evaluated to ensure compliance with the 12L Regulations. This means that the data should be obtained from either invoices or measurements from calibrated meters [6]. This ensures that the data is accurate. However, in industrial systems a large amount of measurement points and data exists; which results in numerous dataset options to choose from when developing the baseline model [5].

After selecting a measurement boundary and dataset; the EE savings are calculated. Different mathematical methods may be used for the quantification of the EE savings. These include energy intensity calculations, simulations, predictive modelling and various regression methods [5]. In a study done by *Campbell* [28], where the feasibility of 12L applications was evaluated, the EE savings were determined by means of both regression and intensity calculations.

Hamer [5] investigated the quantification of RSA Section 12L EE tax incentives for large industries. In the study, *Hamer* [5] recommends that various models should be developed to determine the EE savings associated with an EEI. The various models are developed by varying the selected measurement boundaries, datasets and calculation method options available.

There are various types of energy users in industrial systems on which various potential EEI may be implemented. Furthermore, different measurement boundaries are available when evaluating the EE savings resulting from the implementation of such an EEI. In industrial systems the dataset options are also numerous within a selected measurement boundary. Finally, the calculation of the EE savings can also be done in different ways.

Previous studies recommend that multiple baseline models should be developed to fully evaluate the EE savings [5] [28]. This increases the confidence that the reported EE savings is a realistic reflection of the actual achieved savings [5]. Numerous baseline modelling options are available when considering the various options of energy saving measures, measurement boundaries, datasets, and calculation methods. Figure 1-4 illustrates this concept.

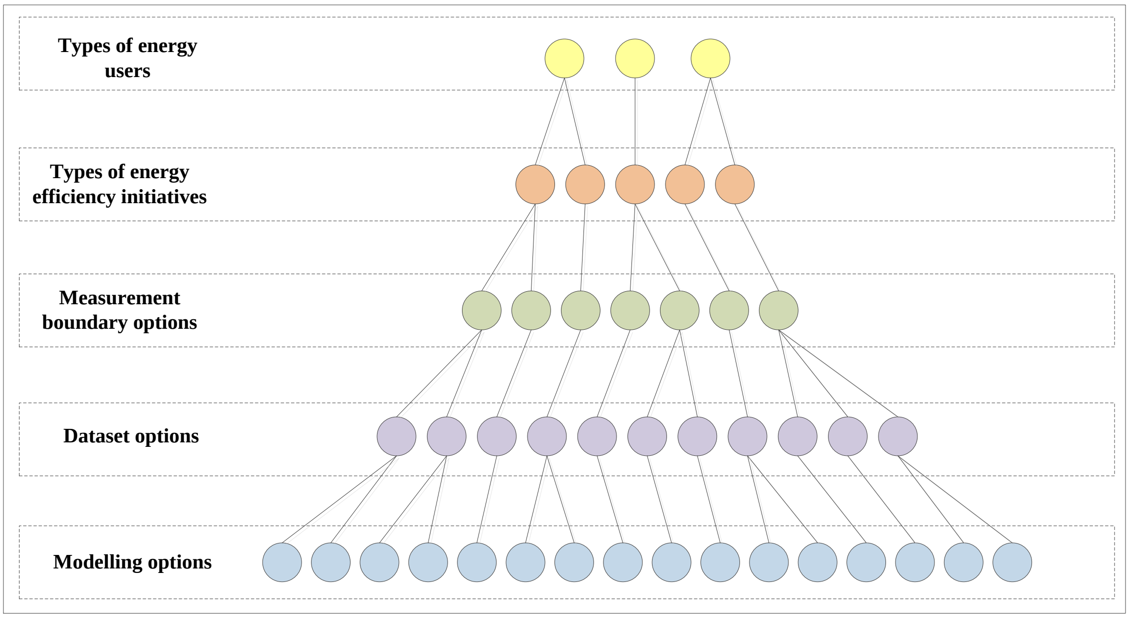

Figure 1-4: Illustration of multiple modelling options

This section identifies that various options are available for the quantification of 12L EE savings. Published studies indicate that multiple models should be developed in order to quantify the EE savings resulting from an EEI. However, none of these studies provide guidance to evaluate the multiple modelling options in order to select the most appropriate model. This becomes critical when considering that different modelling options result in different EE savings, which will have a direct impact on the monetary value associated with 12L.

1.3. Problem statement

This chapter showed that the industrial sector is the largest energy consumer in South Africa. There are numerous initiatives that can be implemented in order to reduce the energy intensity of the various industrial processes. Section 12L of the Income Tax Act allows a significant tax rebate for quantified EE savings resulting from an EEI. There are, however, strict rules and regulations related to 12L. Applications need to adhere to these rules and regulations in order to receive the allowance.

Previous studies that focussed on Section 12L for industries recommend that multiple models should be developed in order to quantify the EE savings. These studies however do not give guidance on how to objectively evaluate the various models or how to select the most appropriate model. This becomes critical when considering that different models would result in different EE savings which has a direct impact on the monetary value associated with 12L.

A need exists to prove that the most appropriate model was chosen between multiple modelling options. The various models should be evaluated to ensure that the final model adheres to all of the requirements associated with 12L. Furthermore, the evaluation process leading to the selection of the final model should be transparent in order to increase the confidence of the reported EE savings.

1.4. Objectives and scope of investigation

1.4.1 Objectives

The main objective of this study is to develop a methodology which assists the 12L application process to evaluate and select a final model for 12L applications when more than one modelling option is available. This will be done by achieving the following objectives:

- providing relevant research regarding the requirements of 12L applications,
- providing research regarding decision support methods when more than one solution is available,
- identifying the criteria that 12L models need to adhere to,
- devising a methodology which aids in the evaluation process of multiple modelling options and the selection of a final model, and
- verifying the methodology by applying it to actual case studies.

1.4.2 Scope of investigation

Chapter 1 consists of the introduction to this study. The problem statement section emphasises the need for the study. The objectives that must be met throughout the course of this study are also detailed in Chapter 1.

Chapter 2 contains a review of the relevant literature regarding three specific research areas. Firstly, the 12L Regulations and Standard are discussed to identify the legal requirements of 12L. Secondly, the technical scope of 12L is investigated by providing research regarding industrial measurement and verification, which would be required to provide the legal and technical requirements of 12L. Thirdly, decision support methods are studied to find the optimal balance between the different 12L requirements and, thereafter recommend an appropriate final 12L model.

In *Chapter 3* the methodology is developed. The methodology consists of three steps. Firstly, various modelling options are generated. Thereafter the modelling options are evaluated according to the requirements of a 12L model. Lastly, the various models are ranked according to their evaluation and a recommendation is made for the final 12L model.

In *Chapter 4* the methodology is verified by applying it to actual case studies. Three case studies are discussed in detail. The case studies vary according to three different types of industries; namely the chemical and petrochemical, the iron and steel, and the mining industries. Multiple modelling options were evaluated for each case study; where after a final modelling option was selected. Lastly, the results were validated by comparing the results obtained, i.e. the final modelling option, to that of independent, SANAS accredited M&V results.

Chapter 5 provides a summary of the conclusions made from this study. This chapter refers back to the objectives stated in Chapter 1 to prove that all the objectives were met. Furthermore, recommendations for further studies are also proposed in Chapter 5.

1.5. Conclusion

In this chapter the industrial sector was identified as the largest energy consumer in South Africa. Numerous EEI were identified to reduce the energy intensity of the various industrial processes. An overview was provided regarding Section 12L of the Income Tax Act (1962); which is the flagship incentive to overcome the financial barriers associated with the implementation of such EEI and encourage energy efficient operation.

This chapter also provided an overview of previous research in the Section 12L field and why the need exists for a methodology which assists the 12L application process to evaluate and select a final model for 12L applications when more than one modelling option is available. Objectives were also provided to show how the problem will be addressed throughout the course of this study.

2. LITERATURE STUDY

2.1 Preamble

This chapter will provide the relevant literature from which the methodology in Chapter 3 will be developed. Firstly, an overview of the 12L Regulations and Standard will be provided in order to identify the legal requirements of 12L (Section 2.2). Secondly, industrial measurement and verification (M&V) will be reviewed to describe the technical scope related to 12L (Section 2.3). This will provide a good understanding of the multiple legal and technical requirements related to 12L. Finally, decision support methods will be examined in order to find a balance between these legal and technical requirements, and to select the appropriate 12L model (Section 2.4).

2.2 12L Regulations and Standard

2.2.1 Overview

The National Treasury introduced section 12L to the Income Tax Act No 58 of 1962. This was done in the Taxation Laws Amendment of 2009. The National Treasury is a department of South Africa's government and is responsible for managing the national finances.

The mandate of the National Treasury is stipulated in the Public Finance Management Act No 1 of 1999. The National Treasury's responsibilities include the promotion of economic development; management of the budget preparation process; and ensuring a fair distribution of nationally raised funds between the various spheres of government.

The introduction of section 12L by the Treasury incentivises taxpayers to utilise energy efficiently by benefiting financially from the process [22]. 12L is funded by the National Treasury [5]. It is therefore critical that the funds allocated to 12L are used for the intended purpose. For this reason, a regulatory structure with specific compliance requirements is implemented to uphold the intent of 12L. The regulatory structure and compliance requirements are discussed further in Section 2.2.2 and Section 2.2.3, respectively.

2.2.2 Regulatory structure

Section 12L of the Income Tax Act (1962) stipulates the allowance of a tax deduction as a result of energy efficiency savings. The allowance came into effect on the 1st of November 2013 and allows a tax deduction of 0.95R/kWh for measured and verified energy efficiency savings [24].

The process of claiming this allowance is governed by a regulatory structure. The basic 12L regulatory structure illustrating the major role players is depicted in Figure 2-1 [5].

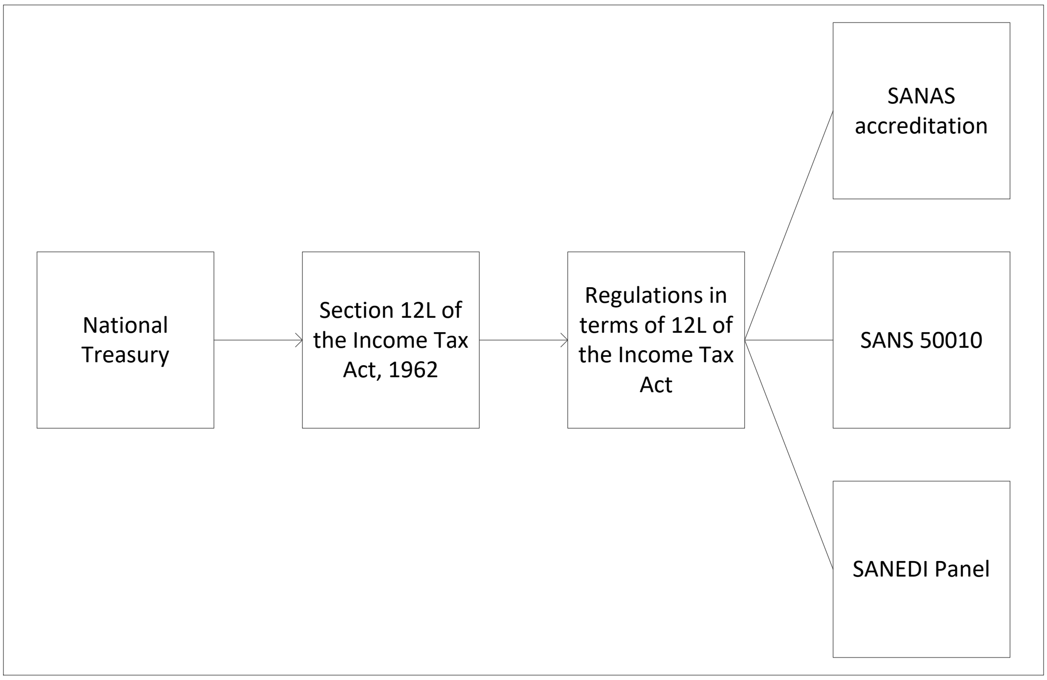

Figure 2-1: Basic 12L regulatory structure. Adapted from [5]

The Act stipulates the principles of section 12L and is supported by the Regulations. The Regulations in terms of section 12L of the Income Tax Act, 1962, was published on the 9th of December 2013. The Regulations support the Act by providing the mandatory requirements and 12L procedure to follow for claiming the allowance [6].

The Regulations make reference to two designated bodies of government. These are the South African National Accreditation System (SANAS) and the South African National Energy Development Institute (SANEDI). The responsibilities of each of these key players are prescribed by the Regulations. The two bodies are supported by a South African National Standard regarding the measurement and verification of energy savings. Each of these will now be discussed.

The South African National Accreditation System (SANAS) is the country's only national body performing accreditation that is internationally recognised. This body is responsible for accreditations in respect of compliance assessments, good laboratory practice and calibrations. The M&V body that assesses 12L applications needs to be accredited with SANAS. This provides assurance that the standard processes were followed by relevant, independent and competent professionals.

The South African National Energy Development Institute (SANEDI) was initiated by the National Energy Act, 2008 (No. 34 of 2008) which also describes its mandate and responsibilities. In short, the National Energy Act provides two main functions of SANEDI. The first one being energy research and development, while the second one is the implementation and promotion of energy efficiency in the economy [31]. The Regulations specifies SANEDI as the custodian of 12L [6]. Per the Regulations, SANEDI needs to appoint a panel of suitable qualified persons to review 12L applications. This is done to ensure that 12L applications are approved only if it is compliant with the Regulations and the Standard.

The South African National Standard (SANS) for the measurement and verification of energy savings, SANS 50010:2011, is a national standard (referred to as the Standard), which describes the process of measurement and verification of energy savings [30]. The M&V bodies that assess 12L applications need to quantify reported EE savings in accordance with the Standard. This provides assurance that a standard process was followed to arrive at the claimed energy saving.

The description of the 12L regulatory structure demonstrates that 12L is based on a well-defined regulatory framework and that each key player has a vital role to play. After understanding the 12L structure it is required to be informed of the process and requirements in order to apply for the incentive. These requirements are further discussed in Section 2.2.3.

2.2.3 Regulatory compliance

The regulatory requirements of the 12L tax incentive are based on the Regulations in terms of section 12L of the Income Tax Act. The Regulations were critically analysed to identify the required outcomes, and categorising each of them according to classification and the responsible party thereof.

The classification of the required outcomes could be described as either an administrative, technical or legal requirement. The respective parties recognised to be responsible for each requirement is the applicant, SANEDI or M&V body. The evaluation is given in Table 2-1 while more detail regarding the Regulations can be seen in *Appendix A*.

Table 2-1: Evaluation of requirements from 12L Regulations

Classification	Required outcome	Responsible party
Administrative	Register with SANEDI	Applicant
	Appoint a M&V body	
	Submit M&V report to SANEDI	
	Provision of a registering platform	SANEDI
	Issuing of a tax certificate	
	Name, accreditation number and other details of appointed M&V body	M&V body
	Name and tax registration number of applicant	Applicant
Technical requirement	Baseline and assessment period energy use adjusted according to the Standard	M&V body
	Quantified EE savings expressed in kWh	
Legal requirement	Evaluation of M&V reports	SANEDI
	Exclusion of limitations of allowance from application	M&V body
	Exclusion of concurrent benefits from application	

Administrative requirements

Administratively, the appointed M&V body is required to be SANAS accredited. By being SANAS accredited it is ensured that the M&V body is technically competent to perform their duties in a compliant manner [32]. The responsibilities of the M&V body are stipulated in the Regulations and include the quantification of the achieved EE savings and compilation of a report thereof [6].

It is required that the savings calculated by the M&V body comply with the SANS 50010 standard for the M&V of energy savings [6]. The Standard provides the methodologies available to quantify the EE savings. The approaches given by the Standard ensures that savings be quantified conservatively. Thus, the reported savings should be the actual achieved savings or less [30]. This is done in order to mitigate any uncertainty relating to the quantified savings. The EE may thus be adjusted towards lower values to compensate for uncertainty. This concept is illustrated in Figure 2-2.

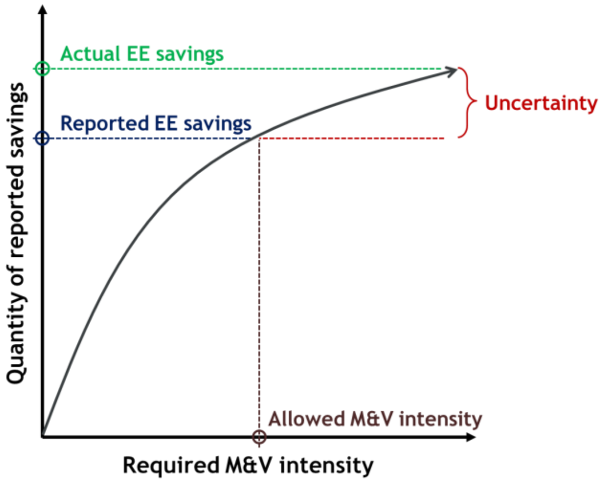

Figure 2-2: Effect of uncertainty on energy efficiency savings. Adapted from [5]

Figure 2-2 shows that the quantity of the reported EE savings is decreased in order to increase conservativeness and mitigate uncertainty. However, uncertainty may also be mitigated by increasing M&V intensity [33]. This is done by acquiring more and/or better operational data. Increasing the M&V intensity is, however, related to additional costs. The amount of uncertain savings should thus be compared to the additional costs of increased M&V in order to determine the need to decrease uncertainty. This will, however, vary for different scenarios.

Technical requirements

The Standard provides technical guidance by supplying various options or methodologies regarding the measurement boundary selection, baseline calculations and the requirements of the measurements used [30]. The EE savings should be quantified by using these methodologies in order to comply with the Standard. The Standard provides multiple generic methods for the quantification of the EE savings which can be used for different scenarios. The level of certainty at which different methods are used can be established at the discretion of the M&V professional involved. This implies that the Standard's methodologies can be used in different levels of rigour.

Legal requirements

Legal requirements to take into consideration include that the calculation of the EE savings should exclude any limitations and concurrent benefits specified in the Regulations. The limitations of allowance states that savings obtained as a result of energy generated from renewable sources or co-generation (other than waste heat recovery) are not claimable. Furthermore, in the case of a captive power plant, the allowance may not be claimed unless the conversion efficiency is above 35% [6].

The concurrent benefits that should be excluded from the application refer to savings that were achieved as a result of any other government funded project, or as a result of a power purchase agreement [6].

This segment included the regulatory requirements of 12L as stated in the Regulations. The content of the Regulations indicates that the 12L incentive has clear administrative and legal requirements.

2.2.4 Summary

The 12L tax incentive is based on a well-defined regulatory structure. The 12L Act is supported by the Regulations which stipulate the mandatory requirements and procedure to follow to claim the allowance. The Regulations gives an adequate indication of the legal requirements that applications need to comply with. The essence of 12L regulatory compliance is based on assurance that the claimed savings are an accurate and conservative reflection of achieved savings. This shifts the focus to the technical requirements of related to the M&V of energy savings.

The technical M&V requirements that need to be adhered to are not as clearly defined in the regulatory structure. Generic guidance regarding the technical requirements is given by the Standard. The Standard is, however, not as rigid and provides multiple methods for the quantification of the EE savings; this prompts further investigation into the technical requirements of 12L.

2.3 Industrial measurement and verification

2.3.1 Overview

Measurement and Verification (M&V) teams are responsible for the reliable determination of energy savings as a result of an energy efficiency initiative [33] [34]. However, several challenges can arise when performing the M&V process in an effective and accurate manner [27]. These challenges may include limited time, resource intensiveness and accuracy of the savings determination.

The South African M&V process was standardised by the development of the SANS 50010 standard [30]. The methodologies provided by the Standard need to be followed in order to comply with the 12L Regulations [6]. It is thus the most important M&V resource relating to 12L.

In addition to SANS 50010, several guidelines are available to aid in the M&V process. The most common guidelines in the field are the International Performance Measurement and Verification Protocol (IPMVP) and the Federal Energy Management Program (FEMP) [35] [33] [36]. Committees such as the Association for Energy Engineers (AEE), the American Society of Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE) and the Council of Measurement and Verification Professionals of South Africa (CMVPSA) make use of these guidelines as a basis for M&V practices [37] [27].

Hamer [5] did a study to practically quantify 12L energy efficiency for large industries. In the study a hierarchy of M&V practice regarding 12L is provided. The hierarchy is depicted in Figure 2-3. The hierarchy indicates that the Standard is at the top of the hierarchy and is the most generic guideline available. It further indicates that less generic guidance is provided by published protocols and guidelines. The most specific guidance is provided by published academic literature of practically applied M&V in the 12L field [5].

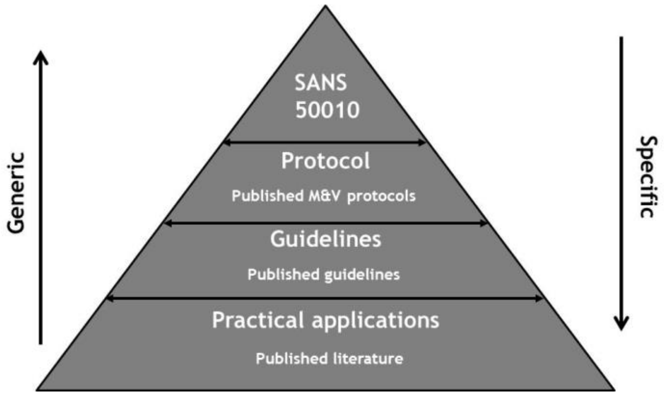

Figure 2-3: Hierarchy of M&V practice regarding 12L. Adapted from [5]

The basic M&V approach is depicted on the left side of Figure 2-4 [33]. The appointed M&V team will not necessarily be involved with the designing, planning and commissioning steps of the energy efficiency initiative. The appointed M&V team's involvement will thus include steps 1, 2, 4, 5, 7 and 8 of the M&V approach.

The outline of the SANS 50010 framework is depicted in the centre of Figure 2-4. Each step in the M&V process is connected to a section of the Standard's framework. From the connections the key technical aspects of 12L are summarised on the right of Figure 2-4.

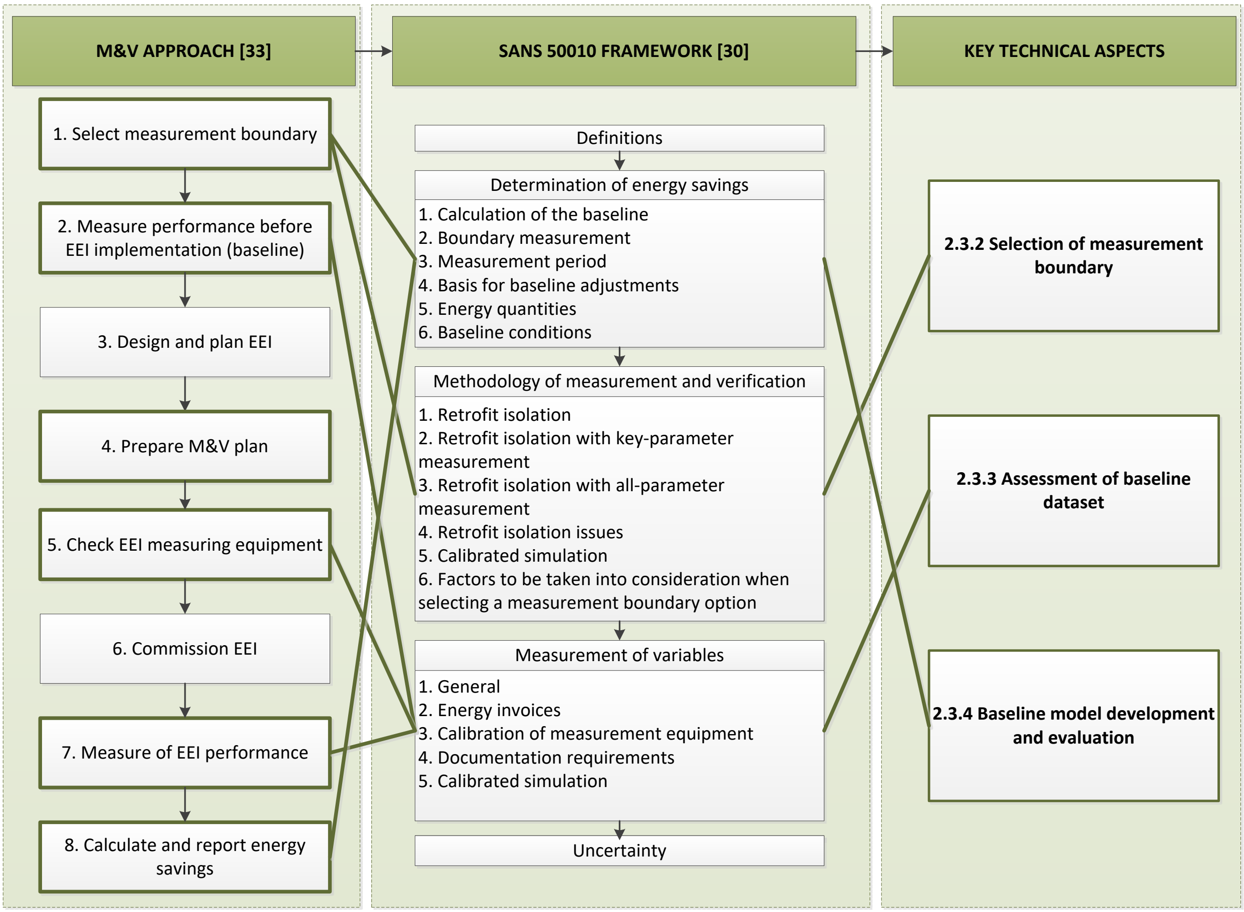

Figure 2-4: Key technical aspects of 12L

The next sections will give guidance according to the Standard and published literature on each of the main focus areas of M&V as illustrated in Figure 2-4. This is done to establish how the key technical aspects of 12L are addressed in available M&V resources.

