METERING AND MONITORING GUIDELINE

FOR THE AGRI-PROCESSING SECTOR IN SOUTH AFRICA

IN PARTNERSHIP WITH

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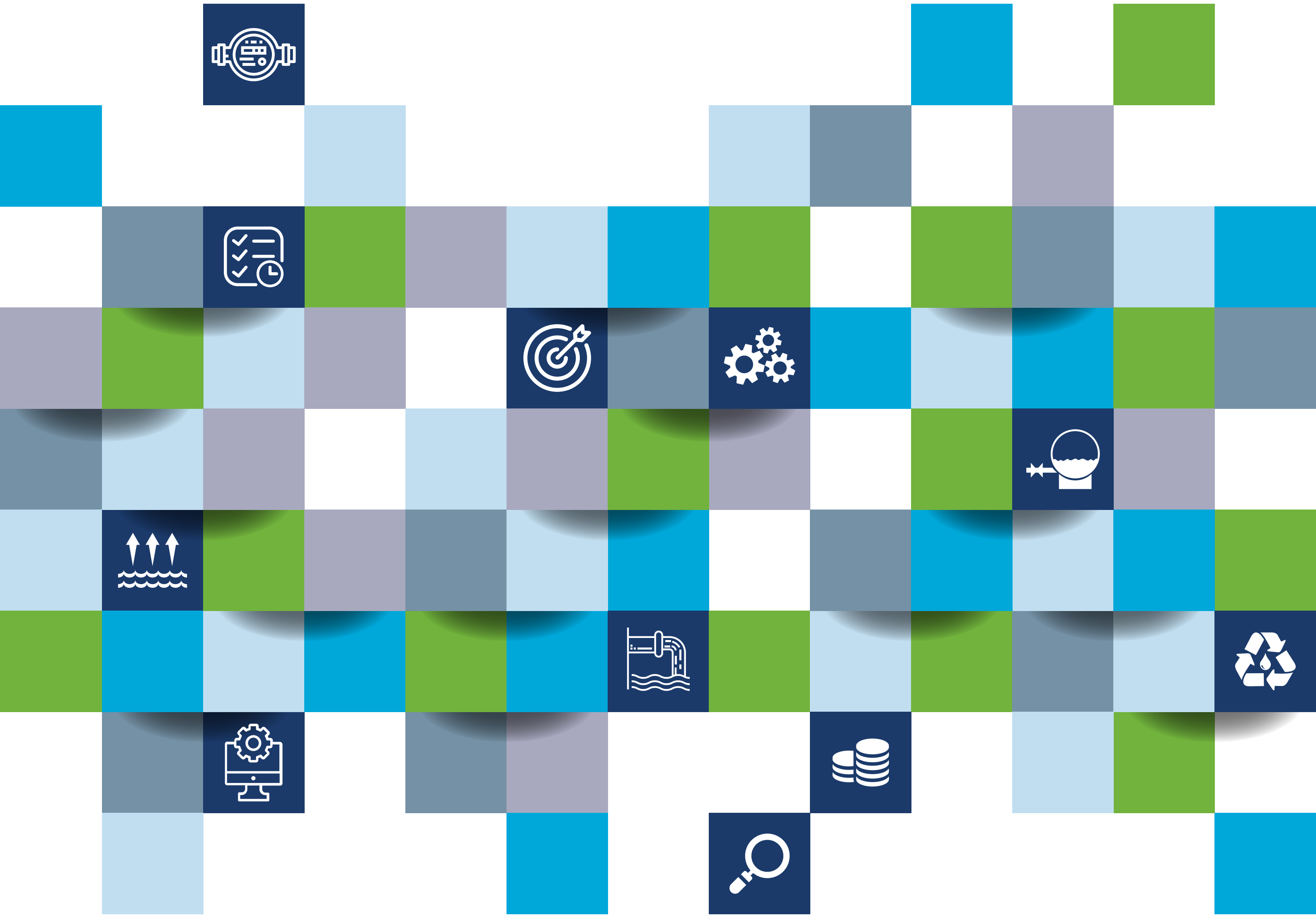

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INDUSTRIAL EFFICIENCY IN SOUTH AFRICA

ABOUT THE NATIONAL CLEANER PRODUCTION CENTRE SOUTH AFRICA

The National Cleaner Production Centre South Africa is a national support programme that drives the transition of South African industry towards a green economy through appropriate resource efficient and cleaner production (RECP) interventions.

The NCPC-SA's mission is to drive RECP in industrial and selected commercial and public sectors by equipping them to operate in an efficient, sustainable and competitive manner.

Services and focus areas include industry and sector knowledge-sharing, company technical support; green skills development; and advocacy and awareness-raising.

AGRI-PROCESSING RESOURCE EFFICIENCY PROJECT IN SOUTH AFRICA

The Metering and Monitoring Guideline for the Agri Processing Sector in South Africa was produced as part of a broader International Finance Corporation (IFC) Agri-Processing Resource Efficiency (APRE) project in South Africa, aimed to assist companies engaged in agricultural processing to transition to better water and resource efficiency practices. The Project is expected to help mitigate water supply risks in the sector, resulting from the water scarcity challenge in South Africa and throughout the region. The project is implemented in partnership with the Swiss State Secretariat for Economic Affairs (SECO).

This report has been developed by the IFC and the NCPC-SA with inputs from the Danish Strategic Water Sector Cooperation (represented by the Royal Danish Embassy and Department of Water and Sanitation).

water & sanitation
Department:
Water and Sanitation
REPUBLIC OF SOUTH AFRICA

Ministry of Environment of Denmark
Environmental Protection Agency

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1. GLOSSARY

A (Amps)	The measure of electricity flow in a conductor and usually measured with an ammeter or current transformer.
COD	Chemical oxygen demand (COD) is the amount of dissolved oxygen that must be present in water to oxidize chemical organic materials. COD is used to gauge the short-term impact wastewater effluents will have on the oxygen levels of receiving waters
APRE	Agri-Processing Resource Efficiency
HDD	Heating degree days are a measure of how much (in degrees), and for how long (in days), the outside air temperature was below a certain level.
hl	Hectolitre
kl	Kilolitre
kg	Kilogram
kl	Kilolitre
kWh	Kilowatt hour
KPI	Key Performance Indicator
PPE	Personal Protective Equipment
M&V	Measurement and Verification protocols
NCPC-SA	National Cleaner Production Center of South Africa
R	South African Rands
SECO	Swiss State Secretariat for Economic Affairs
TDS	Total Dissolved Solids
WBG	World Bank Group

2. EXECUTIVE SUMMARY

South African companies in the Agri-Processing sector range between companies whose only metering data is derived from monthly utility bills (often estimates by the local council), to those companies that have hundreds of metering points in the plant measuring at one second intervals. In general, South Africa companies have limited sub metering systems in place and most rely on intensity targets (kWh or litre per kg production) to determine performance. With few exceptions, companies that have world class resource management systems have invested heavily in metering and measurement systems in order to drive efficiencies. These companies will typically target projects with a 2-3 year payback period and utilise the data from the metering systems to motivate for additional budget and approval of CAPEX. This guide is targeted at a technical or plant manager at an agri-processing facility and aims to provide clear steps and budgets to implement a measurement programme that is aligned to international standards. The sections include:

1. Metering Planning – which explains how to set objectives and targets, how to align the measurement approach accordingly and provides some practical examples for a typical agri-processing company.
2. Metering Technologies and Strategies – which reviews the different types of meters and their applications in the following areas:
    a. Water
    b. Water and effluent discharge quality
    c. Steam
    d. Electrical
3. Metering