2.3.2 Measurement boundary selection

The Standard allows savings to be determined for different measurement boundaries on a facility. Three measurement boundary options are provided by the Standard. The options are retrofit isolation, whole facility and calibrated simulation [30].

When using the retrofit isolation option, only a portion of the facility is evaluated to assess EE savings. Where the whole facility option is used, the entire facility is considered as a measurement boundary. When baseline or performance assessment data is either unavailable or unreliable the third option, calibrated simulation can be used. The calibrated simulation option may be used for either the whole facility or a portion of it [30].

When selecting a measurement boundary it is important to encapsulate the effect of the energy saving measure implemented. Thus all interactive effects should either be considered within the chosen measurement boundary or such effects beyond the boundary should be estimated [30].

The various measurement boundary options provided by the Standard are useful to evaluate different aspects of a facility and the achieved savings. For example, a whole facility approach provides a holistic view of a process and accounts for possible interactive effects within a facility. Whereas more specific insight regarding the energy performance of different sections of a facility can be evaluated by the use of the retrofit isolation approach. Furthermore, the measurement boundary can be varied to obtain different measurement points which are useful to manage data availability and compliance [5].

Methodologies for the selection of a measurement boundary have been thoroughly investigated in various sources from literature [5] [27] [30] [10] [33]. Several of these studies have been investigated and applied for the 12L tax incentive [5] [10]. The methodologies proposed by recent studies are well established and discussed in more detail.

Janse van Rensburg [10] proposed the top-down hierarchical decomposition of organisational structures method to identify possible measurement boundaries. This method reduces the complexity of industrial facilities by evaluating each boundary generically with little detail to more specific boundaries with more detail. This approach is depicted in Figure 2-5 [5] [38].

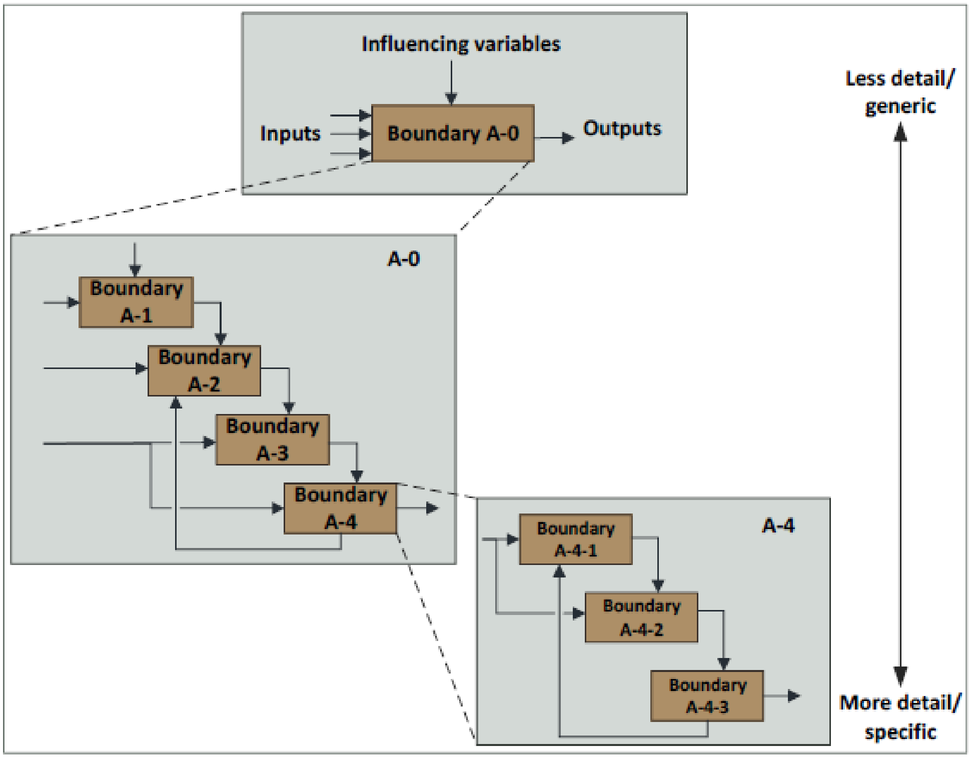

Figure 2-5: Hierarchical decomposition of measurement boundaries. Adapted from [5] [38]

Janse van Rensburg [10] further developed a boundary selection framework for 12L mining purposes. Figure 2-6 shows these four necessary steps to select a measurement boundary. The steps are Understand, Identify, Simplify and Select.

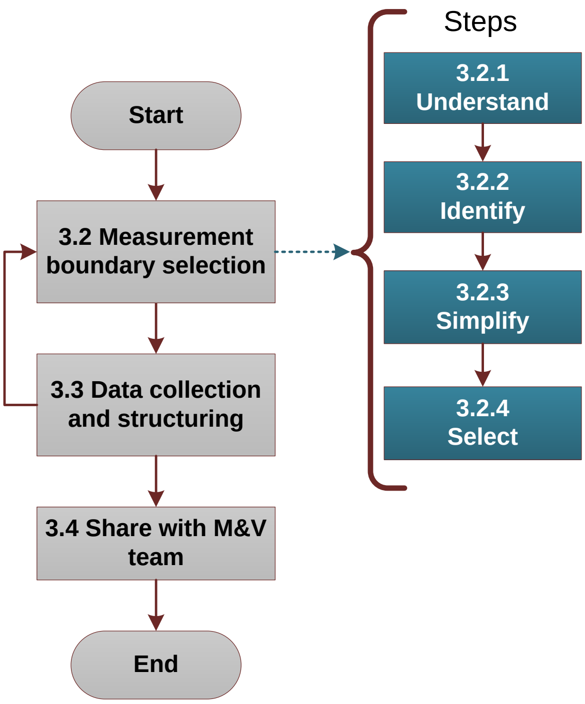

Figure 2-6: Measurement boundary selection framework. Adapted from [10]

The first step consists of understanding the process within the facility under consideration. This can be done by evaluating the production flow of the process. To further understand the process, the diagram must indicate all operational boundaries, external companies and the energy driver and carriers of each production stage of the facility.

In the second step, the measurement points of the energy carriers and drivers should be identified. Any limitations to the project and operations excluded from the tax entity should also be indicated on the diagram in this step.

In the third step, the compliance of measurements are simplified by establishing whether each measurement point is unavailable, available or compliant. Unavailable indicates that the specific measurement point does not have sufficient data available. Available indicates that data is accessible for the respective measurement point; however, the compliance thereof is unknown or difficult to prove. A compliant measurement point has both sufficient data and compliance documentation available.

Lastly, in the fourth step, possible measurement boundaries can be determined on the flow diagram. The final measurement boundary can then be selected by encapsulating the energy efficiency initiative within the boundary while adhering to data availability and compliance requirements. The existing measurement boundary selection methodologies are well established to do this. However, it is clear that there are multiple boundary options, each with different M&V traits, which need to be considered for a potential 12L application. Once the available measurement boundaries have been selected, datasets can be gathered and evaluated.

2.3.3 Baseline dataset evaluation

The chosen measurement boundary defines the measurement points which are used to populate the baseline and performance assessment datasets. The Standard allows two options to evaluate the energy use of a measurement boundary. The options are either key-parameter or all-parameter measurement approaches [30].

When using the key-parameter measurement option, only certain parameters that are significant to the energy governing factors or energy use of the system are included. The all-parameter measurement option includes all the parameters associated with the energy system [30].

Within the chosen measurement boundary each variable requires specific measurement points. The types of variables that contribute to the energy use of a system include the energy drivers, energy carrier flows and energy content measurements. The energy carrier measurements may consist of electrical power, energy, mass or volumetric flow measurements. The energy driver measurements refer to service level indicators of the chosen boundary. These may include production quantities, product quality, operational set-points of temperatures or pressures, etc. Energy content measurements are used to convert mass or volumetric flows to an energy equivalent unit, such as kWh [5].

The Regulations requires the quantified EE savings to be an accurate reflection of the actual achieved savings [6]. This is greatly affected by the data used to construct the baseline and quantify the reported savings. To ensure that accurate data is used the Standard deems two primary sources of data as compliant. The first is data obtained from invoices of measured quantities while the second is actual measurements from calibrated equipment. It is further required that measurement equipment is calibrated by either SANAS accredited calibration laboratories or specialists approved by the original equipment manufacturer [30].

The data, metering points and measuring equipment used in quantifying the reported savings should be made available if requested during investigation of the application [30]. The dataset requirements of 12L includes proving that datasets are compliant (i.e. from invoices of calibrated measurements), traceable and accurate. Data quality is thus a crucial part of a successful 12L application [39].

In industrial systems a large amount of measurement points and data exists. Figure 2-7 illustrates a procedure to identify and classify various measurement points. The measurement points are classified according to the measured variable, measurement type, variable type and 12L compliance status of the data. This procedure simplifies the boundary and dataset selection process [5].

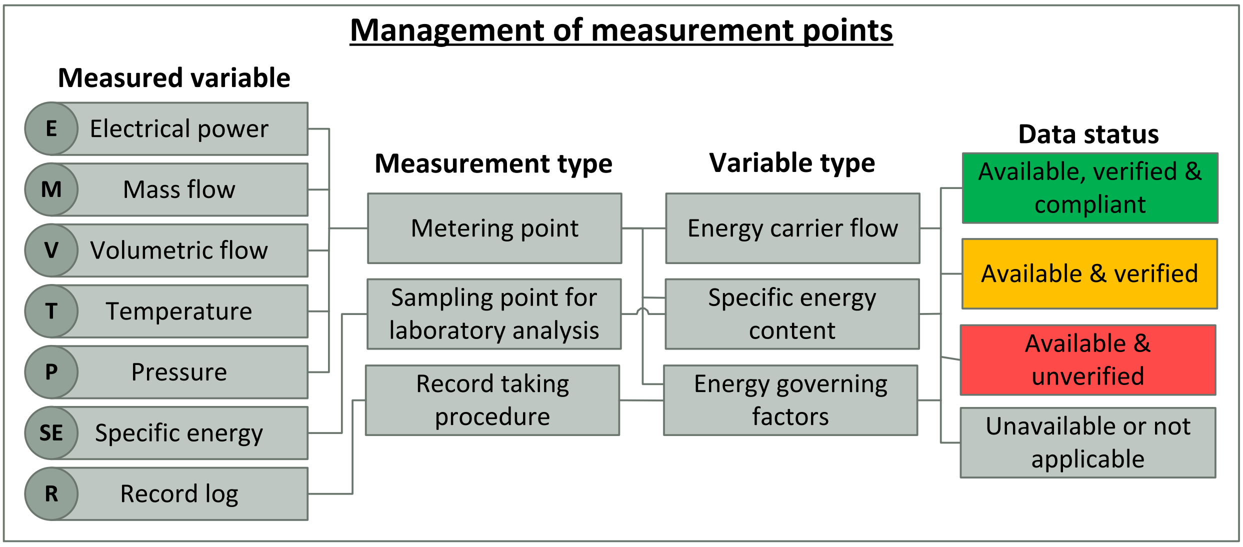

Figure 2-7: Management of measurement points. Adapted from [5]

Figure 2-8 provides an example in which the management of measurement points procedure is applied to the process layout of an energy system. The procedure is used to identify and classify the various measurement points in the system. The procedure thus identifies multiple dataset options that may be evaluated and used to select a measurement boundary.

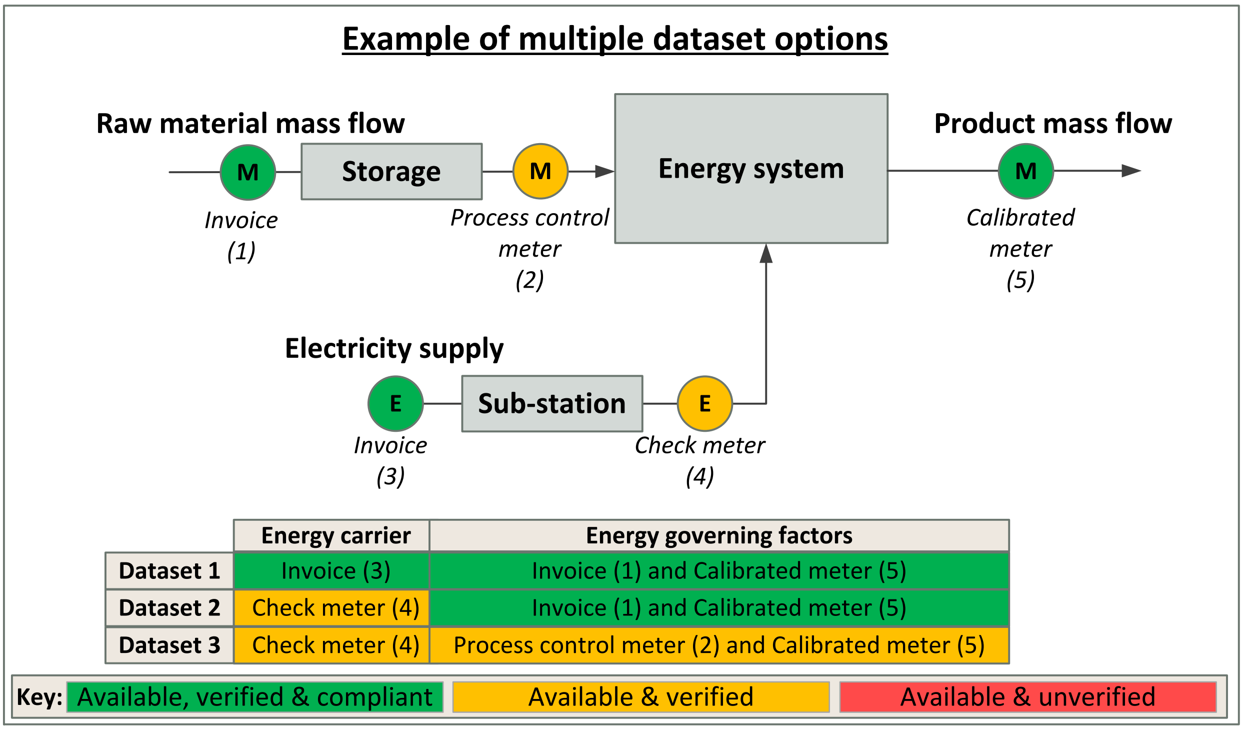

Figure 2-8: Example of measurement point classification procedure. Adapted from [5]

Five different measurement points are identified in the example shown in Figure 2-8. Conventionally only the compliant measurement points (1, 3 and 5) would be selected for the M&V of the energy system. This would allow a single dataset (Dataset 1). However, additional datasets (such as Dataset 2 and 3) may be provided by using the check meter (4) and process control meters (2).

In a study done by *Wang & Strong* [40] a framework was developed which captures the important aspects of data quality to data consumers. According to the study the four aspects attributing to high quality data includes the following [40]:

- Intrinsic data quality,
- contextual data quality,
- representational data quality, and
- accessibility data quality (accessibility and access security)

Intrinsic data quality refers to the accuracy, objectivity and believability of data. Contextual data quality considers the relevancy, completeness and amount of data. Representational data quality includes the interpretability, representation and ease of understanding data. Lastly, accessibility data quality refers to data access security and how accessible data is [40]. Of these four aspects of data quality, data accuracy has the biggest influence from an M&V perspective.

The importance of a high quality dataset in the 12L M&V process is discussed in a study done by *Gous et al.* [39]. In this study methodologies were developed to evaluate the quality of datasets and data sources [39]. Strategies were developed to:

- Evaluate data source quality,
- Evaluate dataset quality, and
- Select a baseline dataset.

The quality of data sources is evaluated in three phases. The phases are collecting data from different sources, calculating the difference between the data sources and sorting the results. The data source quality evaluation methodology is depicted in Figure 2-9.

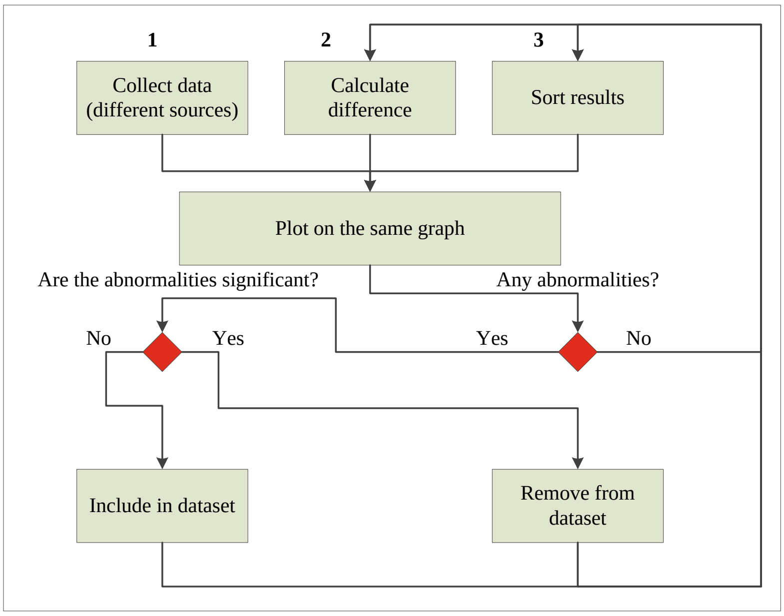

Figure 2-9: Data source evaluation. Adapted from [39]

The first phase consists of collecting data from different data sources and comparing them visually on a graph to identify any significant abnormalities. In the second phase the difference between data sources for a corresponding measurement point is calculated. The magnitude of the differences between the data sources can be evaluated to identify large deviations [39].

In the third phase the results of phase two are represented in a more interpretable manner. This is done by sorting the error values in an ascending order and plotting them on a graph. This methodology enables an objective review of data source quality [39].

Significant abnormalities are identified from the methodology and should be excluded from the dataset. Abnormalities that are not significant should be included in the dataset. A thorough investigation should however be done to ensure that possible outliers do not affect the data's representation of the system [39].

The quality of the dataset is evaluated in four steps. The four steps identify any abnormalities related to the measurement equipment and system operations. These abnormalities are evaluated and either removed or included in the dataset. This ensures a high quality dataset from evaluated data sources. The dataset quality evaluation methodology is depicted in Figure 2-10 [39].

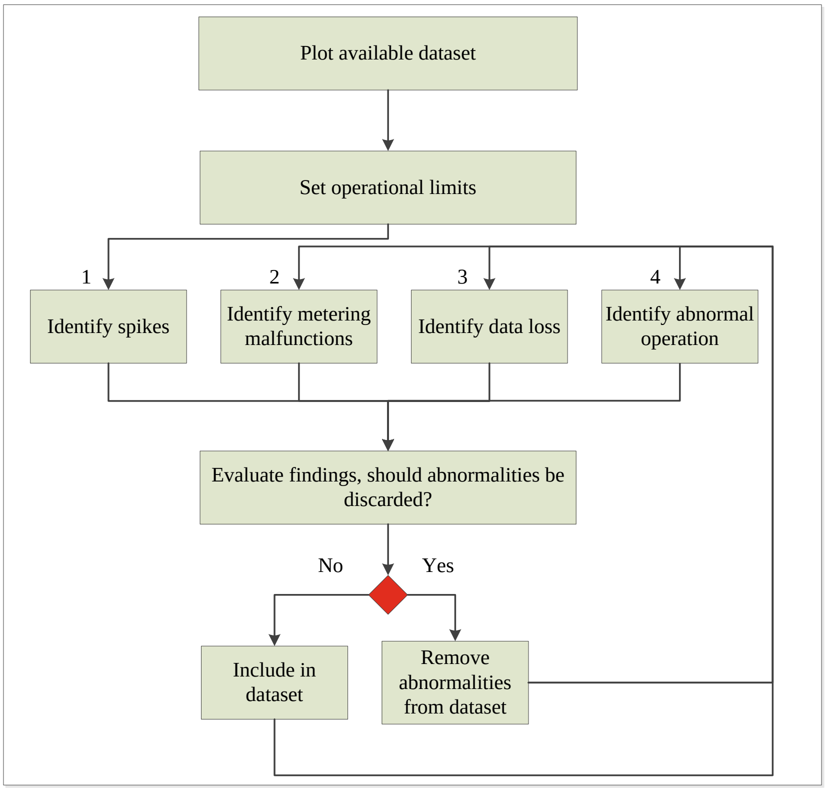

Figure 2-10: Dataset evaluation. Adapted from [39]

In the first step, spikes within the dataset are identified. Spikes within a dataset could be attributed to equipment malfunction. The amplitude of such data spikes could affect the accuracy of the dataset and should therefore be investigated [39].

Meter malfunctions are identified in the second step. This might include values that are within the operational limits but remain constant for a period of time. Using this data in future calculations may affect the accuracy of the results obtained [39].

Data loss within the dataset is identified in the third step of the methodology. Data loss can be identified by either the absence of or flagged data, depending on the relevant data system in place [39].

In the fourth and final step abnormal system operations are identified. It should be noted that different operational profiles within a dataset does not necessarily indicate abnormal data. Various systems may have different operational profiles during e.g. weekdays and weekends. The various operational profiles should be identified and considered during baseline development [39].

After evaluating the data sources and dataset quality a dataset needs to be selected for baseline development. *Gous et al*. [39] provides guidelines for selecting a baseline dataset. To adhere to 12L Regulations and M&V guidelines the baseline must consist of a full year's data preceding the year of assessment and represent a full cycle of normal operations. The data needs to be evaluated to ensure that the baseline dataset portrays the correct representation of system operations [39].

Hamer [5] developed a data quality evaluation framework for industrial energy systems, within the context of 12L M&V. The focus of the framework consists of the evaluation of compiled datasets. The framework evaluates the quality of datasets according to three distinct aspects; accuracy, integrity and relevance. The framework then further classifies the dataset depending on whether or not compliance can be proven. The dataset quality evaluation framework is depicted in Figure 2-11 [5].

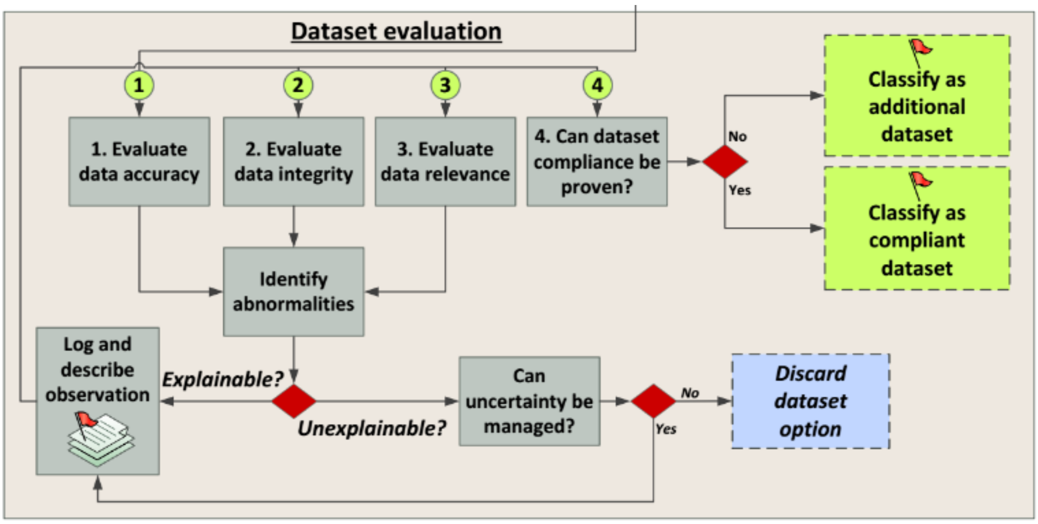

Figure 2-11: Dataset quality evaluation framework. Adapted from [5]

The first aspect of data quality evaluates data accuracy which may be linked to the uncertainty of measurements. The uncertainty of measurements may be mitigated by linking respective measurement equipment to invoices, calibration records or manufacturer specifications [5].

The second aspect of data quality is data integrity. Evaluation of data integrity entails the evaluation of data traceability. The traceability of a dataset may be tested by compiling a traceability pathway to identify whether data could have been compromised in the data transfer process. In the traceability pathway the dataset is traced to a specific data source. The data source is then traced to a distinct measurement point of a variable in the energy system [5]. Figure 2-12 illustrates this process.

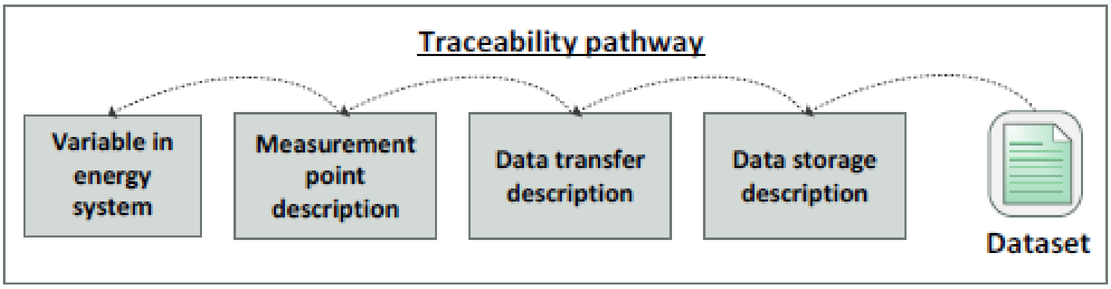

Figure 2-12: Data traceability pathway to test data integrity. Adapted from [5]

Data integrity may be further tested by identifying any discrepancies in the data. This can be done by comparing data from different data sources or redundant metering equipment. Visual and analytical methods may be used to identify deviations between the respective data sources or measurement points. Abnormalities may be linked to data loss, meter malfunctions, abnormal operations, etc. [5]. Figure 2-13 illustrates an example where three different datasets are compared for the same measured variable.

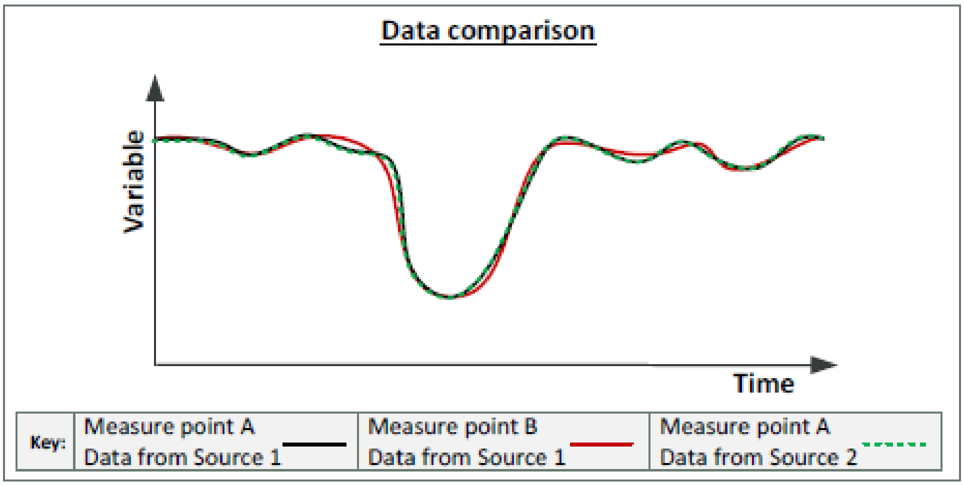

Figure 2-13: Example of visual data comparison. Adapted from [5]

The third aspect of data quality evaluates the relevance of a dataset. Long term energy intensity trends provide a simple method for evaluating the relevance of a dataset. Observations can be made from the intensity trend and should be linked to operational events such as scheduled or unscheduled maintenance stops. An increasing or decreasing energy intensity trend should also be linked to a certain activity or energy saving measure. Identifying and explaining observations from the trend will indicate whether the dataset is representative of the energy system [5]. An example of a long term energy intensity trend to evaluate data relevance is illustrated in Figure 2-14.

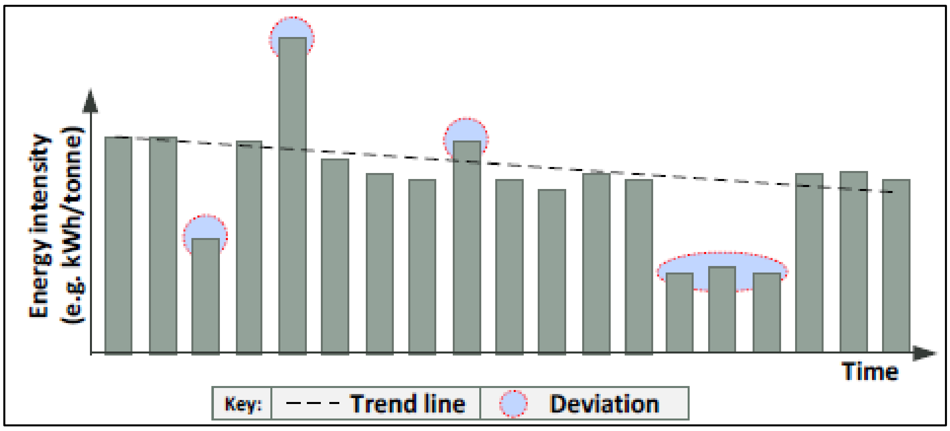

Figure 2-14: Example of long term intensity trend to evaluate data relevance. Adapted from [5]

After evaluation of the dataset according to its accuracy, integrity and relevance, datasets may either be discarded or deemed as a useable dataset. In the last step of the evaluation framework the compliance of the dataset is determined by providing sufficient supporting documentation such as invoices and calibration records. Only compliant datasets may be used for quantifying the official EE savings. Non-compliant datasets may, however, be used to develop additional baseline models or conduct supplementary analyses. This ensures a holistic evaluation of the energy system since compliant data often restricts modelling options by being limited to monthly aggregated data e.g. from invoices [5].

Other factors to take into consideration when selecting a dataset are measurement points in series, data resolution and processing capacitance or storage capacities between point of measurement and point of use. The accuracy, integrity and compliance of measurement points in series should be evaluated to establish the best quality data. The statistical relevance of the baseline model may be improved by using data with higher resolution (e.g. daily opposed to monthly data) and shorter latencies (e.g. data with shorter time delays between measurement and point of use). The alternative dataset options should therefore be used to develop various baseline models [5].

Industrial energy systems usually have a large amount of data sources and measurement points available, all with different levels of accuracy and compliance. It is important to evaluate the various dataset options [5]. This section discussed well-established methodologies for the evaluation of a baseline dataset. These methodologies can readily be used in this study.

2.3.4 Baseline model development and evaluation

Energy efficiency savings refer to the absence of energy use after the implementation of an energy saving measure (ESM) [30]. The absence of energy usage cannot be directly measured. Therefore, baseline models are used to predict what the energy usage would have been in the performance assessment if the initiative was not implemented. The baseline and performance assessment refer to the periods before and after the implementation of an ESM, respectively [30].

Energy savings can be calculated as the difference between the measured energy consumption before and after an energy efficiency initiative. The general equation for the quantification of energy savings is shown in Equation 2-1 [30] [33]:

$$E_S = E_{BL} - E_{PA} \pm E_{adjustments}$$

Equation 2-1: General quantification of energy savings

Where E_S is the energy savings, E_{BL} is the baseline energy usage, E_{PA} is the assessment period energy usage and $E_{adjustments}$ is the adjustments. Suitable adjustments to the baseline energy consumption ensure that the baseline and assessment periods are assessed under the same operational conditions [30]. Figure 2-15 illustrates the quantification of energy savings visually [28].

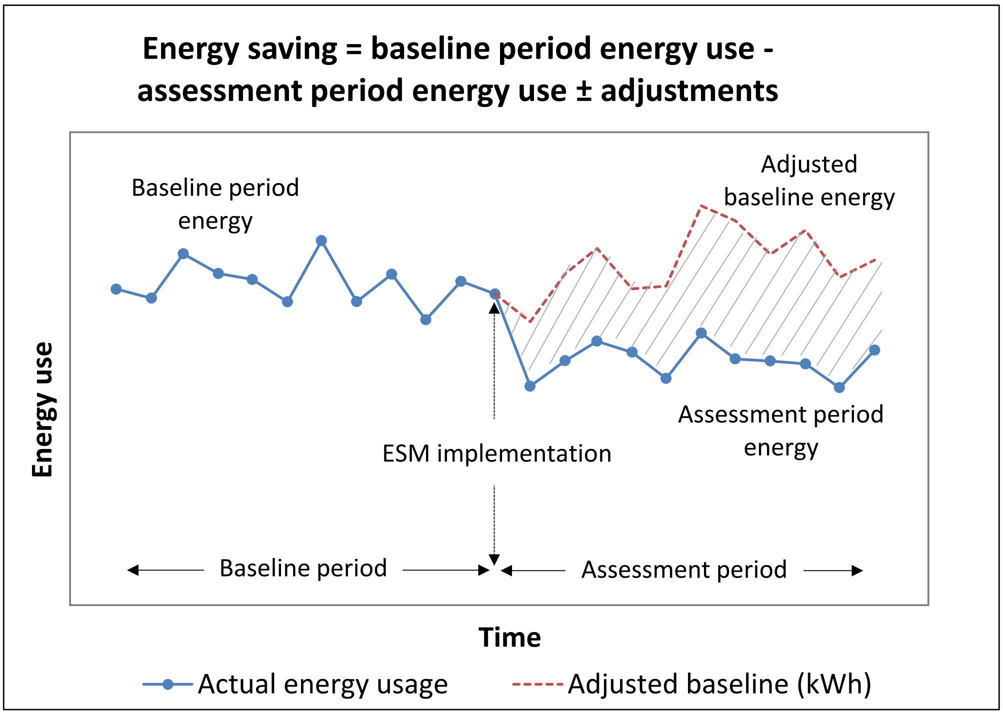

Figure 2-15: Overall approach to energy efficiency baseline determination. Adapted from [28] [30]

The Standard allows different calculation methods to be used for the determination of the achieved EE savings. Various mathematical methods exist, such as; energy intensity calculations, simulations, predictive modelling and various regression methods [5]. However, energy intensity calculations and regression analyses are the most common methods used in practice [5] [28].

Intensity calculations

Energy intensity calculations are a simple way of determining the EE savings. This is done by determining the energy intensity of the process during the baseline and assessment period. Thereafter, the baseline period energy consumption is adjusted for performance assessment conditions. The calculation of energy savings by using intensity calculations is shown in Table 2-2 [28].

Table 2-2: Intensity calculation of energy savings. Adapted from [28]

Description of value to be calculated	Baseline period (BL)	Assessment period (AP)
Total energy consumption *(kWh)*	E_{BL}	E_{AP}
Total production *(e.g. tonnes)*	P_{BL}	P_{AP}
Energy intensity *(e.g. kWh/tonnes)*	I_{BL}	I_{AP}
Adjusted BL energy consumption *(kWh)*	$E_{BL(adjusted)}$	-
Annual energy savings *(kWh)*	$E_{savings}$	

The first step is to calculate the energy consumption (E_i) and production (P_i) of the established boundary during the baseline and assessment period. The energy consumption includes the energy streams entering the boundary, expressed in kWh equivalent values. The production values refer to the production or energy driver of the system boundary. This value may be expressed in units of mass, volume, energy, temperature, etc. [28].

The energy consumption and production values are then used to determine the energy intensity of the system during the baseline and assessment periods. The energy intensity (I_i) is calculated by dividing the energy consumption by the production value, as shown in Equation 2-2. A decrease in the energy intensity value indicates a more efficient utilisation of energy [28].

$$I_i = \frac{E_i}{P_i}$$

Equation 2-2: Calculation of energy intensity

In order to calculate the energy savings, the baseline energy usage needs to be adjusted for the possible change in production from the baseline to assessment period. Evidently, it is needed to determine the energy that would have been consumed in the assessment period if the energy intensity remained constant. This is done by multiplying the assessment period production (P_{AP}) with the baseline energy intensity (I_{BL}), as shown in Equation 2-3 [28].

$$E_{BL(adjusted)} = P_{AP} \times I_{BL}$$

Equation 2-3: Adjusted baseline energy consumption

The energy savings can then be calculated as the difference between the adjusted baseline energy usage ($E_{BL(adjusted)}$) and the actual assessment energy usage (E_{AP}). This is shown in Equation 2-4 [28].

$$E_{savings} = E_{BL(adjusted)} - E_{AP}$$

Equation 2-4: Quantification of energy savings by means of intensity calculation

Regression models

Regression models are the most prevalent method of quantifying energy savings [5] [27] [28]. A regression analysis is used to establish the relationship between an independent variable and one or more response variables through a mathematical model [41] [42].

Additionally, regression models are useful for prediction purposes [41] [43] [44]. This makes regression models a useful tool for the development of benchmarks or baselines to evaluate system performance [41]. In 12L applications regression models can be used to correlate energy usage to one or more independent variables and make predictions for the energy use in order to calculate energy savings [28].

The first step in developing a regression model is to construct a scatter plot of the data observations. A line is then fitted through the data points to yield a regression equation by means of the least squares method. If the relationship is that for a straight line, then it will be of the generalized linear equation form [44]:

$$y = mx + c$$

Equation 2-5: Generalized linear regression equation model

Where y denotes the dependent variable, x the response variable, m the slope of the fitted line and c the intercept of the line with the y-axis. Figure 2-16 illustrates the development of a regression model with air conditioning (AC) power consumption as the dependent or response variable and ambient temperature as the independent variable [41].

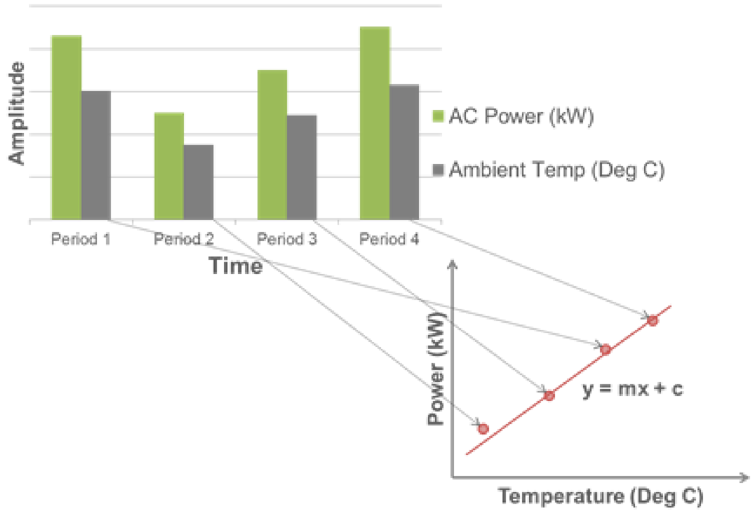

Figure 2-16: Developing a regression model. Adapted from [41]

The regression equation, i.e. baseline model, may be used to predict what the system's energy consumption would have been in the assessment period if no efficiency improvement took place [28]. This can be done by substituting x with assessment period production/driver values and determining new y values. The new y values represent the predicted assessment period energy usage.

The energy savings for each data point can then be determined as the difference between the predicted and the actual energy consumption. Annual savings are determined by aggregating all the individual saving values [28].

Evaluation of regression models

Energy efficiency savings calculated by the regression baseline model will never be completely accurate. The modelled results are expected to fall within a range of uncertainty. Models should therefore be evaluated to ensure that the selected model is the most accurate representation of the system [27].

Various statistical parameters may be used to evaluate the fit and relevance of a regression model to a given dataset. The most common statistical parameters used in the M&V field are listed below with referencing literature [27]:

- Coefficient of determination (R^2) [41] [45] [46] [47],
- Root mean squared error (RMSE) [45] [46],
- Standard error [41] [46],

- F-statistic [41] [47] and t-statistic [45] [46],
- Average error [48],
- Mean bias error [46],
- Degrees of freedom (df) [47], and
- Absolute and relative precision [33].

The most prevalent statistical parameters used include the coefficient of determination and the root mean squared error [5] [27]. The coefficient of determination is the primary indicator of the fit of the regression line and the relationship between the variables. The R^2 value must typically be above 0.75 while the statistical relevance becomes stronger as it approaches 1 [27] [28]. R^2 can be calculated using the equation [44]:

$$R^2 = 1 - \frac{SSResid}{SSTo}$$

Equation 2-6: Calculation of coefficient of determination (R^2)

Where *SSResid* is the residual sum of squares and *SSTo* is the total sum of squares. The former can be calculated using Equation 2-7:

$$SSResid = \sum_{i=1}^{n} (y_i - \acute{y}_i)^2$$

Equation 2-7: Calculation of residual sum of squares

Where y_i is the i^{th} y-value, $\acute{y}_i$ the respective predicted value of y_i and n the number of values. The calculation for *SSTo* (the total sum of squares) is calculated as shown in Equation 2-8 [44]:

$$SSTo = \sum_{i=1}^{n} (y_i - \bar{y})^2$$

Equation 2-8: Calculation of total sum of squares

Where $\bar{y}$ denotes the mean y-value and can be calculated as follows [44]:

$$\bar{y} = \frac{y_1 + y_2 + \cdots + y_n}{n}$$

Equation 2-9: Calculation of mean y-value

The RMSE represents the error between the predicted and actual values. Typically the RMSE should be below 15% [27]. It can be calculated using Equation 2-10 [44]:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n} (y_i - \acute{y}_i)^2}{n}}$$

Equation 2-10: Calculation of Root mean squared error (RMSE)

Where y_i is the i^{th} actual value, $\acute{y}$ the respective predicted value and n the number of values.

Hamer [5] developed a baseline development framework which is depicted in Figure 2-17. In this framework, different modelling options are developed from available information. Thereafter, each modelling options is evaluated in order to determine whether the model should be discarded or classified as either a 12L compliant model or a validation model [5].

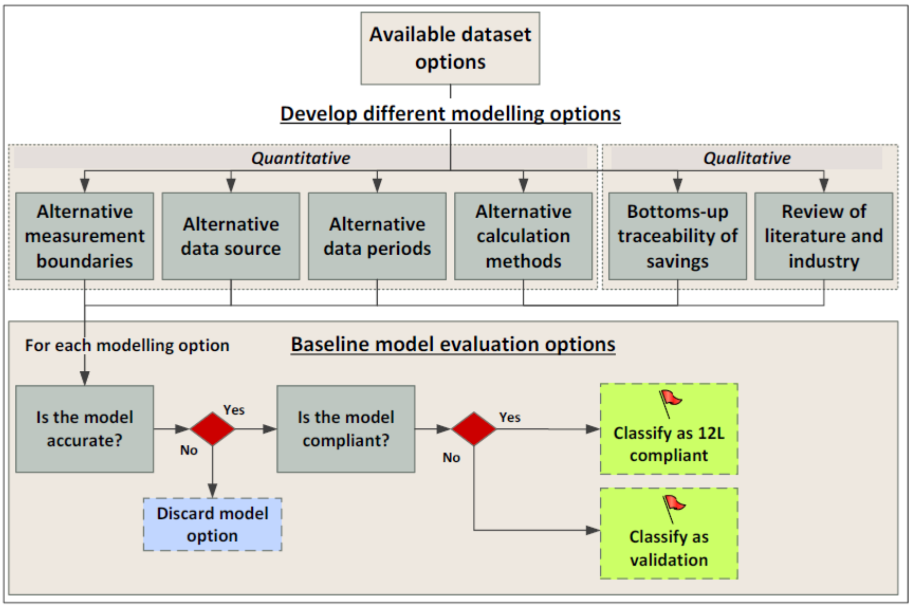

Figure 2-17: Baseline model development framework. Adapted from [5]

According to the framework different modelling options may be developed to quantify energy savings based on four alternatives. These include alternative measurement boundaries, data sources, data periods and calculation methods. Furthermore, two methods are provided to give a qualitative indication of energy savings [5]. The focus of this study will, however, not include the qualitative indicators since it cannot be used as an official 12L compliant model.

Alternative measurement boundaries that encapsulate the targeted ESM may be considered in the baseline model. Varying the measurement boundary is useful to manage compliance of measurement data and evaluate the significance of the savings. Furthermore, the use of larger boundaries may account for any possible interactive effects. However, the availability of multiple data options may limit certain measurement boundaries to be evaluated [5].

Different baseline models may be developed by varying the data sources used. Datasets vary according to their accuracy and compliance, which will ultimately have an effect of the final model. Multiple measurement points in series should be considered during baseline development. By using various data options, different resolution and precision modelling options are made available [5].

The use of alternative data periods may be useful in certain cases, such as when the baseline period data is not sufficient, e.g. if the plant experienced an extended shutdown which limits the available baseline data. A model developed with an alternative data period is, however, only allowed to be used as a validation model since it does not comply with the Regulations which restrict the baseline period to the year preceding the year of assessment [5].

Lastly, the Standard allows different calculation methods to be used when determining the energy savings. Numerous calculation methods exist. The most commonly used method to represent baseline energy usage are regression models [5].

Developing baseline models for each available measurement boundary, dataset option and calculation method allows more options that can be evaluated in order to select the most appropriate baseline model. Furthermore, the development of multiple modelling options as validations increases the confidence that the reported EE savings are a fair reflection of the actual achieved savings [5].

Amundson et al. [45] identified six steps to develop regression-based energy models for monitoring and reporting energy savings in industrial operations. The six steps are illustrated in Figure 2-18 [45].

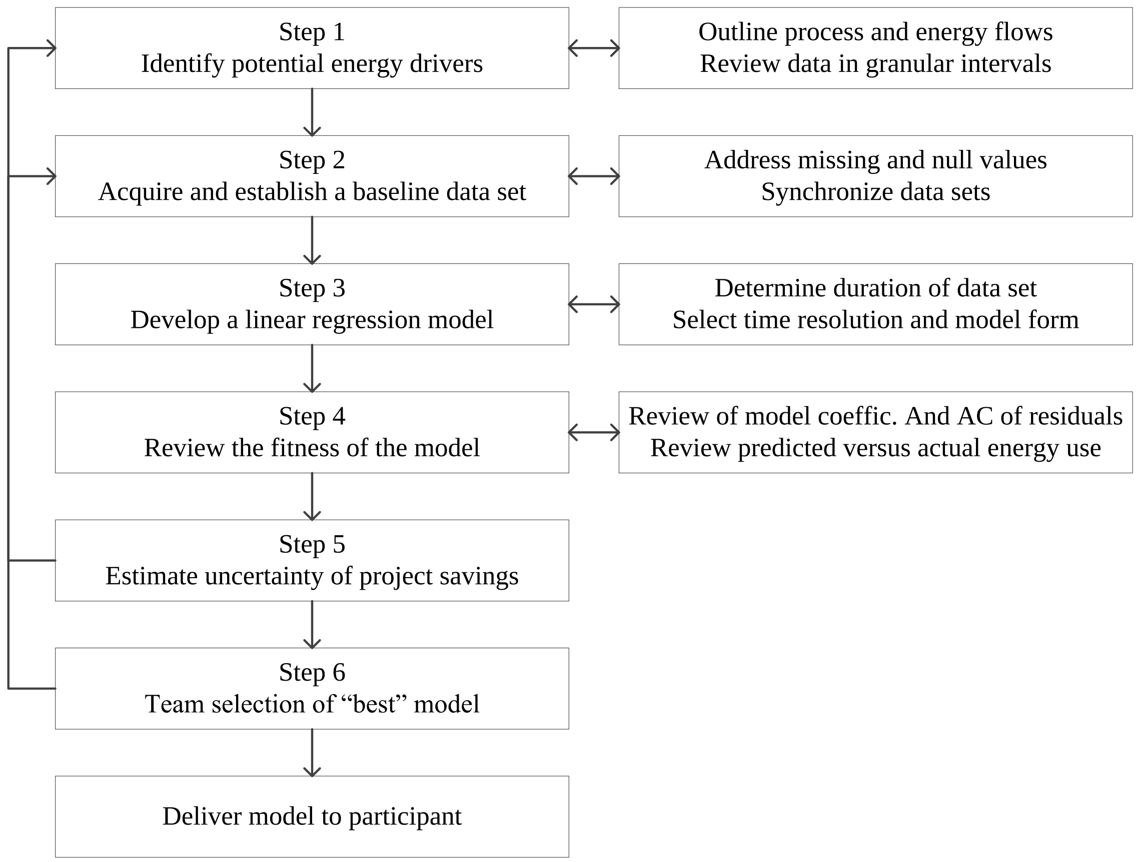

Figure 2-18: Six key steps in regression-based energy model development process. Adapted from [45]

The first step involves understanding the energy flows of the process to identify potential energy drivers. In step two, the relevant dataset is acquired in order to develop the regression-based baseline model in step three. Thereafter, the model should be evaluated and the uncertainty of results should be estimated in steps five and six, respectively [45].

Amundson et al. [45] recommends that several models with acceptable model fitness and level of uncertainty should be developed depending on the available data. The models should then be reviewed in order to select the "best" model by the relevant stakeholders [45].

This section provided sufficient knowledge regarding the development of the baseline model. Statistical parameters used to evaluate the statistical relevance of the baseline model were also reviewed. Furthermore, practical methods from published literature for baseline model development were provided. These methods are well established and can readily be used in this study. The methods result in multiple modelling options that may be evaluated in order to select the appropriate model for the system.

2.3.5 Summary

To have a better understanding of the technical scope relating to 12L the key technical aspects of 12L M&V were discussed in this section. The key technical aspects include the selection of a measurement boundary, assessment of the baseline dataset and the development and evaluation of the baseline model.

Methodologies regarding each of the main focus areas of 12L M&V are well established in available literature. The available methodologies can readily be used in this study. The methodologies, however, result in many options that may be considered in the quantification of the achieved EE savings.

The Standard allows the evaluation of various measurement boundaries, data sources and quantification methods of the EE savings. Therefore, multiple modelling options exist when considering the various options resulting from the available methodologies. The multiple models delivers more options to be evaluated in order to select the model that best reflects the energy system while still reporting fair and accurate savings.

2.4 Decision support methods

2.4.1 Overview

It is evident from the literature discussed in Section 2.2 and Section 2.3 that many options exist for the computation of EE savings. The various modelling options will not only differ on a technical level, but can also adhere to the regulatory requirements in different levels.

An equitable trade-off between the various legal and technical criteria will have to be made to select the preferred model. A decision therefore needs to be made between the multiple modelling alternatives which should adhere to multiple legal and technical criteria.

To aid in the selection process decision support methods are investigated in this section. This will be done by first providing a general discussion on how multi-criteria problems are solved. Thereafter, various decision aid methods used during multi-criteria decision making will be investigated.

2.4.2 Multi-criteria decision making

Decision making involves identifying alternatives and selecting the best one based on preferences, objectives, desires or goals [49]. When multiple stakeholders are involved, a decision needs to be made that takes into account the preferences or objectives of all stakeholders [50]. If a decision has to be made based on multiple objectives, the process can then be referred to as multi-criteria decision making (MCDM) [51].

Multi-criteria decision making results in a compromised solution which takes several contradicting, qualitative and/or quantitative criteria into account in order to be acceptable to all stakeholders involved [51]. Thus, in the MCDM process a solution between alternative options is obtained which best fits these criteria.

The handbook *Multi-Criteria Analysis in the Renewable Energy Industry*, written by Monteo [50] aims to show how the use of multi-criteria decision making methods can aid in the selection of renewable energy projects. According to this handbook, the decision making process primarily consists of five stages as listed below:

- Define the problem, generate alternative solutions and establish appropriate criteria,
- Assign appropriate criteria weights,
- Evaluation of alternatives,
- Select the appropriate multi-criteria method in order to rank alternatives, and
- Rank the alternatives.

Bruen [52] discusses decision making approaches for the water framework directive. In the study a classical approach for systematic decision making relating to large infrastructural projects is described. According to the study such an approach consists of the following five steps:

- Define the objectives or criteria of the project,
- Establish measures of effectiveness, i.e. establish procedures to assess each objective that may be either qualitative or quantitative,
- Generate alternative solutions,
- Evaluate each possible alternative solution in relation to the measures of effectiveness for each objective or criteria, and
- Analyse evaluation results and make a decision or recommendation, when there are many objectives/criteria a multi-criteria decision support method is recommended.

Azar [53] made use of three different multi-criteria decision aid methods to compare the performance of various imaging techniques used to detect breast cancer. The steps followed by all three methods were:

- Determining the goal of the analysis (in this case study the goal was to determine the best imaging technique to correctly diagnose breast cancer),
- Identify alternatives (identification of alternative imaging techniques to be evaluated),
- Establish the relevant attributes that the alternatives need to adhere to,
- Obtain attribute weights (assign weights to various attributes according to relative importance),
- Evaluate each alternative in respect of each attribute,
- Use the multi-criteria decision aid method in order to rank the various alternatives, and
- Evaluate results and decide which alternative is the best.

Tzeng et al. [54] performed a multi-criteria analysis to determine which alternative-fuel bus is the most suitable substitute in Taiwan. The analysis made use of two different MCDM methods in order to rank the various alternatives. The approach followed involved the following steps:

- Identification of the types of alternative-fuel buses,
- Establishing the evaluation criteria,
- Relevant experts in the field assessed the importance of the criteria to establish criteria weights,
- Each alternative was evaluated by professional experts,
- Application of MCDM method in order to rank the alternative options, and
- Results are analysed and a compromised solution is determined.

Volkart et al. [55] developed a methodology to evaluate various energy system transformation pathways in Switzerland. In the study, energy system scenarios are compared according to various environmental, economic and social criteria. According to the study the methodology is generic and can be applied to any region of interest for comparative analyses. The methodology consists of the following four steps:

- Scenario specification (specification of alternative energy system scenarios),
- Scenario quantification (quantification of end-use energy demands for energy carriers in four different demand sectors of each scenario),
- Criteria definition and specific indicator quantification (establishing criteria and quantification of specific indicators for each scenario with regards to each criteria), and
- Results calculation and interpretation (analysis of scenarios according to a dedicated multi-criteria decision aid method and interpretation of results).

In conclusion, the information regarding multi-criteria decision making gathered from all of the abovementioned approaches is summarised into Table 2-3. The steps followed in previous studies (*columns A-F*) were critically reviewed to provide a general method of how multi-criteria problems are usually approached (*column G*). This generic method will be applied to the evaluation of quantified EE savings for 12L specifically in Chapter 3 (Methodology).

Table 2-3: Summary of generic method to multi-criteria problems

<table>
<tr><th>A</th><th>B</th><th>C</th><th>D</th><th>E</th><th>G</th></tr>
<tr><th colspan="5">Steps of multi-criteria decision making from literature</th><th rowspan="2">Generic</th></tr>
<tr><th>[50]</th><th>[52]</th><th>[53]</th><th>[54]</th><th>[55]</th></tr>
<tr><td rowspan="4">Define the problem, generate alternative solutions and establish criteria</td><td rowspan="2">Define objectives</td><td>Determine the goal of the analysis</td><td rowspan="2">Identify alternative solutions</td><td rowspan="2">Scenario specification and quantification</td><td rowspan="2">Generate/identify alternative solutions</td></tr>
<tr><td>Identify alternatives</td></tr>
<tr><td>Establish measures of effectiveness</td><td rowspan="2">Establish relevant attributes</td><td rowspan="2">Establish evaluation criteria</td><td rowspan="4">Criteria definition and indicator quantification</td><td rowspan="2">Establish criteria</td></tr>
<tr><td>Generate alternatives</td></tr>
<tr><td>Assign criteria weights</td><td rowspan="3">Evaluate alternatives</td><td>Obtain attribute weights</td><td>Establish criteria weights</td><td rowspan="2">Evaluate alternatives</td></tr>
<tr><td>Evaluation of alternatives</td><td>Evaluate each alternative in respect of each attribute</td><td>Evaluate alternatives</td></tr>
<tr><td>Select the appropriate multi-criteria method</td><td>Apply a MCDA method</td><td>Apply MCDM</td><td rowspan="2">Results calculation and interpretation</td><td>Apply a MCDA method</td></tr>
<tr><td>Rank the alternatives</td><td>Make decision or recommendation</td><td>Evaluate results and decide which alternative is the best</td><td>Analyse resutls and determine solution</td><td>Evaluate results and results and recommend a suitable solution</td></tr>
</table>

The final strategy for evaluating EE modelling options for 12L, which will be used throughout the rest of this study, will be based on the generic list of steps provided in Table 2-3 *(column G)*, as shown below:

- Generate/identify alternative solutions,
- Establish criteria,
- Evaluate alternatives,
- Apply a multi-criteria decision aid method, and
- Evaluate results and recommend a suitable solution.

The multi-criteria decision aid methods, also referred to as multi-criteria decision making methods, used to evaluate alternatives will be discussed in the next section.

2.4.3 Multi-criteria decision aid methods

Multi-criteria decision aid methods make use of numeric techniques to aid in the decision making process among a set of alternative decisions or solutions. This is done on the basis of a desired set of criteria that alternatives need required to adhere to [56]. The use of MCDM methods ensures that the decision making process is objective and rational [57] [50].

Multi-criteria decision aid methods have been used extensively in various fields, such as resource allocation planning [58], the medical field [53] [59] and most prevalently the sustainable and renewable energy field [51] [50]. The most common MCDM methods applied in the energy applications field are listed below with referencing literature:

- Weighted sum and weighted product method (WSM/WPM) [50] [51] [60],
- Technique for the order of preference by similarity to the ideal solution (TOPSIS) [50] [51],
- Analytical hierarchy process (AHP) [50] [61] [51],
- *Elimination et choix traduisant la realité* (ELECTRE) [50] [51] [60], and
- Preference ranking organization method for enrichment evaluation (PROMETHEE) [50] [51].

Kolios et al. [51] undertook a comparative study between the WSM, WPM, TOPSIS, AHP, PROMETHEE Type I, PROMETHEE Type V and ELECTRE I methods. The study concluded that the results obtained from the various methods were in very good agreement while the more sophisticated methods (i.e. TOPSIS and PROMETHEE) gave the most accurate results. Furthermore, the study showed that the WSM, AHP and PROMETHEE Type I methods showed very similar results [51].

A study by *Kolios et al.* [62] compared the WSM and TOPSIS methods on the problem of risk identification and assessment within the tidal energy industry. The results showed good agreement between the two methods [51], [63], [62].

The simplest of the above-mentioned methods is the WSM. It is also the oldest and most widely used method [56]. This method is extensively employed due to how straight forward it is to implement [51]. The WSM is the preferred method used throughout this study since M&V results generally need to be presented to multiple stakeholders that don't necessarily have expertise to understand the more complex methods.

Triantaphyllou [56] established three common steps that are required during the implementation of any MCDA WSM method. The first step involves determining the relevant criteria and alternative solutions. Secondly, the relative importance of the individual criteria should be established by attaching numerical weights to each criterion.

The second step also involves rating each alternative with respect to each criterion. This can be done by assembling an evaluation/decision matrix [57]. Considering a problem with a set of finite alternatives A_i ($i= 1, 2, ...,m$) and decision criteria C_j ($j= 1, 2, ...,n$); then the evaluation matrix will have m by n dimensions with a_{ij} representing the performance of alternative A_i in respect to criterion C_j.

In the third step, each alternative is evaluated by considering all the criteria simultaneously. This enables decision makers to rank each alternative. The WSM considers the alternative that satisfies the following equation as the optimum solution to the problem [56]:

$$A^*_{WSM} = Max \sum_{j=1}^{n} a_{ij} w_j \, , \quad for\ i = 1, 2, 3, \ldots, m.$$

Equation 2-11: Weighted sum method

Where A^*_{wsm} denotes the score of the best alternative, n the amount of criteria, a_{ij} the evaluation score of the i^{th} alternative in terms of the j^{th} criteria and w_j the weight of the j^{th} criterion. The total score of an alternative is thus the weighted sum of its evaluation ratings, while the alternative with the highest score is considered the best alternative [50].

A weakness of the WSM arises when alternatives show considerably different values in respect to a criterion, e.g. when null values are present in the evaluation matrix. In such a case the WSM tends to rank alternatives in a way that is heavily conditioned by that criterion [60].

The WSM is easily applicable to problems where the units' ranges across criteria are the same. However, when the unit's ranges vary across criteria, e.g. when qualitative and quantitative criteria are present, it becomes difficult to handle. The problem can be overcome by employing normalisation schemes in order to score alternatives in terms of various criteria [51].

The key concept of employing a normalisation scheme involves the construction of a scale which represents the preference of an outcome. The scales are thus anchored at their ends by the least and most preferred outcomes of a specific criterion. This is illustrated in Figure 2-19 [64]:

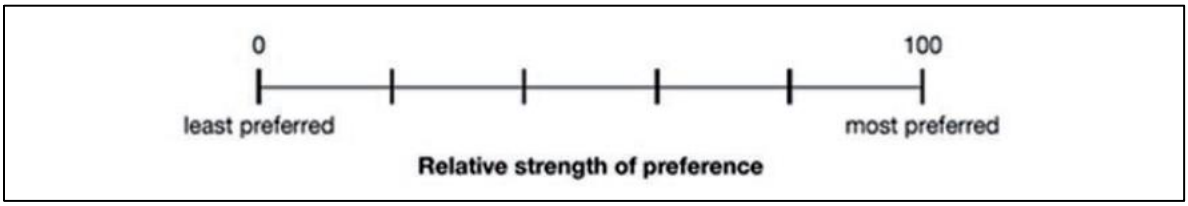

Figure 2-19: Relative strength of preference scale. Adapted from [64]

This scoring method may be utilised by first constructing a performance matrix, which indicates the performance of each alternative in terms of each criterion. Thereafter, the relative strength of preference scale may be utilised to obtain numerical values that represent the performance of each alternative, i.e. the evaluation matrix. The concept of a relative preference scale thus ensures that different units, i.e. apples and oranges, can be compared [64].

Various sources suggest that the process of pairwise comparisons, as introduced by *Saaty* (1980), be employed for criteria weight determination [65] [61]. In this process, each criterion is rated for its importance relative to every other criterion by using a reciprocal scale. The reciprocal scale utilised in this process indicates how much a criteria is more important than the criteria it is compared to. The scale is presented in Table 2-4.

Table 2-4: The 9-point reciprocal rating scale. Adapted from [61]

Intensity of Importance	*Definition*	*Explanation*
1	Equal Importance	Two activities contribute equally to the objective
2	Weak or slight	
3	Moderate importance	Experience and judgement slightly favour one activity over another
4	Moderate plus	
5	Strong importance	Experience and judgement strongly favour one activity over another
6	Strong plus	
7	Very strong or demonstrated importance	An activity is favoured very strongly over another; its dominance demonstrated in practice
8	Very, very strong	
9	Extreme importance	The evidence favouring one activity over another is of the highest possible order of affirmation
Reciprocals of above	If activity *i* has one of the above non-zero numbers assigned to it when compared with activity *j*, then *j* has the reciprocal value when compared with *i*	A reasonable assumption
1.1–1.9	If the activities are very close	May be difficult to assign the best value but when compared with other contrasting activities the size of the small numbers would not be too noticeable, yet they can still indicate the relative importance of the activities.

When comparing two criteria with each other, one automatically enters the reciprocal rating in the transpose comparison. This results in an $n \times n$ (for n decision criteria) matrix of ratings. Thereafter, the criteria weights may be determined by raising the matrix to large powers, adding each row and dividing by the total sum of all the rows [61].

2.4.4 Summary

When dealing with multi-criteria decision problems a decision needs to be made between multiple alternatives which need to adhere to various criteria. The criteria are often conflicting. Thus, the selection of a 12L model of the achieved EE savings is a multi-criteria decision problem. A generic method of solving multi-criteria decision problems was therefore investigated in this section.

These generic steps will be used to select the best 12L model among multiple modelling options. The selected model should take the legal and technical requirements into account in order to be a satisfactory solution. The relevant literature was provided regarding the key steps in solving a multi-criteria decision problem.

2.5 Conclusion

This chapter provided an overview of the strict rules and guidelines associated with 12L. This was done to familiarise the reader with the requirements of the 12L tax incentive. These requirements could be categorised as either regulatory or technical requirements. It was established that the legal requirements are clearly defined by the 12L Regulations. However, the technical requirements were found to be more flexible.

The key technical aspects relating to the technical scope of 12L were identified as the selection of a measurement boundary, assessment of the baseline dataset and the baseline model development and evaluation. Methodologies regarding these key technical aspects were found to be well-established in available literature. These methodologies can readily be used in this study. These methodologies, however, deliver multiple modelling options that may be used to quantify the achieved EE savings. It is not evident from literature how these multiple options should be evaluated to consistently reach a singular option.

The multiple modelling options must adhere to both the legal and technical requirements of a 12L application in various levels. Decision support methods were therefore investigated in this section. A generic strategy for solving multi-criteria decision problems was established. The relevant steps in the generic strategy were also discussed. In the next chapter, the knowledge obtained in this chapter will be used to develop a methodology which enables the selection of a 12L energy efficiency model among multiple modelling options.

3. METHODOLOGY

3.1 Preamble

The problem statement in Chapter 1 emphasised the need to prove that the most appropriate 12L energy efficiency (EE) model was chosen between multiple modelling options. Chapter 2 reviewed the relevant literature relating to the requirements of Section 12L. Generic methods for making decisions between multiple solutions were also reviewed in Chapter 2. In this chapter the knowledge obtained from literature was used to develop a methodology to evaluate industrial energy efficiency models for 12L applications.

The methodology developed in this chapter consists of three phases. These phases were the generation of modelling options (Section 3.2), evaluation of the modelling options (Section 3.3) and lastly ranking of results and recommendation of the preferred model (Section 3.4). These phases are consistent with the generic decision support methods which were researched in Chapter 2. The strategy is illustrated in Figure 3-1 and is discussed in detail in the following sections.

Figure 3-1: Three phases of methodology

3.2 Generation of modelling options

Overview

In this first phase of the methodology the available information of the system under consideration is identified in a checklist. Thereafter the information is then used to develop multiple baseline models. The models are generated according to the various strategies provided from the literature study. The models may vary according to different measurement boundaries, data and calculation methods used. Phase one of the methodology is presented in Figure 3-2.

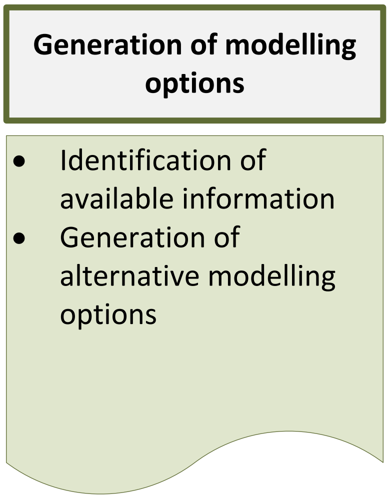

Figure 3-2: Phase one of methodology

Identification of available information

The measurement data generally required for 12L model development can be identified from literature. These measurements can be summarised in a table and used as a checklist to identify all the available information of the system under consideration. The checklist is shown in Table 3-1 and makes provision to identify:

- The energy saving measure implemented,
- any concurrent benefits and limitations to consider,
- energy streams entering and exiting applicable measurement boundary,
- measured variables of each energy stream, and
- available proof of compliance of measurements.

Table 3-1: Checklist of available information on system

AVAILABLE INFORMATION CHECKLIST								
Energy saving measure description:								
Concurrent benefits/limitations:								
Measurable		Data resolution			Data resolution			Compliance
		Boundary i	Boundary i + 1	Boundary n	Boundary i	Boundary i + 1	Boundary n	
Energy input/output	Point of measurement i							
	Quantity							
	Energy conversion							
	Quality							
	Point of measurement i+1							
	Quantity							
	Energy conversion							
	Quality							
	Point of measurement n							
	Quantity							
	Energy conversion							
	Quality							

The checklist identifies the various measured variables entering and exiting the process. Alternative points of measurement may then be identified, such as measurement points in series of a specific process variable. The various measurements may then be classified as quantity, energy conversion or quality measurements.

Quantity measurements refer to mass or volumetric values while energy conversion refers to the energy content of an energy stream, such as calorific values or heating values. Energy conversion measurements are used to convert the mass or volumetric values to kWh equivalent values. Quality measurements refer to values indicative of the quality of a process stream. These measurements may include proximate analyses of coal, composite analysis of product streams, temperatures and pressures of steam, etc.

Furthermore, the checklist makes provision to identify the resolution (e.g. hourly, daily, monthly etc.) that data is available in as well as the measurement boundary that it is applicable to. Lastly, the 12L compliance status of a specific measurement point may be identified on the checklist.

From the checklist, multiple measurement boundaries and various dataset options will generally be available to choose from during model development. These options will all differ on a level of legal compliance and technical accuracy. To further aid in the selection process of a measurement boundary and dataset the various available measurement points can be illustrated on the process flow layout of the system under consideration [5]. This concept was discussed in Chapter 2, and is illustrated in an example in Figure 3-3.

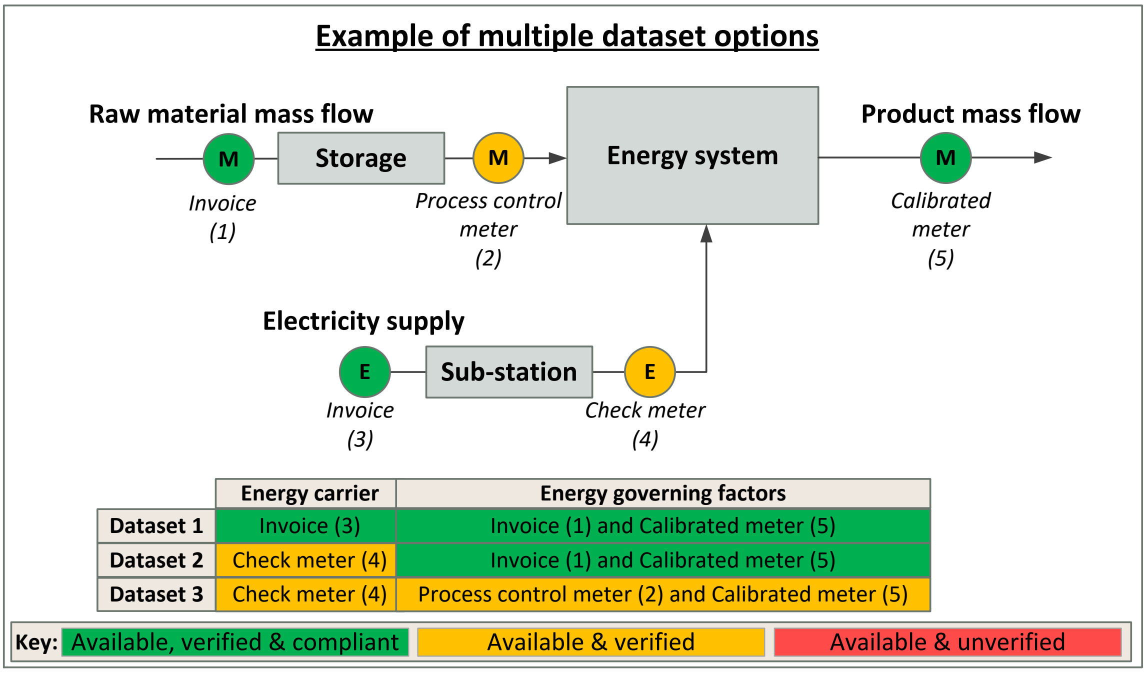

Figure 3-3: Example of illustration of multiple dataset options. Adapted from [5]

Generation of alternative modelling options

The information gathered in the checklist is used to develop the 12L EE baseline model. As discussed in Chapter 2, various methodologies regarding 12L model development are available in literature. These methodologies are well-established and can readily be used in this study. Figure 3-4 shows one of these methodologies:

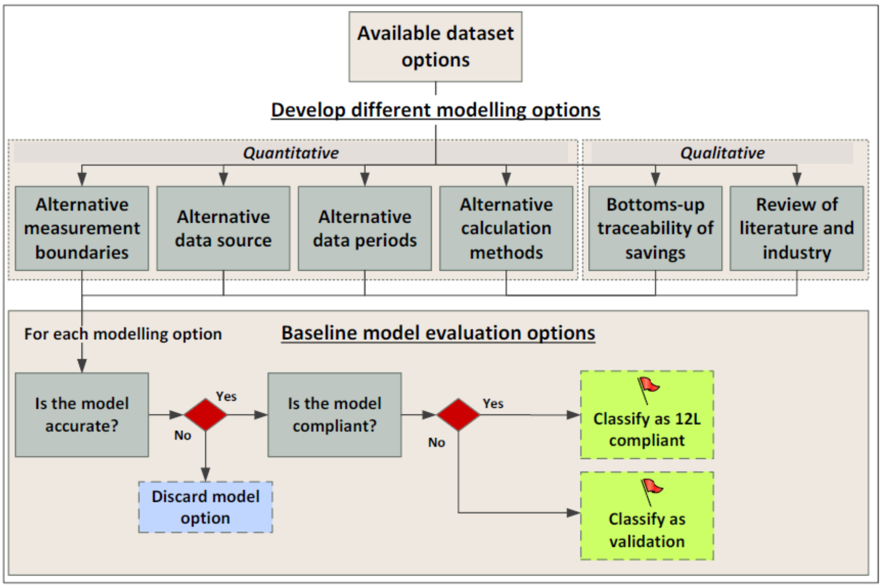

Figure 3-4: Baseline model development framework. Adapted from [5]

Various modelling options may exist from applying the above methodology, as well as the other strategies presented in Chapter 2. From the model development strategies presented, there are three main variations during model development. These variations include measurement boundaries, data considerations and mathematical methods used to calculate the EE savings.

From identifying all of the available information on the system in a checklist it is possible to identify the various options available to choose from during model development. The result of multiple modelling options when considering the multiple measurement boundaries, data and mathematical methods are illustrated in Figure 3-5.

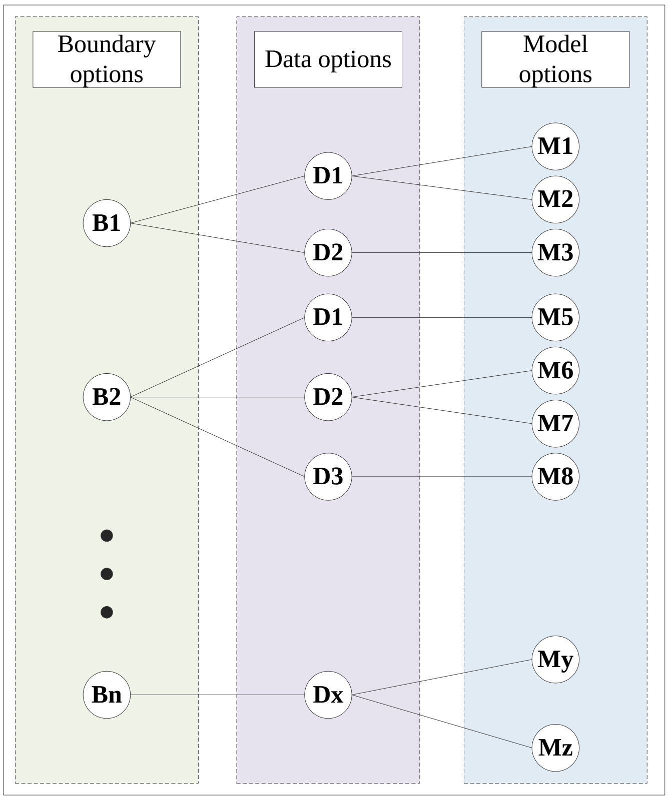

Figure 3-5: Illustration of multiple modelling options

The last step after generating multiple modelling options is to summarise and consolidate the various options that are available. This can be done by illustrating the final alternative modelling options such as presented in Table 3-2.

Table 3-2: Alternative modelling options

Model	Boundary	Data	Calculation Method
Model 1	Boundary 1	Dataset 1	Method 1
Model 2	-	-	-
…	…	…	…
Model m	Boundary n	Dataset x	Method z

Table 3-2 summarises the developed models according to the selected boundary, data used and calculation method used. The table thus contains the various modelling options from which the final model should be selected.

Summary - Generation of modelling options

In the first phase of the methodology alternative modelling options are generated. This is done by first identifying all of the available information on the system under consideration. Thereafter, the identified information is used to develop multiple baseline models. This is done by making use of the model development strategies and methodologies provided in Chapter 2.

Lastly, the developed models are summarised in the form of a table. The table indicates the major differences between the models according to alternative measurement boundaries, data and calculation methods considered.

3.3 Evaluation of modelling options

Overview

In order to select a final modelling option the alternatives need to be evaluated. The final model, however, needs to be selected from various available options and adhere to multiple criteria. The selection of a modelling option can thus be seen as a multi-criteria decision making (MCDM) problem. Solving MCDM problems were reviewed in Chapter 2. From the literature study the necessary steps needed in order to select an appropriate 12L model from the alternative options could be identified. Figure 3-6 presents the steps followed in the second phase of the methodology.

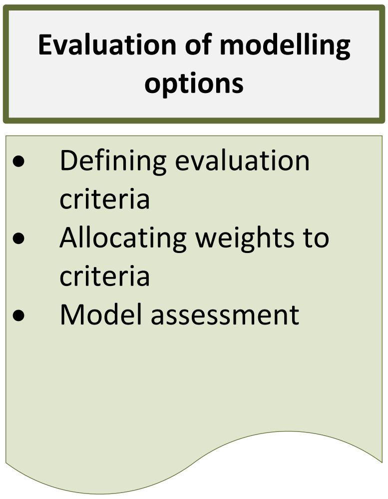

Figure 3-6: Phase two of methodology

Firstly criteria and criteria weights are established. Thereafter each alternative is assessed according to their performance in respect to each criterion. A scaling method is then used to convert the performance scores to comparable scores between 0 and 1. Thereafter the weights may be incorporated into the scores to obtain the weighted scores of each alternative in respect to each criterion. The overall score of each modelling option will be determined in the last phase of the methodology.

Defining evaluation criteria

The evaluation criteria considered in this study were identified from a critical analysis of the literature provided in Section 2.2 and Section 2.3. The first two criteria consider key legal requirements of a 12L application. This includes the compliance of the measurements used in the model development as well as the conservativeness of the quantified EE savings. Next, the model accuracy may be evaluated by considering the most common statistical parameters used to evaluate regression models, as identified from literature (Chapter 2). The statistical parameters include the correlation (R^2) and the root mean squared error (RMSE) of the model.

Further criteria used to evaluate the alternative modelling options in this study include the significance of the savings, variance in the savings and the fraction of energy the model accounts for. The significance of the quantified savings deems as an indication that the correct boundary was selected for the respective model. The variance in savings of a specific model to the other models is used to identify extreme models. Lastly, the fraction of energy a model accounts for is indicative that the relevant parameters have been included in the model. These last three criteria evaluates that the models are technically sound.

The final criteria that will be used to evaluate the alternative modelling options in this study are listed below:

- Compliance of measurements (C_1)
- Conservativeness of quantified EE savings (C_2)
- Model correlation (R^2) (C_3)
- Root mean squared error of model (RMSE) (C_4)
- Significance of quantified savings (C_5)
- Variance in savings (C_6)
- Fraction of energy accounted for (C_7)

Allocating weights to criteria

The next step is to determine the criteria weights. This is done in order to determine the relative importance of each criterion. The criteria weights are determined by the use of a pairwise comparison matrix and a 9-point reciprocal scale. First an *n x n* matrix is derived, where *n* is the number of criteria. In this study the weights of seven criteria need to be determined, therefore a *7 x 7* matrix is derived.

Thereafter each criterion can be rated relative to its importance to every other criterion using the reciprocal scale. The diagonal of the matrix is 1, since the importance of a criterion relative to itself is equal. Furthermore, if a number is entered in its appropriate position then the reciprocal is automatically entered in the transpose position. The 9-point reciprocal scale is shown in Figure 3-7 while the *7 x 7* pairwise comparison matrix is illustrated in Table 3-3.

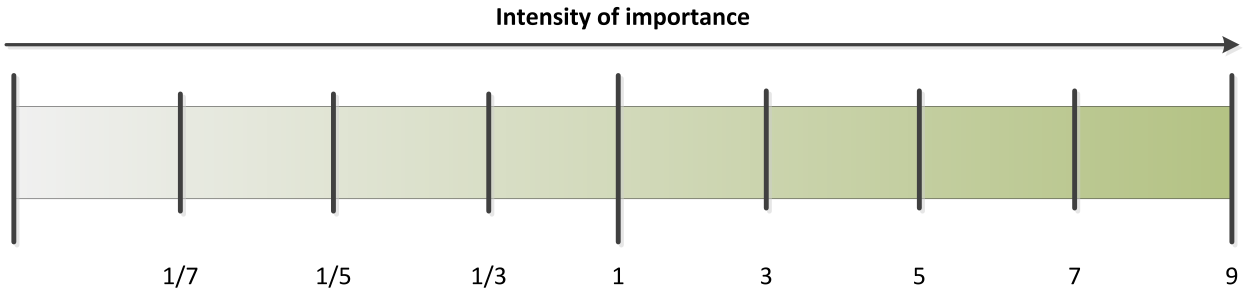

Figure 3-7: 9-point reciprocal scale

Table 3-3: Pairwise comparison matrix for criteria weight determination

	Criterion 1	Criterion 2	Criterion 3	Criterion 4	Criterion 5	Criterion 6	Criterion 7
Criterion 1	1						
Criterion 2		1					
Criterion 3			1				
Criterion 4				1			
Criterion 5					1		
Criterion 6						1	
Criterion 7							1

The criteria weights used in this study were obtained by means of a survey. Ten suitably qualified individuals with experience in the field of M&V were asked to complete the pairwise comparison matrices. Details of the individuals as well as the results of the ten matrices can be seen in *Appendix B.* The respective weights obtained from the analysis is summarised in Table 3-4.

Table 3-4: Derived criteria weights

Criteria	Derived weight
Compliance of measurements (C_1)	0.213
Conservativeness of savings (C_2)	0.165
R^2 (C_3)	0.182
RMSE (C_4)	0.112
Significance of savings (C_5)	0.126
Variance of savings (C_6)	0.105
Fraction of energy accounted for (C_7)	0.096

At this stage of the methodology, the specific criteria and criteria weights are established. Although this study relied on literature and survey results to establish the specific criteria, it should be noted that the methodology can allow other methods to define criteria. This allows flexibility to apply the methodology generically to different scenarios.

Model assessment

The third step in this phase of the methodology was to assess each model according to each criterion. This is done by first evaluating the performance of each model in respect to each criterion. The results are then summarised in a performance matrix. In the performance matrix different units might be present depending on the various criteria. Construction of a performance matrix is illustrated in Table 3-5, where *m* models are evaluated according to *n* criteria.

Table 3-5: Construction of a performance matrix

	C_1	C_2	…	C_j	…	C_n
Model 1	230	2		0.97		75%
Model 2	285	5		0.83		50%
…						
Model i	260	4		0.86		100%
…						
Model m	250	4		0.71		20%

The fifth step consists of *normalising the scores* present in the performance matrix. This is done to eliminate the various units present and obtain comparable scores. A relative strength of preference scale rating from 0 to 1 will be used in this study. The scale is depicted in Figure 3-8.

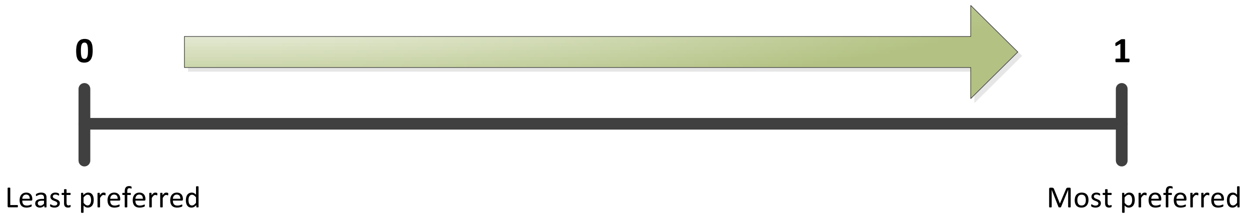

Figure 3-8: Relative strength of preference scale

Each anchor point of the scale (0 and 1) represents the least preferred and most preferred scenario in terms of each criterion, respectively. The least and most preferred scenario with respect to the seven criteria identified in this study is summarised in Table 3-6. The preference scale of each criterion is discussed thereafter.

Table 3-6: Criteria normalisation scoring scale

Scoring scale	0	1
	Least preferred	**Most preferred**
Compliance of measurement (C_1)	No compliant measurements used	All measurements used are compliant
Conservativeness of savings (C_2)	Least conservative (highest EE savings)	Most conservative (lowest EE savings)
Correlation (C_3)	No correlation between variables (R^2 of zero)	Perfect correlation between variables (R^2 of 1)
RMSE (C_4)	RMSE larger than 15%	RMSE of zero
Significance of savings (C_5)	No significance (zero)	Maximum significance
Variance in savings (C_6)	Maximum distance from average savings	No variance in savings (zero)
Fraction of energy accounted for (C_7)	No energy accounted for (zero)	100% of energy accounted for

The least preferred scenario with respect to model compliance (C_1) is that none of the measurements used to develop the model is 12L compliant. The most preferred scenario is that all of the measurements used to develop the model are 12L compliant. When considering the conservativeness of the quantified EE savings (C_2); the 0 anchor point (least preferred scenario) is the least conservative EE savings between the various modelling options. This is equal to the highest EE savings value. The 1 anchor point (most preferred scenario) is then the most conservative EE saving, i.e. the lowest savings value.

The least preferred scenario when considering the correlation of a model (C_3) is a R^2 value of 0, which indicates no correlation existed between the variables used to develop the model. The most preferred correlation, and thus representing the 1 anchor point, is a R^2 value of 1, which indicates a good fit of the regression line and relationship between variables [28] [27].

The RMSE (C_4) should typically be below 15% [27]. Therefore the least preferred anchor point includes RMSE values of 15% or higher. The most preferred scenario is a RMSE of 0%, which indicates no error between the predicted and actual values of the regression model.

The least preferred scenario with respect to the significance of savings (C_5) is that there is no significance (significance of zero). The most preferred scenario is the significance of the quantified EE savings of the model with the highest significance of savings between the various modelling options.

Models with large variances in savings (C_6) with respect to the average savings between multiple modelling options indicate extreme models. The least and most preferred scenarios with respect to this criterion is thus the maximum variance from the average savings and no variance from the average savings, respectively.

When considering the fraction of energy a model accounts for (C_7) the least preferred scenario is that the model accounts for zero percent of the energy, while the most preferred scenario is that the model accounts for 100% of the energy within the selected measurement boundary of the model.

The respective anchor points of each criterion are used to linearly scale the evaluations in the performance matrix. This results in a score between 0 and 1 for each alternative model in terms of each criterion. Thereafter the weighted scores may be calculated. This is done by multiplying each evaluation score with the respective criteria weight:

$$weighted\ score = a_{ij}w_j$$

Equation 3-1: Calculation of weighted score

Where a_i denotes the evaluation score (between 0 and 1) of model i and w_j the weight of criteria j. The weighted scores are then summarised in a scoring matrix as illustrated in Table 3-7.

Table 3-7: Illustration of weighted scoring matrix

	C_1	…	C_j	…	C_7
model 1	$a_{11}w_1$	…	$a_{1j}w_j$	…	$a_{17}w_7$
model 2	$a_{21}w_1$	…	$a_{2j}w_j$	…	$a_{27}w_7$
. . .					
model i	$a_{i1}w_1$	…	$a_{ij}w_j$	…	$a_{i7}w_m$
model i +1	$a_{(i+1)1}w_1$	…	$a_{(i+1)j}w_j$	…	$a_{(i+1)7}w_m$
. . .					
model m	$a_{n1}w_1$	…	$a_{nj}w_j$	…	$a_{n7}w_m$

Summary - Evaluation of modelling options

In this phase of the methodology the alternative modelling options were evaluated. This was done to aid in the selection process of the final modelling option. The first two steps in this phase consisted of the identification of evaluation criteria and criteria weights. This step is however flexible, since the evaluation criteria and weights can easily be adapted.

In the next step the alternative modelling options were assessed according to their performance with respect to each evaluation criterion. This is done by making use of a performance matrix. The performance matrix may however include various units. The performance scores are therefore converted to comparable score values between 0 and 1. This is done by making use of a relative strength of preference scale for each criterion. Lastly, the criteria weights are taken into consideration by determining the weighted score for each model with respect to each criterion. This results in a weighted scoring matrix.

3.4 Ranking and recommendation of preferred model

Overview

In the third phase of the methodology the overall score for each alternative modelling option is calculated. Thereafter the models are ranked according to their overall scores. This is done to assist in the selection of the final preferred model. Figure 3-9 presents the steps taken in the third step of the methodology.

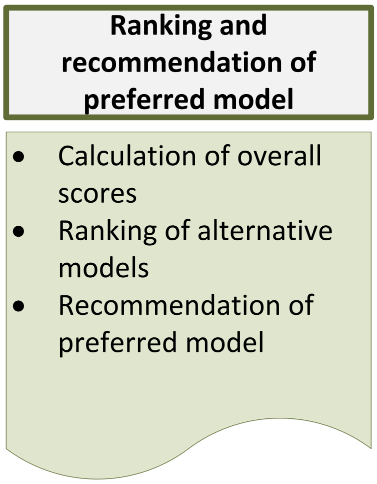

Figure 3-9: Third phase of methodology

Scoring methodology

The overall score may also be referred to as the multi-criteria score since it takes all of the evaluation criteria into consideration. The Weighted Sum Method (WSM) will be used to calculate the multi-criteria scores and rank the results obtained. According to the WSM the overall score of each alternative is equal to the sum of the respective weighted scores in terms of each criterion for that alternative [51]. The calculation of the multi-criteria scores is presented in Equation 3-2:

$$A_i = \sum_{j=1}^{n} a_{ij} w_j$$

Equation 3-2: Calculation of multi-criteria score

For $i = 1, 2, \ldots, m$ alternative modelling options and $j = 1, 2, \ldots, n$ evaluation criteria. Furthermore a_{ij} denotes the evaluation score for alternative i in terms of criteria j, and w_j the weight of criteria j. Table 3-8 shows the calculation of the multi-criteria scores of m alternative modelling options and seven evaluation criteria.

Table 3-8: Calculation of overall score of each alternative modelling option

	C_1	...	C_j	...	C_7	A(C)
model 1	a_1w_1	...	a_1w_j	...	a_1w_7	A_1
model 2	a_2w_1	...	a_2w_j	...	a_2w_7	A_2
. . .						
model i	a_iw_1	...	a_iw_j	...	a_iw_7	A_i
model i +1	$a_{i+1}w_1$	...	$a_{i+1}w_j$	...	$a_{i+1}w_7$	A_{i+1}
. . .						
model m	a_nw_1	...	a_nw_j	...	a_nw_7	A_m

Ranking methodology

After obtaining the multi-criteria scores they can be used to rank the alternative modelling options. Ranking of the modelling options identifies the most and least preferred model between the alternative options. The WSM identifies the optimum solution as the one satisfying the following equation:

$$A^*_{WSM} = Max \sum_{j=1}^{n} a_{ij}w_j$$

Equation 3-3: Optimum solution according to weighted sum method

The overall scores obtained should thus be ranked from highest to lowest. For example, Figure 3-10 shows four alternative modelling options that have been ranked according to their multi-criteria scores.

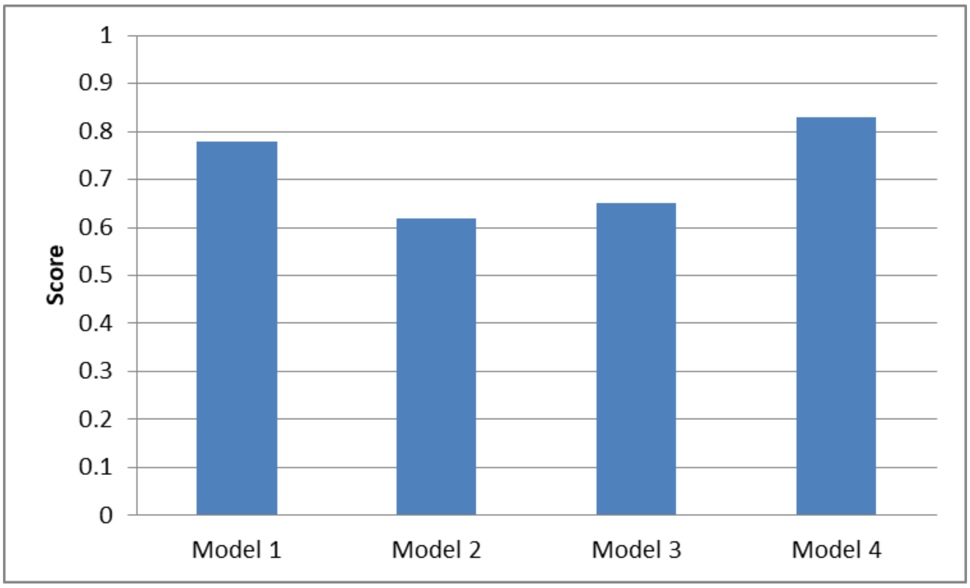

Figure 3-10: Ranking obtained from MCDA results

From the example in Figure 3-10 the ranking obtained with the WSM showed that model four is the best model. This means that model four adheres to all of the criteria more satisfying than the other modelling options available. The results obtained from the WSM may be analysed to recommend a preferred model for the specific 12L application under consideration.

Summary – Ranking and recommendation

In the last phase of the methodology the various modelling options were ranked in order to select the final modelling option. Ranking was done based on the overall scores of each model. The overall score of each model was calculated as the sum of the weighted scores with respect to each evaluation criterion. The overall score therefore took into consideration how each model adhered to all of the evaluation criteria.

The models were then ranked from the highest score to the lowest. The model with the highest score was then recommended as the preferred model according to the multi-criteria analysis.

3.5 Conclusion

In this chapter a methodology was developed to calculate and evaluate models for 12L applications. The methodology consisted of three phases, as illustrated in Figure 3-11.

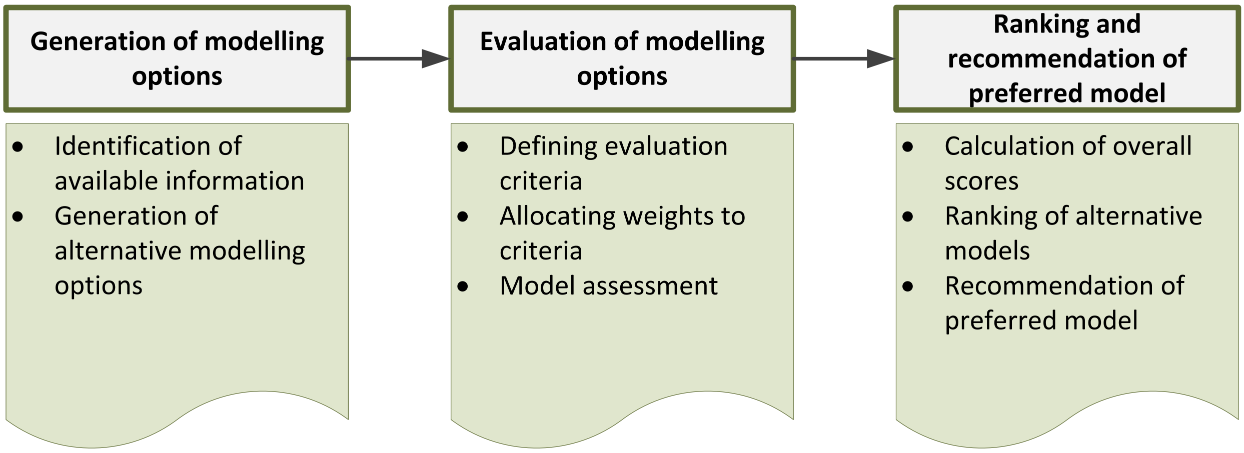

Figure 3-11: Extended three phases of methodology

Firstly, alternative modelling options were generated. This was done by identifying all the available information on the system under consideration. Thereafter, the identified information was used to develop multiple baseline models. Literature provided numerous well-established methodologies that may be used to develop these models.

The need, however, existed to select a final model from the multiple modelling options available. This selection should be done in a transparent and traceable manner in order to support decisions to the relevant stakeholders involved. This was done in the second phase of the methodology where the various modelling options were evaluated according to multiple criteria.

The second phase included the identification of evaluation criteria and assigning criteria weights. Seven evaluation criteria were used in this study. The criteria were identified from a critical analysis of the typical requirements of 12L models as stated in literature (from Chapter 2). Furthermore, the criteria weights were obtained by surveying ten individuals with experience in the field of M&V with pairwise comparison matrixes. The method of defining criteria is, however, flexible since the evaluation criteria and weights can easily be adapted for different scenarios.

The second phase was completed by assessing the alternative modelling options according to their performance with respect to each evaluation criteria. This was done by completing a performance matrix and converting the results to comparable scores between 0 and 1. These scores were obtained by making use of a relative strength of preference scale for each criterion. The weighted scores of each model with respect to each criterion were then determined.

In the third and final phase of the methodology, the overall score of each model was calculated. The overall scores were then used to rank the alternative modelling options. This was done in order to aid in the selection process of a final 12L EE model. According to the multi-criteria method, the model with the highest overall score is recommended as the preferred model.

The methodology allowed a transparent and objective framework for model selection. The developed methodology thus aided in the evaluation and selection process of a final model for 12L applications when more than one modelling option is available. In the next chapter the methodology will be verified by applying it to actual case studies.

4. RESULTS AND DISCUSSION

4.1. Preamble

In the previous chapter, a methodology was developed to quantify and evaluate 12L energy efficiency (EE) models. The methodology may assist the 12L applicant in the selection of a final 12L model among various possible modelling options. This may be done in three phases namely, generation of alternative modelling options, evaluation of alternative modelling options and ranking and recommendation of preferred model. Figure 4-1 presents the methodology.

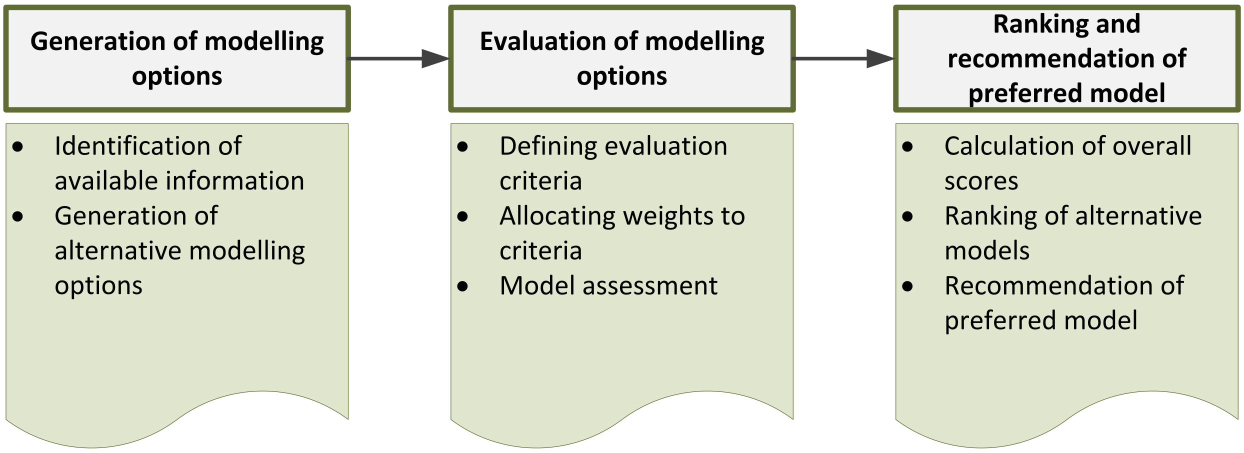

Figure 4-1: Methodology for the objective evaluation of 12L energy efficiency models

In this chapter, the methodology will be applied to actual case studies. This is done to verify the developed methodology. The methodology will be applied to three case studies which vary according to industry. The case studies are in the chemical and petrochemical industry, iron and steel industry and the mining industry, respectively. Furthermore, a validation of the results is provided in Section 4.5.

4.2. Case study 1: Steam stations (Chemical and Petrochemical industry)

4.2.1 Site description

The first case study represented the evaluation of alternative 12L EE models on the steam stations of a petrochemical plant. During the assessment period the water and coal quality to the steam stations were improved, which resulted in a measureable improvement in EE performance. This was done by repairing boiler tubes during general overhauls, improving water quality management and a review of the coal received from mines. Coal is used to generate steam from two steam stations, which in turn is sent to the process or used for electricity generation. The basic layout is depicted in Figure 4-2.

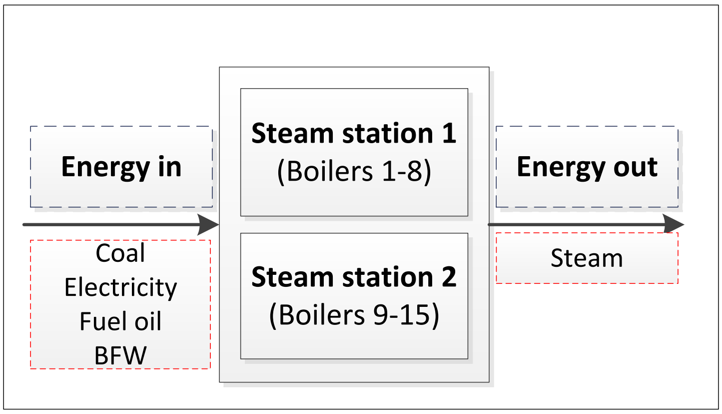

Figure 4-2: Basic layout of steam stations

Fifteen boilers are used to generate steam in two steam stations. Eight boilers are located in steam station 1, of which three have been mothballed. Steam station 2 has seven boilers, all of which are operational. The major energy sources consumed by the steam stations are coal, electricity, fuel oil and boiler feed water (BFW).

4.2.2 Generation of modelling options

In the first phase of the methodology, generation of modelling options, the first step consists of the identification of the available information. Figure 4-3 presents additional detail of the steam stations. The figure identifies the relevant energy streams and measurement points. Selected sections will be discussed in more detail.

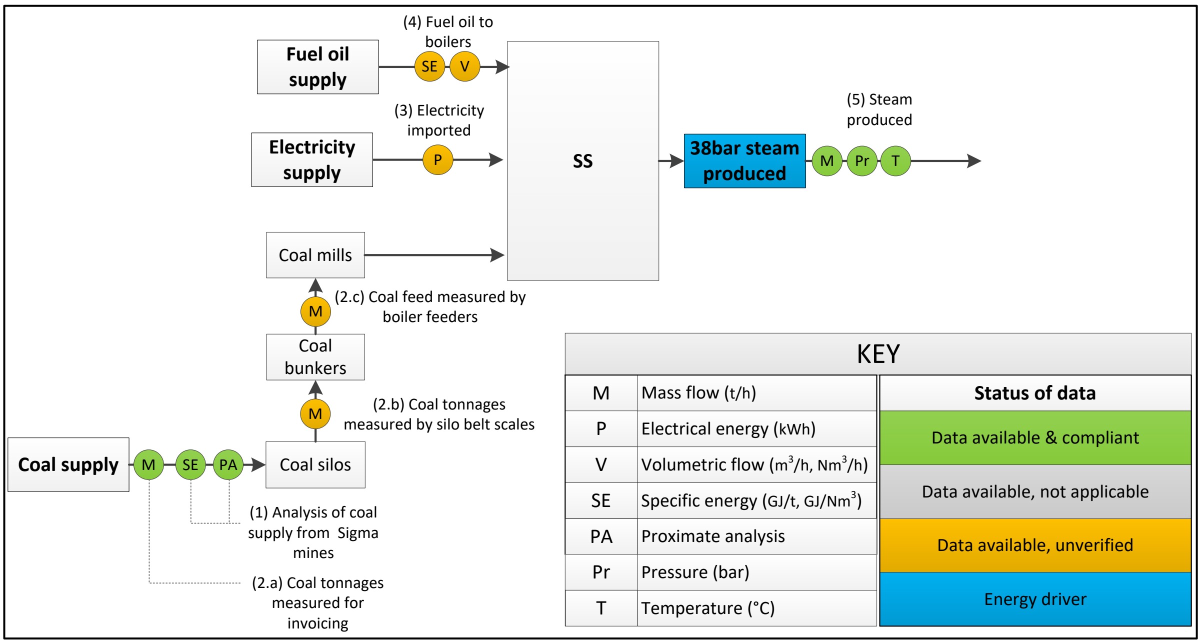

Figure 4-3: Overview of steam stations measurement points

Measurement points are indicated by coloured circles. Each type of measurement is indicated by the key, where M represents mass measurement, P electrical power metering, V volumetric measurement, SE specific energy, PA proximate analysis, Pr pressure and T temperature.

The compliance status of each available measurement is further indicated by a colour key. Green indicates available and 12L Regulatory compliant data while yellow indicates available but unverified data. Each of the various measurement points will now be discussed.

Regular samples are taken from coal which is sourced from mines. These samples are analysed to monitor the compositional characteristics of the coal, this included the specific energy (CV) and proximate analysis (1). Proximate analyses include inherent moisture, ash content, volatile matter and fixed carbon measurements. The coal supply is measured at three different points. Firstly the coal supply is measured (2.a) before being stored in silos. Invoices, which are 12L compliant, are available for these measurements. Thereafter the coal is weighed while being transported to individual bunkers (2.b). From the bunkers the coal is measured while being fed to individual boilers (2.c).

The electricity used to power auxiliaries per steam station is indicated by point (3) on Figure 4-3. Fuel oil is used during boiler start-up and for stability purposes. The specific energy as well as the volumetric flow of the fuel oil is measured before entering the boilers (4).

As indicated by point (5) on Figure 4-3, the temperature of the boiler feed water sent to the boilers are measured. Furthermore, the production, temperature and pressure of the produced steam are measured before being sent to the steam header (6).

All of the available information is summarised in Table 4-1. The table indicates the various measured variables and the different boundaries that the data is applicable to. Furthermore, the table indicates the resolution of the available data as well as the respective available compliance documentation.

Table 4-1: Available information (case study 1)

AVAILABLE INFORMATION CHECKLIST								
Energy saving measure description:								
Repairing boiler tubes during general overhauls, improving water quality management and review of coal quality received from Sigma mines.								
Concurrent benefits/limitations:								
None within measurement boundary								
Measurables		**Daily**			**Monthly**			**Compliance**
		Total SS	Per SS	Per Boiler	Total SS	Per SS	Per Boiler	
Coal	**Coal supply**							
	Mass flow				✓			*Invoices*
	Specific energy (CV)	✓			✓			*Accredited laboratory*
	Proximate analysis	✓						*Accredited laboratory*
	Boiler feeders							
	Mass flow			✓				*None*
	Belt scales							
	Mass flow			✓				*None*
Steam production	Steam flow rate			✓				*Calibration records*
	Steam pressure			✓				*Calibrated check meters*
	Steam temperature			✓				*Calibrated check meters*
Boiler feedwater	Feedwater temperature			✓				*Calibrated check meters*
Fuel oil	Mass/volumetric flow			✓				*None*
Electricity	Power consumption		✓					*None*

From the above table, it can be seen that there are multiple measurement options available relating to the coal consumption of the boilers. Furthermore, all of the provided data may be applicable to various measurement boundaries. These boundaries include the total steam stations, per individual steam station or per individual boiler. The various measurements also differ according to their level of compliance.

The various measurement boundaries and data considerations may be paired in several different ways to model the efficiency savings of the system. Different calculation methods may also be used in the model development. The strategies and methodologies provided in Chapter 2 were utilised in order to select the relevant measurement boundaries, evaluate the given datasets and ultimately develop a baseline model. The strategies resulted in five different and feasible modelling options.

Descriptions of the alternative modelling options are given in Table 4-2. The main variations between them are indicated according to the selected measurement boundary, data and calculation method. Only high level results are provided regarding these models, which is sufficient information in order to test the applicability of the methodology. More detail regarding the calculations and model development is, however, available on request but is not shown in this report due to confidentiality.

Table 4-2: Description of alternative modelling options (case study 1)

Model	Boundary	Data	Calculation method
Model 1	Total steam stations	Select parameter	Intensity
Model 2	Total steam stations	Select parameter	Regression model
Model 3	Total steam stations	All parameters	Regression model
Model 4	Aggregate of per steam station	Select parameter	Intensity
Model 5	Aggregate of per boiler	Select parameter	Intensity

The first model determines the EE improvement by comparing the energy intensities of the baseline and assessment periods. The measurement boundary used consists of the total steam stations. The model is, however, a select parameter approach since it does not consider the boiler feed water in the calculations. All data sources used for this model are 12L compliant, except for the fuel oil and electricity. Together these two energy sources however only contribute to 2% of the energy distribution of the system. The savings quantified from this model is 314.3 GWh.

Model 2 considers the same dataset and boundary as used in Model 1 (total steam stations with select parameter). However, a regression analysis was used to quantify the savings instead of an intensity calculation. This resulted in an EE savings of 293.2 GWh. Model 3 was based on the same measurement boundary and calculation method as Model 2 (total steam stations and regression analysis). However, in this case an all parameter approach was chosen. Thus, the boiler feed water, coal, electricity and fuel oil was considered as energy carriers, while steam was considered as the energy driver. A total EE saving of 251.4 GWh was found from Model 3.

Model 4 and Model 5 both used intensity analyses to model the energy consumption of the individual steam stations and boilers respectively. These models exclude the boiler feed water as an energy carrier and resulted in 324.8 GWh and 341.2 GWh EE savings respectively.

Each of the five developed models will be evaluated in the next phase of the methodology. This was done in order to determine which one model should be selected as the final 12L model.

4.2.3 Evaluation of modelling options

In second phase of the methodology, the models were evaluated according to certain criteria that 12L models need to adhere to. Seven criteria were identified in Chapter 3 and are listed below:

- Compliance (C_1)
- Conservativeness (C_2)
- Correlation (C_3)
- Root mean squared error (C_4)
- Significance of savings (C_5)

- Variance in savings (C_6)
- Fraction of energy accounted for (C_7)

Firstly, the performances of each of the five models were evaluated with respect to each evaluation criteria. The results are summarised in Table 4-3.

Table 4-3: Performance matrix (case study 1)

	C_1	C_2	C_3	C_4	C_5	C_6	C_7
	%	*GWh*	-	*%*	*%*	*GWh*	*%*
Model 1	50.00	314.27	-	-	2.89	9.29	87.60
Model 2	50.00	293.20	0.77	5.49	2.70	11.78	87.60
Model 3	60.00	251.40	0.75	6.49	2.31	53.58	100.00
Model 4	25.00	324.82	-	-	2.99	19.84	87.60
Model 5	33.33	341.19	-	-	3.14	36.22	86.48

Since compliance cannot be fully proven for the electricity and fuel oil measurements, none of the models are 100% compliant (C_1). However, Models 4 and 5 are less compliant due to the higher resolution, but non-compliant coal measurements were used in these models. The quantified savings ranged from 251.4 GWh to 341.2 GWh (C_2). Model 3 was the most conservative model and also the model with the largest variance from the average quantified savings (C_6).

Model 2 and Model 3 are regression analyses while the other three models are intensity calculations. Therefore, only Model 2 and Model 3 have correlations and RMSE's that can be evaluated (C_3 and C_4). The significance of the quantified savings was in the same range for all of the models (C_5). This indicated that the appropriate measurement boundaries were selected to encapsulate the effect of the energy saving measure.

Furthermore, all of the models were based on a select parameter approach, except for Model 3 (C_7). Thus; this model accounts for 100% of the energy within the selected measurement boundary. Model 5 accounts for the least amount of energy since electricity had to be excluded from the model, which was due to electricity not being available on the selected measurement boundary (per individual boiler).

Next, the performance scores were converted to a score between 0 and 1. This was done to eliminate the different measurements of the performance scores and obtain comparable values. Table 4-4 gives the score of each model in respect to each criterion. These scores were obtained by making use of the relative strength of preference scale. This scale was discussed in Chapter 3 and makes use of the least and most preferred scenarios for each criterion as anchor points, i.e. 0 and 1 values, respectively.

Table 4-4: Scoring matrix (case study 1)

	C_1	C_2	C_3	C_4	C_5	C_6	C_7
Model 1	0.50	0.30	0.00	0.00	0.92	0.83	0.88
Model 2	0.50	0.53	0.77	0.63	0.86	0.78	0.88
Model 3	0.60	1.00	0.75	0.57	0.74	0.00	1.00
Model 4	0.25	0.18	0.00	0.00	0.95	0.63	0.88
Model 5	0.33	0.00	0.00	0.00	1.00	0.32	0.86

Lastly, the importance weights of each criterion were taken into consideration in order to determine the weighted scores. The weighted scores were determined by multiplying the scores (between 0 and 1) with the weight of the respective criterion. Table 4-5 presents the weighted scores for the five alternative modelling options according to each criterion.

Table 4-5: Weighted scoring matrix (case study 1)

	C_1	C_2	C_3	C_4	C_5	C_6	C_7
Model 1	0.11	0.05	0.00	0.00	0.12	0.09	0.08
Model 2	0.11	0.09	0.14	0.07	0.11	0.08	0.08
Model 3	0.13	0.17	0.14	0.06	0.09	0.00	0.10
Model 4	0.05	0.03	0.00	0.00	0.12	0.07	0.08
Model 5	0.07	0.00	0.00	0.00	0.13	0.03	0.08

4.2.4 Ranking and recommendation of preferred model

In the third and final phase of the methodology the overall score of each model was determined. The overall score of each model is calculated as the sum of the seven weighted scores of each crtierion. Table 4-6 shows the overall scores for each of the five modelling options.

Table 4-6: Overall score of each modelling option (case study 1)

Model	Overall score
Model 1	0.179
Model 2	0.275
Model 3	0.276
Model 4	0.143
Model 5	0.127

The scores presented in Table 4-6 are used to aid in the selection process of the final 12L model. The calculated overall scores are graphically summarised in Figure 4-4. Each model is ranked from worst to best and numbered from 1 to 5. The ranking was done according to the results obtained from the overall scores. The results are further discussed thereafter.

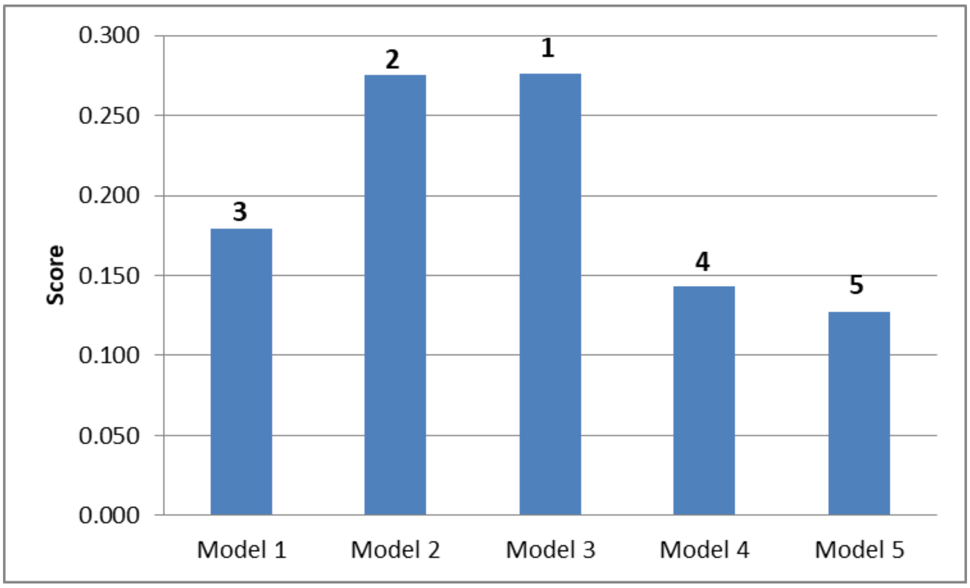

Figure 4-4: Summary of overall score of each modelling option (case study 1)

From Figure 4-4, it can be seen that Model 2 and Model 3 obtained similar scores, with Model 3 achieving the highest score and ranked first place. Model 5 however was ranked in last place due to having the lowest overall score. The overall scoring results can be investigated in more detail by considering each criterion’s contribution to the final scores. This is shown in Figure 4-5 and discussed thereafter.

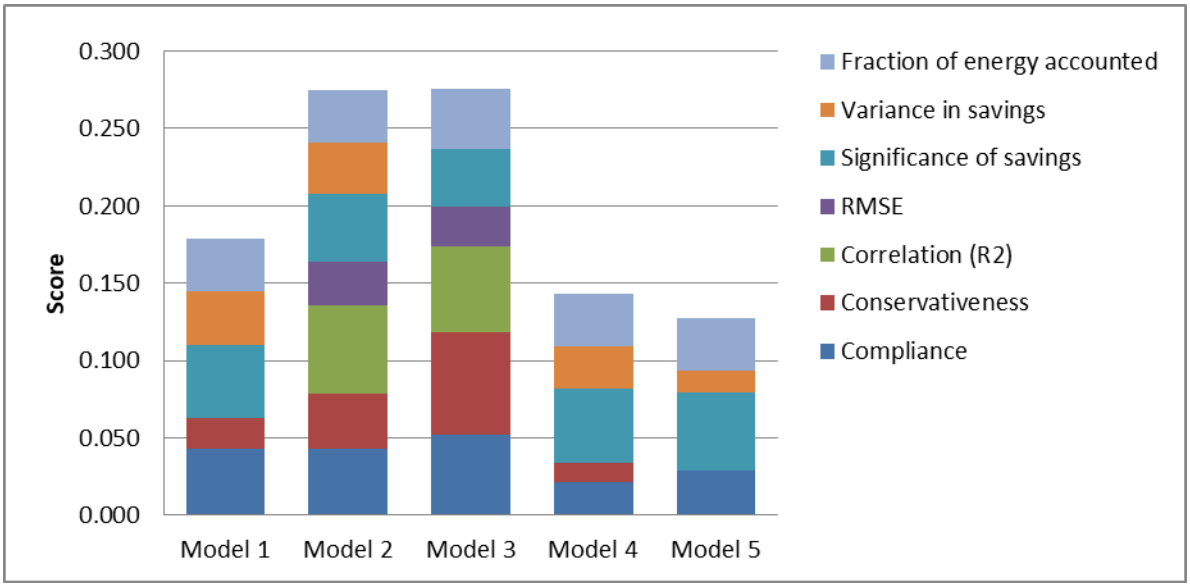

Figure 4-5: Summary of results (case study 1)

Figure 4-5 show that Model 2 and Model 3 obtained higher scores than the other three models presented due to being regression analyses. The other three models were based on intensity calculations and did thus not obtain a score with respect to the correlation and RMSE evaluation criteria. Furthermore, it can be observed that a large portion of the score attributed to Model 3 is due to the conservative nature of the model. Model 3 obtained the largest overall score and is therefore recommended as the final 12L modelling option according to the methodology for this case study.

4.3. Case study 2: Blast furnace (Iron and steel industry)

4.3.1 Site description

The second case study was focussed on the iron and steel industry, specifically the blast furnace of a steel plant. In this case study alternative 12L modelling options are generated and evaluated in order to determine the energy efficiency savings due to the relining of the blast furnace. The purpose of the blast furnace is to produce liquid iron. Various energy sources and raw materials are consumed during this process. Figure 4-6 presents a basic layout of the blast furnace operations.

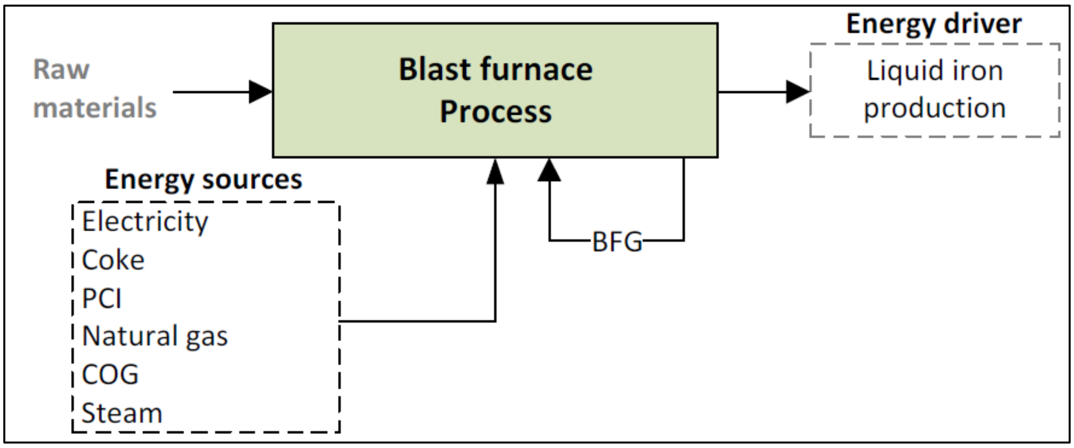

Figure 4-6: Basic layout of blast furnace

From Figure 4-6, it can be seen that there are multiple sources which contribute to the energy consumption of the blast furnace. These sources include coke, pulverised coal injection (PCI), steam, natural gas, coke oven gas (COG) and electricity. Blast furnace gas (BFG) is a by-product gas which is flared or re-used as a fuel gas in the process.

4.3.2 Generation of modelling options

In this section various modelling options will be generated to quantify the energy savings due to the relining of the blast furnace. The measurement boundary for each modelling option remained the blast furnace section of the plant in order to encapsulate the effect of the relining. The relevant energy streams and measurements relating to the blast furnace are depicted in Figure 4-7. A checklist of the available information on the system is provided in *Appendix C*.

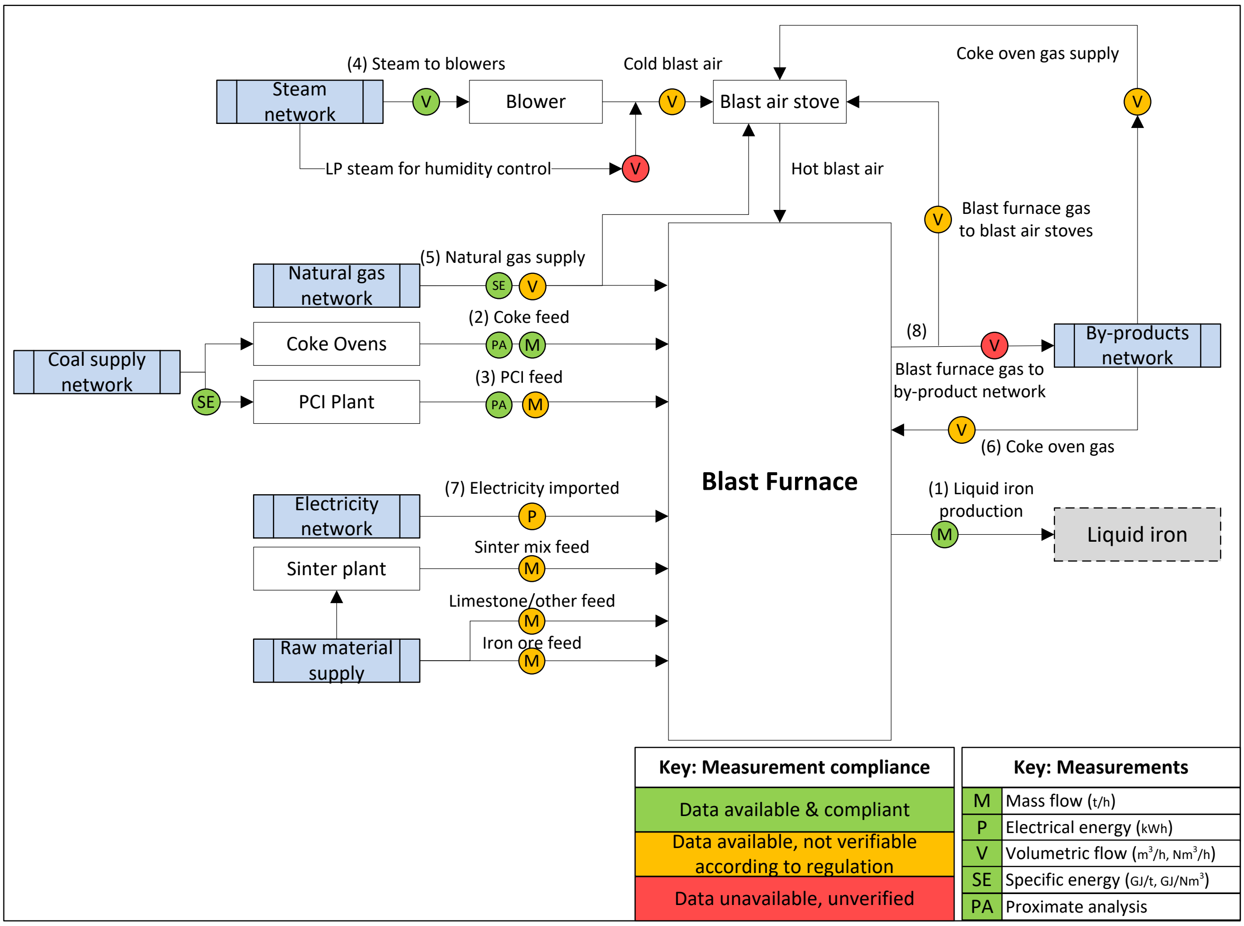

Figure 4-7: Overview of blast furnace measurement points

From Figure 4-7, it can be seen that only the steam consumption, coke supply and liquid iron production measurements are 12L compliant. The other measurements were however still considered during model development. The methodologies provided in Chapter 2 were used to select the blast furnace measurement boundary, evaluate the available datasets and ultimately develop a 12L model to quantify the EE savings.

During the relining of the blast furnace, no production took place for a period of seven months (May 2014 to November 2014). December 2014 was part of the start-up procedure, and therefore the useable data from 2014 was restricted to January to April 2014. Therefore, two baseline periods were considered during model development. The two baseline periods as well as the assessment period are depicted in Figure 4-8.

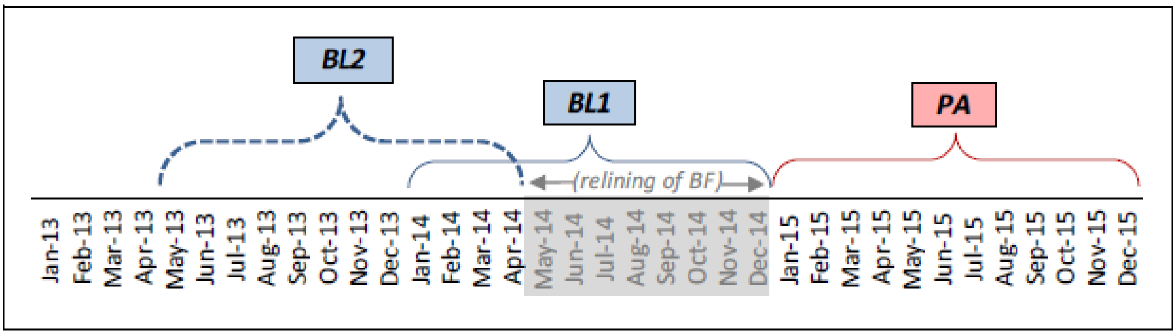

Figure 4-8: Blast furnace baseline selection

The first baseline (BL1) considers the 12 months prior to the assessment period, with the unusable months eliminated. BL1 thus only consists of four months. The second baseline (BL2) considers the 12 months prior to the relining.

The modelling options resulting from the various model development methodologies provided in Chapter 2 are summarised in Table 4-7. The main differences between the models are indicated according to the selected measurement boundary, data used and calculation method. Only high level results are provided regarding these models, which is sufficient information in order to test the applicability of the methodology. More detail regarding the calculations and model development is, however, available on request but is not shown in this report due to confidentiality.

Table 4-7: Description of alternative modelling options (case study 2)

Model	Boundary	Data	Calculation method
Model 1	Total blast furnace	BL1	Intensity
Model 2	Total blast furnace	BL1	Regression
Model 3	Total blast furnace	BL2	Regression

All three models consider the blast furnace as measurement boundary. Model 1 and Model 2 considers the 4 months prior to the relining as baseline (BL1), while Model 3 considers the 12 months prior to relining (BL2). Furthermore, Model 1 is based on an intensity calculation, while Model 2 and Model 3 are based on regression analyses.

4.3.3 Evaluation of modelling options

Each of the three developed models were evaluated in this section in accordance to the seven evaluation criteria identified in Chapter 3. The performance of each model according to each criterion is given in Table 4-8.

Table 4-8: Performance matrix (case study 2)

	C_1	C_2	C_3	C_4	C_5	C_6	C_7
	%	*GWh*	-	%	%	*GWh*	%
Model 1	42.86	348.41	-	-	5.00	38.99	100.00
Model 2	42.86	345.67	0.99	0.75	4.96	36.26	100.00
Model 3	42.86	234.17	0.96	1.74	3.19	75.25	100.00

All the models considered the blast furnace section as the measurement boundary and considered all of the energy streams associated with the boundary (C_7). Since only the steam, coke and liquid iron production measurements are 12L compliant, all of the models have the same level of compliance (C_1). The quantified savings vary from 234.17 GWh to 348.41 GWh (C_2). Model 3 is the most conservative model and has the largest variance in savings (C_6).

Model 1 is an intensity based calculation while Model 2 and Model 3 are regression analyses, therefore only these two models may be assessed according to correlation and root mean squared error (C_3 and C_4). The significance of the savings quantified from the three models were in the same range and varied between 3.19% and 5.00% (C_5).

Next, the performance scores were normalised to obtain comparable scores between 0 and 1 for each model according to each criterion. Thereafter, the weights of each criterion were taken into consideration and the weighted scores of each model were calculated. The weighted scores of the three models with respect to each criterion are presented in Table 4-9.

Table 4-9: Weighted scoring matrix (case study 2)

	C_1	C_2	C_3	C_4	C_5	C_6	C_7
Model 1	0.09	0.00	0.00	0.00	0.13	0.05	0.10
Model 2	0.09	0.00	0.18	0.11	0.13	0.05	0.10
Model 3	0.09	0.17	0.17	0.10	0.08	0.00	0.10

4.3.4 Ranking and recommendation of preferred model

In this section the overall score of each of the three modelling options were calculated. Figure 4-9 presents the final scores of the three models and the contribution of each criterion thereto. Each model is ranked according to their overall scores and numbered from 1 to 3.

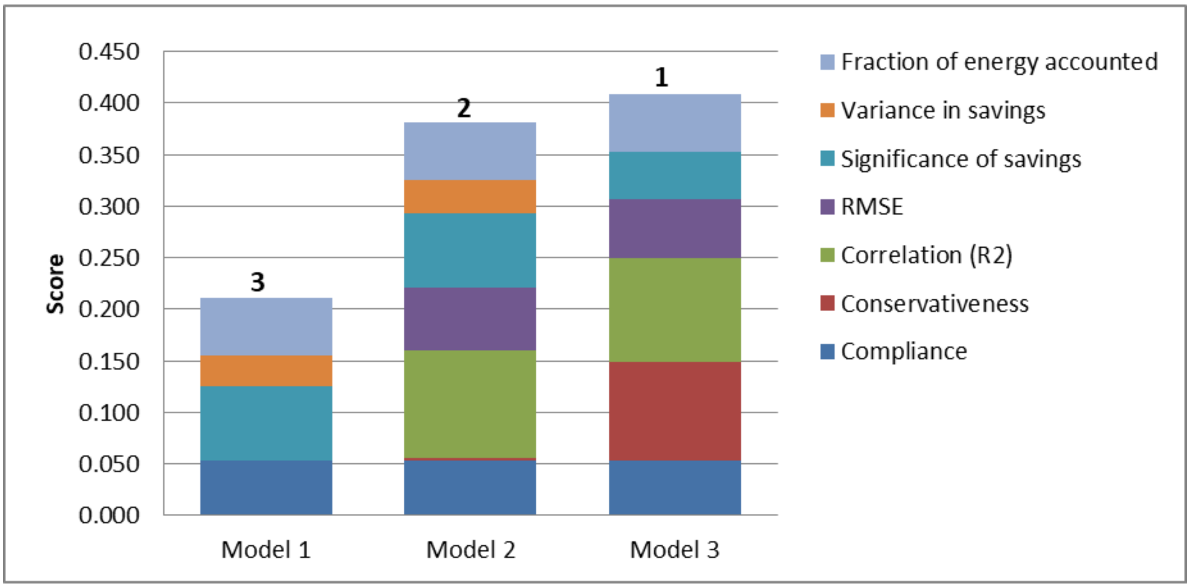

Figure 4-9: Summary of results (case study 2)

Figure 4-9 shows that Model 1 obtained the lowest ranking and score. This may be attributed to the fact that Model 1 did not obtain any score for RMSE and model correlation, since Model 1 is based on the unadjusted raw reduction of the compressors energy consumption.

Furthermore, Figure 4-9 shows that Model 1 did not obtain a score for variance in savings. This is due to the fact that Model 3 is the most conservative model, and thus varies the most from the average calculated savings. However, since Model 3 is the most conservative model a large portion of this model's overall score may be attributed to its conservativeness. Model 3 resulted in the highest overall score and is recommended as the preferred option to model the EE savings of the blast furnace.

4.4. Case study 3: Compressed air network (Mining industry)

4.4.1 Site description

The third case study focusses on the different modelling options available on the compressed air network of a gold mine. During the performance assessment the compressor control philosophy was optimised to increase the energy efficiency of the compressed air network. This ensured that the compressed air supply could be reduced during non-peak drilling periods. A basic layout of the mine's compressed air network is depicted in Figure 4-10.

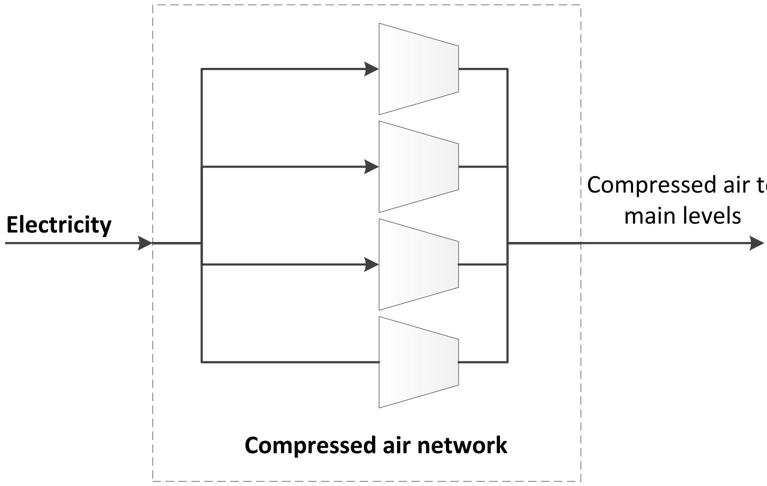

Figure 4-10: Basic layout of compressed air network

The mine is equipped with four large compressors with a total rated capacity of 17.5 MW. The compressors are used to supply air to the relevant sections at the mine. These sections include driving pneumatics such as actuators, loaders and drills.

4.4.2 Generation of modelling options

In this section various modelling options were developed to quantify the energy savings due to the optimised compressor control philosophy. In order to encapsulate the effect of the energy saving measure, the measurement boundary considered is the compressed air network. A checklist containing all of the available information of the system is included in *Appendix C*. The relevant energy streams and measurements relating to compressed air network are depicted in Figure 4-11.

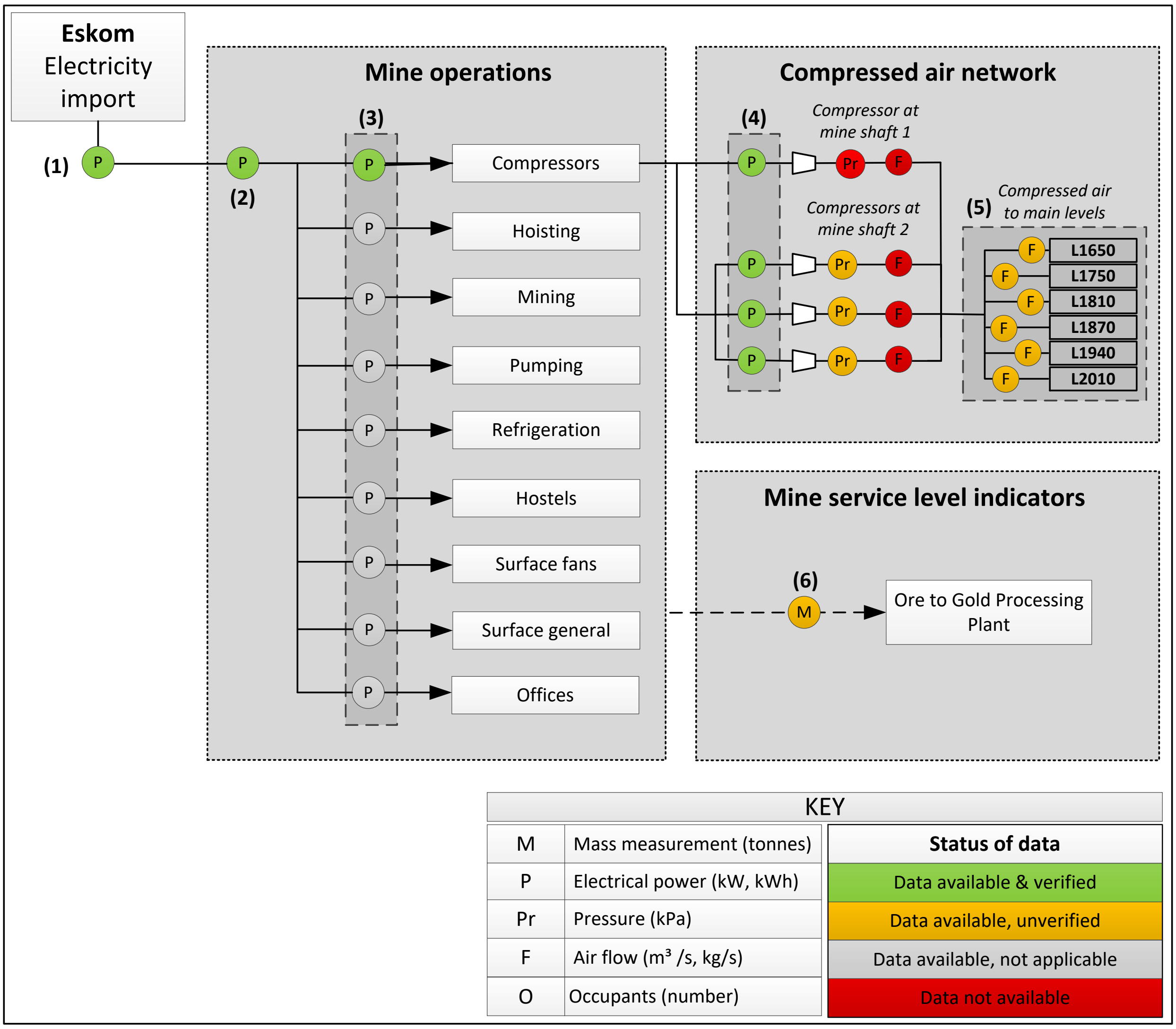

Figure 4-11: Overview of compressed air network measurement points

The energy input consisted of the electricity supplied by the national grid. The electricity is reticulated to the various operations of the mine. Multiple measurement points are available for the electricity consumption of the mine. Firstly, 12L compliant invoices were available for the total electricity supply (1). Mine incomer check metering (2) was also available. Individual sub-system check metering for each operation of the mine is indicated by measurement point (3) on Figure 4-12. Furthermore, the electricity consumption of each compressor was also available (4). The data from the abovementioned measurement points are from calibrated meters and are therefore deemed 12L compliant.

The purpose of the compressors is to provide compressed air to consumers within the mine. The mass flow of the compressed air supplied to the main production levels of the mine are measured and indicated by point (5). Furthermore, the ore mined is hoisted to the surface and then transported to the gold processing plant. Multiple measurement points are available for the mined ore. However, the actual tonnes milled at the processing plant are the main production indicator (6).

The abovementioned information was used to model the compressed air network of the mine. The purpose of the model is to quantify the EE savings as a result from the optimised compressor control philosophy. This can however be done in different ways. The model development strategies provided in Chapter 2 were used to obtain various modelling options. This resulted in three different modelling options being identified. Table 4-10 summarises the main variations between the three modelling options.

Only high level results are provided regarding these models, which is sufficient information in order to test the applicability of the methodology. More detail regarding the calculations and model development is, however, available on request but is not shown in this report due to confidentiality.

Table 4-10: Description of alternative modelling options (case study 3)

Model	Boundary	Data	Calculation method
Model 1	Compressed air network	Electricity consumption	Unadjusted energy reduction
Model 2	Compressed air network	Electricity consumption and peak period compressed air flow as energy driver	Regression
Model 3	Compressed air network	Electricity consumption and mine production as energy driver	Regression

The first model is based on the year-on-year reduction in energy usage of the compressors. This model presents an EE saving of 6.8 GWh. Model 2 was based on a regression analyses and considered the peak drilling period compressed air flow as energy driver. The EE savings resulting from Model 2 is 6.84 GWh. Model 3 was based on a regression fit between mine occupancy and compressor energy consumption. This model quantified an EE saving of 6.17 GWh.

4.4.3 Evaluation of modelling options

In this section the three models were evaluated according to the evaluation criteria identified in Chapter 3. Table 4-11 presents the performance of each of the three models with respect to each criterion.

Table 4-11: Performance matrix (case study 3)

	C_1	C_2	C_3	C_4	C_5	C_6	C_7
	%	*GWh*	-	*%*	*%*	*GWh*	*%*
Model 1	100.00	6.80	-	-	11.61	0.20	100.00
Model 2	50.00	6.84	0.81	5.29	11.67	0.23	100.00
Model 3	50.00	6.17	0.42	6.70	10.52	0.44	100.00

Model 1 only considered the electricity consumption of the compressors, which are deemed as 12L compliant measurements. Therefore Model 1 is based on compliant measurements (C_1), while Model 2 and Model 3 considers energy drivers such as compressed air flow and mine production, which are not based on compliant measurements. The EE savings resulting from the three modelling options vary between 6.17 GWh and 6.84 GWh, with Model 3 presenting the most conservative savings (C_2).

Model 2 and Model 3 was based on regression analyses while Model 1 was based on the raw reduction in energy consumption. Therefore; only Model 2 and Model 3 could be evaluated with respect to model correlation and RMSE (C_3 and C_4). The correlation between compressor energy consumption and compressed air flow (Model 2) was 0.81. The correlation between the compressor energy consumption and mine production (Model 3) was, however, observed to be significantly lower (0.42).

The significance of the quantified savings (C_5) of the three models is in the same range and varied from 10.52% (Model 3) to 11.67% (Model 2). Although the quantified EE savings from the three models were within the same range, Model 3 is the most conservative and varied the most from the average of the quantified savings (C_6). Furthermore, the only energy source of the compressors was the electricity consumption. All of the models account for the electricity consumption of the compressors and therefore account for all of the energy with respect to the measurement boundary (C_7).

The performance scores were normalised to values between 0 and 1 by making use of the relative strength of preference scale presented in Chapter 3. Thereafter the criteria weights were taken into consideration and the weighted scores of each model with respect to each criterion was determined. The weighted scores are presented in Table 4-12.

Table 4-12: Weighted scoring matrix (case study 3)

	C_1	C_2	C_3	C_4	C_5	C_6	C_7
Model 1	0.21	0.01	0.00	0.00	0.13	0.06	0.10
Model 2	0.11	0.00	0.15	0.07	0.13	0.05	0.10
Model 3	0.11	0.17	0.08	0.06	0.11	0.00	0.10

4.4.4 Ranking and recommendation of preferred model

After evaluating the different models, the overall score of each model was determined and used to rank the models. Figure 4-12 summarises the overall scores of the three different options used to model and quantify the EE savings of the compressed air network. The results were ranked and numbered from 1 to 3. Figure 4-12 also presents the contribution of each criterion to the overall score of each model.

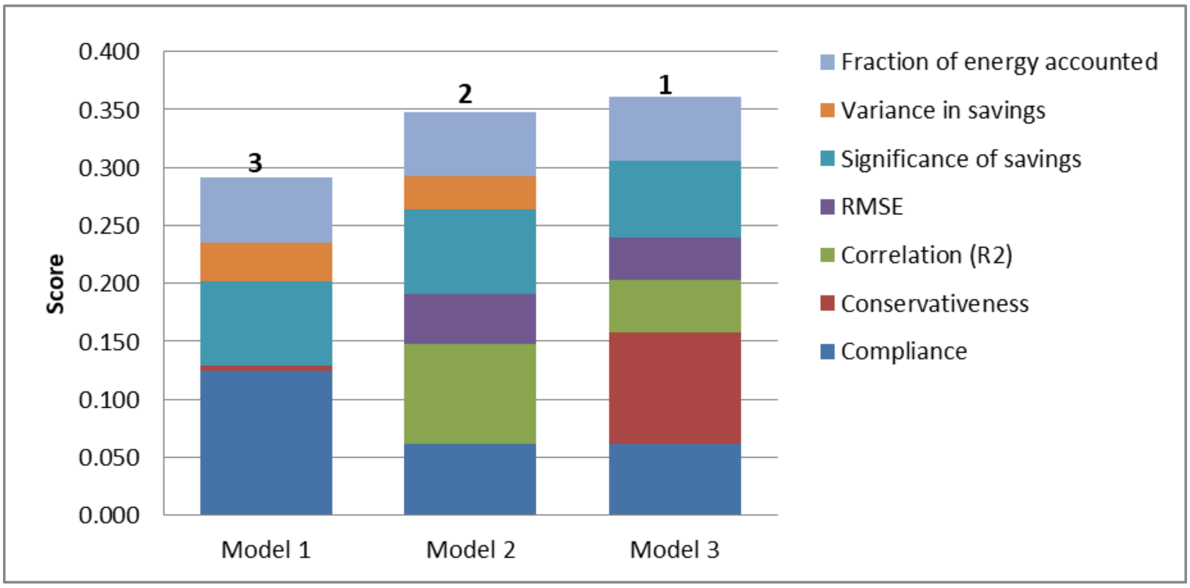

Figure 4-12: Summary of results (case study 3)

From Figure 4-12 it can be seen that Model 3 was ranked in first place, while Model 2 and Model 1 were ranked in second and third place respectively. Although Model 1 was 12L compliant and obtained the largest score with respect to compliance, Model 1 was still outranked by the other two models.

Model 2 obtained a significant score with respect to model correlation in comparison with Model 3; however Model 3 obtained a higher overall score. A significant portion of the overall score of Model 3 may be attributed to the fact that Model 3 is the most conservative model.

Model 3 obtained the highest overall score and is thus ranked in first place. Therefore, Model 3 is recommended as the final 12L model for this case study.

4.5. Validation of results

Independent comparison of results

In this section the results obtained from applying the methodology to actual case studies were validated. This was done by comparing the model recommended by the methodology to the model chosen by an independent SANAS accredited M&V team for each of the case studies from the previous sections.

The model selection process by the independent M&V team was done based on the conservative nature of the selected model as well as model statistics. Table 4-13 shows the comparison between the methodology and independent M&V final model for each case study.

Table 4-13: Comparison of methodology results with independent M&V chosen model

Case study	Methodology	Independent SANAS accredited M&V team
Case study 1	Model 3	Model 3
Case study 2	Model 3	Model 3
Case study 3	Model 3	Model 3

From Table 4-13 it can be seen that the model recommended by the methodology and the independent M&V team were the same for all three case studies, and were therefore validated. Moreover, the three models selected were comparable to real world applications.

Variance in quantified EE savings

In case study one, five modelling options were generated, while case studies two and three both had three modelling options. The final model had to be chosen between the multiple available modelling options. Without a clear and transparent method to aid in the selection process of a final model, any one of the possible options could have been selected as the final model. Each modelling option however quantified different EE savings. This becomes critical when considering that the EE savings have a direct impact on the monetary value associated with 12L.

Table 4-14 shows the most and least conservative EE savings of the various modelling options considered for each case study. Given that 12L allows 95c/kWh the monetary value associated with 12L for each modelling option could be quantified. The difference in the 12L certificate value from selecting either the most or least conservative modelling option is provided in the last column of Table 4-14.

Table 4-14: Difference in 12L certificate value of most and least conservative modelling option

Case study	Quantified EE savings (GWh)		12L Certificate value (R millions)			
	Most conservative	Least conservative	Most conservative	Least conservative	Difference	
Case study 1	251.40	341.19	238.83	324.13	85.30	26%
Case study 2	234.17	348.41	222.46	330.99	108.53	33%
Case study 3	6.17	6.84	5.86	6.50	0.64	10%

Table 4-14 shows that the difference in the 12L certificate value could range significantly (between 10% and 33%) if either the most or least conservative model was selected as the final model for the case studies provided in this study. The results given in Table 4-14 therefore validated the problem statement given in Chapter 1; there is a need to prove that the most appropriate model was selected objectively between multiple modelling options.

4.6. Conclusion

In this section the methodology developed in Chapter 3 was applied to actual case studies. Three case studies were considered and varied according to industry. The first case study focused on the steam stations of a petrochemical plant, while case study two considered a blast furnace in the iron and steel industry. The third case study was focussed on the mining industry, specifically the compressed air network of a gold mine.

By applying the methodology multiple modelling options were generated for each case study. Thereafter, each of the modelling options were evaluated and a final model was recommended. The results obtained were validated by comparing them to that of an independent SANAS accredited M&V team. The results of this study agreed with that of the independent M&V team. This validated that the results of the methodology were comparable with that of real world applications.

A financial comparison of the final results show the monetary value of the 12L tax incentive can be influenced between 10% and 33%. Ultimately, this validated the need for an objective model selection methodology.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1. Preamble

This study was conducted to assist the 12L application process to prove that the most appropriate 12L energy efficiency model was chosen between multiple modelling options. The need for this study and the objectives were highlighted in Chapter 1. Chapter 2 reviewed the relevant literature of what has been done within this field of study. In Chapter 3 the knowledge obtained from the literature study was used to devise the methodology. In Chapter 4 the methodology was applied to actual case studies and the results were discussed.

In this chapter the document will be concluded. Section 5.2 will provide an overview of the study and demonstrate how the required objectives were met, while recommendations for further studies will be proposed in Section 5.3.

5.2. Overview of study

This study showed that multiple modelling options are usually available when developing a baseline model in order to quantify the energy efficiency (EE) savings associated with an energy saving measure for 12L applications. Furthermore, it was highlighted that there is a need to prove that the most appropriate EE model was selected between the multiple available options (Chapter 1).

The selection of the final model has to be compliant with all of the requirements of 12L to protect all stakeholders involved. Therefore, the basic literature was provided to understand the legal and technical requirements of 12L (Chapter 2). Literature regarding decision support methods when more than one possible solution is available was also provided.

In Chapter 3, the relevant literature was used to develop a methodology which aided in the evaluation process of multiple modelling options and the selection of a final EE model. The methodology was devised based on the literature provided in Chapter 2.

The methodology consists of three phases. Firstly, multiple modelling options are generated. Secondly, each modelling option is evaluated according to the specific criteria from the literature. Weights are assigned to the criteria which represent the relative importance of each individual criterion. This step is however flexible; since the relevant stakeholders or decision makers involved may adjust the selected evaluation criteria and assign other criteria weights as desired. Thirdly, the models are ranked according to their evaluation and a final model is recommended.

It is also critical to explain how decisions were made to relevant stakeholders involved. Thus the methodology was developed to ensure a transparent and traceable method of evaluating 12L EE models and selecting a final modelling option.

In Chapter 4, the methodology was verified by applying it to three actual case studies. These case studies varied according to industry; namely, the chemical and petrochemical industry, iron and steel industry, and mining industry. The results obtained were further validated by comparing them to independent, SANAS accredited measurement and verification (M&V) results.

Meeting the required objectives

The main objective of this study was to develop a methodology to evaluate and select a final model for 12L applications when more than one modelling option is available. The methodology must assist the 12L application process by:

- providing relevant research regarding the requirements of 12L applications,
- providing research regarding decision support methods when more than one solution is available,
- identifying the criteria that 12L models need to adhere to,
- devising a methodology which aids in the evaluation process of multiple modelling options and the selection of a final model, and
- verifying the methodology by applying it to actual case studies.

The remaining part of this section will demonstrate that all of the objectives, as stated in Section 1.4, were achieved.

Research regarding 12L requirements

The basic research needed to understand the requirements of 12L was provided in the literature study (Chapter 2). This was done by providing an overview of the 12L Regulations and Standard in order to identify the legal requirements of 12L (Section 2.2). Thereafter, industrial M&V was also reviewed to describe the technical scope related to 12L (Section 2.3).

Research regarding decision support methods

Section 2.4 provided the basic research regarding decision support methods. Methods were provided in order to select a solution among multiple options while considering that the selected solution should adhere to multiple conflicting criteria.

Identifying criteria that 12L models need to adhere to

The literature provided in Section 2.2 and Section 2.3 was critically evaluated to identify the criteria that 12L models need to adhere to. Seven criteria were identified and used in this study. These criteria consist of both legal and technical requirements of 12L applications and are listed in Chapter 3.

Devising a methodology to evaluate and select a final model

In Chapter 3, a methodology was developed which aids in the evaluation process of multiple modelling options and the selection of a final model for 12L applications. The methodology was developed based on the relevant literature provided in Chapter 2. The methodology consists of three phases, namely, generating modelling options, evaluating the modelling options and lastly ranking each modelling options and recommending a preferred model.

Verification of methodology with actual case studies

In Chapter 4, the methodology was applied to actual case studies. Three case studies were discussed in detail. These case studies varied according to industry, namely, the chemical and petrochemical industry, the iron and steel industry, and the mining industry. Multiple modelling options were generated for each case study; where after each modelling option was evaluated. The evaluation results were then used to rank the modelling options and recommend a final model. The results were also validated by comparing them to independent, SANAS accredited M&V results.

5.3. Recommendations

In this section recommendations will be made for further studies. Implementation of these recommendations could further improve the results of this study. Three recommendations are listed below and discussed in more detail thereafter.

- Additional case studies,
- more sophisticated decision aid method, and
- more complex evaluation criteria.

Additional case studies

Three case studies were investigated in this study and were found sufficient to test the applicability of the developed methodology. It would be beneficial to evaluate additional case studies. Case studies of varying complexity also need to be investigated in order to further evaluate the applicability of the study.

More sophisticated decision aid method

The decision aid method used in this study to evaluate the various modelling options and select a final model is the weighted sum method (WSM). The WSM was chosen due to its simplicity and transparency. These factors are important since M&V results generally need to be presented to multiple stakeholders involved that don't necessarily have expertise to understand the more complex methods.

A more sophisticated and complex decision aid method may however be implemented to evaluate whether more accurate results are obtained and to counter the weaknesses associated with the WSM. A critical weakness of the WSM is to rank alternatives in a way that is heavily conditioned by a criterion if considerably different values are present, e.g. null values. This weakness was highlighted in this study when considering that intensity calculations could not be evaluated according to coefficient of determination and root mean square error (C_3 and C_4). More complex decision aid methods can be considered in order to unbiasedly evaluate different calculation methods, e.g. intensity and regression models.

More complex evaluation criteria

In this study seven criteria were used to evaluate the multiple modelling options available. These criteria consisted of both legal and technical requirements associated with 12L. More complex criteria may, however, also be evaluated in future studies. This can be done within the existing developed framework which is generic enough to include additional criteria without changing the core methodology.

Additional evaluation criteria might include incorporating factors that evaluate different mathematical methods used when modelling since the main focus of this study was on regression analyses. It could also be beneficial to include a criterion which evaluates how a model addresses any uncertainties associated with the model. This could be beneficial since any uncertainties associated with a model decrease the confidence in the quantified energy efficiency savings.

5.4. Closure

In this study a methodology was devised which assists the 12L application process to objectively prove that the most appropriate 12L energy efficiency (EE) model was chosen between multiple modelling options. This was done by firstly defining the problem statement. Thereafter the relevant literature was reviewed. The knowledge obtained from literature was then used to develop the methodology. The methodology was verified by applying it to actual case studies. The results obtained were validated by comparing them to independent, SANAS accredited M&V results.

This chapter concluded the document by providing an overview of this study. Furthermore, it was stated how the objectives of the study were met and recommendations were also provided for further studies.

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Appendix A: 12L Regulations

This appendix presents the Regulations in terms of section 12L of the Income Tax Act (1962) as published on 9 December 2013 [6]. Furthermore, the Regulations presented in this appendix, considers the amendments to the Regulations as published on 6 March 2015 which came into operation on 1 April 2015 [66].

SCHEDULE

PREAMBLE

SINCE it has become necessary to promote the efficiency utilisation of energy to safeguard the continued supply of energy and to combat the adverse effects of greenhouse gas emissions related to fossil fuel based energy use on climate change;

AND SINCE energy efficiency saving may be considered as a potentially successful method to guarantee the efficiency utilisation of energy;

AND SINCE the intended purpose of a carbon tax is to mitigate greenhouse gas emissions and also to utilise (recycle) some of the revenue to be generated from such a tax to finance incentives to advance the further efficient utilisation of energy;

THEREFORE a tax incentive as contained in section 12L of the Income Tax Act 1962 and these Regulations is devised to encourage the efficient utilisation of energy.

BE IT THEREFORE ENACTED by Regulation as follows:-

Definitions

1. In these Regulations, any word or expression to which a meaning has been assigned in the National Energy Act, or the Income Tax Act bears the meaning so assigned, and-

"accreditation number" means an accreditation number contained in a certificate of accreditation issued by the South African National Accreditation System under section 22(2)(b) of the Accreditation for Conformity Assessment, Calibration and Good Laboratory Practice Act, 2006 (Act No. 19 of 2006), to a measurement and verification of energy efficiency savings;

"allowance" means the amount allowed to be deducted in respect of energy efficiency savings as contemplated in section 12L of the Income Tax Act;

"baseline" means baseline as defined in the standard;

"captive power plant" means where generation of energy takes place for the purpose of the use of that energy solely by the person generating that energy;

"certificate" means an energy efficiency savings certificate contemplated in section 12L(3) of the Income Tax Act that is issued by SANEDI, comprising the content set out in regulation 4;

"certificate number" means a unique traceable number allocated to a certificate by SANEDI;

"energy efficiency" means energy efficiency as defined in the standard;

"energy efficiency savings" means the difference between the actual amount of energy used in the carrying out of any activity or trade, in a specific period and the amount of energy that would have been used in the carrying out of the same activity or trade during the same period under the same conditions if the energy savings measure was not implemented;

"Income Tax Act" means the Income Tax Act, 1962 (Act No. 58 of 1962);

"measurement and verification body" means a body that is accredited by the South African National Accreditation System in terms of section 22 of the Accreditation for Conformity Assessment, Calibration and Good Laboratory Practice Act, 2006 (Act No. 19 of 2006), for the purposes of inspection, measurement, reporting and verification of energy efficiency savings;

"measurement and verification professional" means a natural person who performs measurement and verification of energy efficiency savings under the auspices of a measurement and verification body;

"National Energy Act" means the National Energy Act, 2008 (Act No. 34 of 2008);

"report" means a measurement and verification report that –

a) contains a computation of energy efficiency savings in respect of a person for a year of assessment; and
b) is compiled by a measurement and verification professional in accordance with the criteria and methodology contained in the standard;

"reporting period energy use" means reporting period energy use as defined in the standard;

"SANEDI" means the South African National Energy Development Institute established in terms of section 7 of the National Energy Act; and

"standard" means the South African National Standard 50010 (SANS 50010, Measurement and Verification of Energy Savings), issued by the South African Bureau of Standards in terms of the Standards Act, 2008 (Act No. 8 of 2008).

Procedure for claiming the allowance

1. A person that claims the allowance must, in respect of each year of assessment for which the allowance is claimed –

a) register with SANEDI in the form and manner and at the place that SANEDI may determine;

b) appoint a measurement and verification professional to compile a report containing a computation of the energy efficiency savings in respect of that person for that year of assessment;

c) submit the report to SANEDI; and

d) obtain a certificate from SANEDI.

Responsibilities of SANEDI

2. (1) SANEDI must appoint suitably qualified persons to consider reports submitted by a person claiming the allowance.

(2) if after consideration of a report SANEDI is satisfied that the information contained in a report –

a) complies with the standard;

b) is an accurate reflection of the energy efficiency savings of the person claiming the allowance in respect of the year of assessment for which the allowance is claimed; and

c) complies with these Regulations,

SANEDI must issue a certificate containing the information set out in regulation 4 to the person claiming the allowance.

(3) SANEDI may investigate or cause to be investigated any energy efficiency savings of a person contained in a report to be satisfied that the information contained in the report is an accurate reflection of the energy efficiency savings of the person submitting the report.

(4) SANEDI must –

a) keep and maintain all reports submitted for consideration;
b) create and maintain a database of all certificates issued by SANEDI in accordance with these Regulations; and
c) at all times provide the Minister of Finance and the Commissioner for the South African Revenue Service with ready access to –
    i. the reports contemplated in paragraph a); and
    ii. the database contemplated in paragraph b).

Content of certificate

1. The certificate issued by SANEDI as contemplated in regulation 3(2) must contain –

a) the baseline at the beginning of the year of assessment for which the allowance is claimed, derived and adjusted in accordance with regulation 5 and determined in accordance with the standard;
b) the reporting period energy use at the end of the year of assessment for which the allowance is claimed, determined in accordance with the standard;
c) (i) the annual energy efficiency savings expressed in kilowatt hours or the equivalent of kilowatt hours for the year of assessment for which the allowance is claimed, determined in accordance with the standard; and

   (ii) in case of a captive power plant, the difference between the kilowatt hours equivalent of energy input and the kilowatt hours equivalent of energy output during the year of assessment in accordance with the standard;
d) the initials and surname of the measurement and verification professional who compiled the report;
e) the name and accreditation number of the measurement and verification body under whose auspices the measurement and verification professional compiled the report;
f) the name and tax registration number of the person to whom the certificate is issued;
g) the date on which the certificate is issued; and
h) the certificate number.

Baseline calculation

2. (1) For the purpose of this regulation "greenfield project" means a project that represents a wholly new project which does not utilise any assets other than a wholly new and unused assets.

(2) The baseline –

a) for the first year of assessment for which the allowance is claimed must –
   i. in the case of a greenfield project, be constructed from comparable data in the relevant sector; or
   ii. in any other case, be derived from data gathered during the year of assessment preceding the first year of assessment for which the allowance is claimed; and

b) must be adjusted for every year of assessment for which the allowance is claimed –
   i. in accordance with the methodology in the standard; and
   ii. by taking into account the reporting period energy use at the end of the immediately preceding year of assessment for which the allowance was claimed to compute the baseline for the beginning of the subsequent year of assessment for which the allowance is claimed.

Limitation of allowance

3. (1) For the purpose of this regulation –

"co-generation" means combined heat and power;

"combined heat and power" means the production of electricity and useful heat form a fuel or energy source which is a co-product, waste product or residual product of an underlying industrial process;

"energy conversion efficiency" means the difference between the useful heat and equivalent kilowatt hours of energy output and the equivalent kilowatt hours of input energy expressed as a percentage;

"renewable sources" means –

a) biomass;
b) geothermal;
c) hydro;
d) ocean currents;
e) solar;
f) tidal waves; or

g) wind;

(2) A person may not receive the allowance in respect of energy generated from renewable sources other than energy generated from combined heat and power.

(3) A person generating energy through a captive power plant may not receive the allowance unless the energy conversion efficiency of the plant is greater than 35 per cent.

Concurrent benefits

4. For the purpose of section 12L(4) of the Income Tax Act any credit, allowance, grant, cost recovery agreement or other similar benefit granted by or through –

a) any sphere of government;

b) any public entity that is listed in Schedule 2 or 3 to the Public Finance Management Act, 1999 (Act No. 1 of 1999); or

c) any power purchase agreement as defined in Electricity Regulations on New Generation Capacity made by the Minister of Energy under section 35 (4) of the Electricity Regulation Act, 2006 (Act No. 4 of 2006) published by Government Notice 721 of 5 August 2009 in respect of the IPP bid programme as defined in those regulations,

for any energy efficiency savings or the sale and purchase of electricity constitutes a concurrent benefit.

Short title and commencement

5. These regulations are called the Regulations in terms of section 12L of the Income Tax Act, 1962, on the allowance for energy efficiency savings and come into operation on 1 November 2013.

Appendix B: Criteria weights determination

The criteria weights used in this study were obtained by surveying ten individuals with experience in the field of measurement and verification (M&V) with pairwise comparison matrixes. This process was explained in Chapter 2 and Chapter 3 of this document. Experience and qualification details regarding the ten individuals are presented in Table B-1.

Table B-1: Details of individuals who completed the pairwise comparison matrix surveys

Individual	Qualification	Experience in M&V field (years)
1	B. Eng, M. Eng	3
2	B. Eng	2
3	B. Eng, M. Eng	4
4	B. Eng, M. Eng, PhD	5
5	B. Eng	1
6	B. Eng	1
7	B. Eng	2
8	B. Eng, M. Eng, PhD, CMVP	4
9	B. Eng, M. Eng, PhD	10
10	B. Eng, M. Eng, PhD, CMVP	10

This appendix provides the pairwise comparison matrixes used to obtain the criteria weights used in this study. Figure B-1 shows the relative strength of preference scale used to rate the relative importance of each criterion.

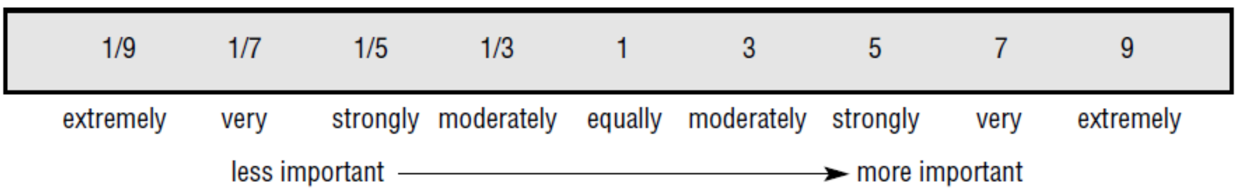

Figure B-1: Relative strength of preference scale used in this study. Adapted from [65]

Firstly, the ten pairwise comparison matrixes completed by each expert in the field will be provided. Thereafter, a summary will be provided where the final criteria weights are determined.

Pairwise comparison matrix 1

Table B-2: Completed pairwise comparison matrix 1

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	Weight
C_1	1	3	3	1/3	7	3	1	**0.230**
C_2	1/3	1	1/3	1	5	5	1/3	**0.163**
C_3	1/3	3	1	5	3	3	3	**0.230**
C_4	3	1	1/5	1	1	1/3	1	**0.094**
C_5	1/7	1/5	1/3	1	1	1/3	1	**0.050**
C_6	1/3	1/5	1/3	3	3	1	3	**0.136**
C_7	1	3	1/3	1	1	1/3	1	**0.096**

Pairwise comparison matrix 2

Table B-3: Completed pairwise comparison matrix 2

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	Weight
C_1	1	3	1/3	3	5	3	1	**0.178**
C_2	1/3	1	1/7	5	3	1	1/3	**0.117**
C_3	3	7	1	9	5	7	3	**0.380**
C_4	1/3	1/5	1/9	1	3	3	1/3	**0.087**
C_5	1/5	1/3	1/5	1/3	1	1	1/3	**0.037**
C_6	1/3	1	1/7	1/3	1	1	1/3	**0.045**
C_7	1	3	1/3	3	3	3	1	**0.156**

Pairwise comparison matrix 3

Table B-4: Completed pairwise comparison matrix 3

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	Weight
C_1	1	1/3	5	3	1/7	1/5	1/3	**0.092**
C_2	3	1	1	7	1/5	1	1/5	**0.123**
C_3	1/5	1	1	3	1/7	1/5	1/3	**0.054**
C_4	1/3	1/7	1/3	1	1/9	1/9	7	**0.083**
C_5	7	5	7	9	1	3	1	**0.302**
C_6	5	1	5	9	1/3	1	1/3	**0.119**
C_7	3	5	3	1/7	1	3	1	**0.148**

Pairwise comparison matrix 4

Table B-5: Completed pairwise comparison matrix 4

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	Weight
C_1	1	1/3	5	5	1/3	7	1/3	**0.209**
C_2	3	1	5	3	1/3	3	1	**0.179**
C_3	1/5	1/5	1	1/5	1/3	1	1/5	**0.034**
C_4	1/5	1/3	5	1	1	3	1	**0.127**
C_5	3	3	3	1	1	7	7	**0.274**
C_6	1/7	1/3	1	1/3	1/7	1	1	**0.043**
C_7	3	1	5	1	1/7	1	1	**0.133**

Pairwise comparison matrix 5

Table B-6: Completed pairwise comparison matrix 5

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	Weight
C_1	1	3	7	5	3	3	3	**0.279**
C_2	1/3	1	3	3	5	5	9	**0.294**
C_3	1/7	1/3	1	1/3	1	3	3	**0.098**
C_4	1/5	1/3	3	1	3	1/3	3	**0.121**
C_5	1/3	1/5	1	1/3	1	1	3	**0.077**
C_6	1/3	1/5	1/3	3	1	1	3	**0.099**
C_7	1/3	1/9	1/3	1/3	1/3	1/3	1	**0.031**

Pairwise comparison matrix 6

Table B-7: Completed pairwise comparison matrix 6

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	Weight
C_1	1	1	3	3	3	3	5	**0.227**
C_2	1	1	1/3	1/3	1/3	1/5	1/5	**0.041**
C_3	1/3	3	1	5	1	5	3	**0.219**
C_4	1/3	3	1/5	1	1/3	1/3	1/3	**0.066**
C_5	1/3	3	1	3	1	1/3	1/3	**0.108**
C_6	1/3	5	1/5	3	3	1	3	**0.186**
C_7	1/5	5	1/3	3	3	1/3	1	**0.154**

Pairwise comparison matrix 7

Table B-8: Completed pairwise comparison matrix 7

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	Weight
C_1	1	1	3	3	5	5	3	0.219
C_2	1	1	3	3	5	5	3	0.219
C_3	1/3	1/3	1	1	9	7	1	0.205
C_4	1/3	1/3	1	1	3	7	5	0.185
C_5	1/5	1/5	1/9	1/3	1	3	3	0.082
C_6	1/5	1/5	1/7	1/7	1/3	1	3	0.052
C_7	1/3	1/3	1	1/5	1/3	1/3	1	0.037

Pairwise comparison matrix 8

Table B-9: Completed pairwise comparison matrix 8

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	Weight
C_1	1	3	3	7	3	3	7	0.259
C_2	1/3	1	1/3	3	3	5	7	0.189
C_3	1/3	3	1	5	5	7	7	0.272
C_4	1/7	1/3	1/5	1	1/5	1/3	1/3	0.024
C_5	1/3	1/3	1/5	5	1	3	5	0.143
C_6	1/3	1/5	1/7	3	1/3	1	1	0.058
C_7	1/7	1/7	1/7	3	1/5	1	1	0.054

Pairwise comparison matrix 9

Table B-10: Completed pairwise comparison matrix 9

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	Weight
C_1	1	1/3	3	3	3	5	5	0.273
C_2	3	1	3	3	1	1	3	0.201
C_3	1/3	1/3	1	1	1/3	1/3	1/3	0.049
C_4	1/3	1/3	1	1	1/5	1/3	1/3	0.047
C_5	1/3	1	3	5	1	1	1	0.165
C_6	1/5	1	3	3	1	1	1	0.137
C_7	1/5	1/3	3	3	1	1	1	0.128

Pairwise comparison matrix 10

Table B-11: Completed pairwise comparison matrix 10

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	Weight
C_1	1	3	1/5	1/5	7	3	5	**0.165**
C_2	1/3	1	1/7	1/7	3	3	7	**0.124**
C_3	5	7	1	1	9	1	9	**0.281**
C_4	5	7	1	1	9	1	9	**0.281**
C_5	1/7	1/3	1/9	1/9	1	1/5	1	**0.025**
C_6	1/3	1/3	1	1	5	1	3	**0.099**
C_7	1/5	1/7	1/9	1/9	1	1/3	1	**0.025**

Final criteria weights

Table B-12: Summary of final criteria weights

	1	2	3	4	5	6	7	8	9	10	Average
C_1	0.230	0.178	0.092	0.209	0.279	0.227	0.219	0.259	0.273	0.165	**0.213**
C_2	0.163	0.117	0.123	0.179	0.294	0.041	0.219	0.189	0.201	0.124	**0.165**
C_3	0.230	0.380	0.054	0.034	0.098	0.219	0.205	0.272	0.049	0.281	**0.182**
C_4	0.094	0.087	0.083	0.127	0.121	0.066	0.185	0.024	0.047	0.281	**0.112**
C_5	0.050	0.037	0.302	0.274	0.077	0.108	0.082	0.143	0.165	0.025	**0.126**
C_6	0.136	0.045	0.199	0.043	0.099	0.186	0.052	0.058	0.137	0.099	**0.105**
C_7	0.096	0.156	0.148	0.133	0.031	0.154	0.037	0.054	0.128	0.025	**0.096**

Appendix C: Checklist of available information

This appendix provides the checklists' which identifies the available information for case studies 2 and 3, respectively.

Case study 2

Table C-1: Available information (case study 2)

<table>
<tr><th colspan="5">AVAILABLE INFORMATION CHECKLIST</th></tr>
<tr><th colspan="5">Energy saving measure description:</th></tr>
<tr><td colspan="5">Relining of blast furnace</td></tr>
<tr><th colspan="5">Concurrent benefits/limitations:</th></tr>
<tr><td colspan="5">None within measurement boundary</td></tr>
<tr><th colspan="2" rowspan="2">Measurables</th><th>Daily</th><th>Monthly</th><th rowspan="2">Compliance</th></tr>
<tr><td colspan="2">Total blast furnace</td></tr>
<tr><td>Liquid iron</td><td>Mass flow</td><td>✓</td><td>✓</td><td>Calibration</td></tr>
<tr><td>Coal supply</td><td>Specific energy (CV)</td><td>✓</td><td></td><td>Lab analysis certificate</td></tr>
<tr><td rowspan="3">Coke</td><td>Mass flow</td><td>✓</td><td></td><td>Calibration</td></tr>
<tr><td>Proximate analysis</td><td>✓</td><td></td><td>Standard operating procedure documentation</td></tr>
<tr><td>Specific energy (CV)</td><td>Constant value</td><td></td><td>Lab analysis certificate</td></tr>
<tr><td rowspan="2">Pulverised coal injection (PCI)</td><td>Mass flow</td><td>✓</td><td></td><td>None</td></tr>
<tr><td>Proximate analysis</td><td>✓</td><td></td><td>Standard operating procedure documentation</td></tr>
<tr><td rowspan="4">Steam</td><td colspan="4">Steam to blowers</td></tr>
<tr><td>Volumetric flow</td><td>✓</td><td></td><td>Calibration</td></tr>
<tr><td colspan="4">Cold blast air</td></tr>
<tr><td>Volumetric flow</td><td>✓</td><td></td><td>None</td></tr>
<tr><td rowspan="2">Natural gas</td><td>Volumetric flow</td><td>✓</td><td></td><td>None</td></tr>
<tr><td>Specific energy (HV)</td><td></td><td>✓</td><td>Invoices</td></tr>
<tr><td rowspan="4">Coke oven gas</td><td colspan="4">To blast air stove</td></tr>
<tr><td>Volumetric flow</td><td>✓</td><td></td><td>None</td></tr>
<tr><td colspan="4">To blast furnace</td></tr>
<tr><td>Volumetric flow</td><td>✓</td><td></td><td>None</td></tr>
<tr><td>Electricity</td><td>Electrical energy</td><td></td><td>✓</td><td>None</td></tr>
</table>

Case study 3

Table C-2: Available information (case study 3)

AVAILABLE INFORMATION CHECKLIST					
Energy saving measure description:					
Optimisation of compressor control philosophy					
Concurrent benefits/limitations:					
None within measurement boundary					
Measurables		**Half hourly**	**Daily**	**Monthly**	**Compliance**
Electricity	**Electricity suppy**				
	Electrical power			✓	*Invoices*
	Mine check meter				
	Electrical power	✓			*Match invoices*
	Individual sub-system check metering				
	Electrical power	✓			*Match invoices*
	Per compressor				
	Electrical power	✓			*Calibration certificates*
Compressed air flow	**Compressor outlet**				
	Air flow	N/A			
	Pressure	✓			*None*
	Main production levels				
	Air flow	✓			*None*
Ore	Mass flow			✓	*None*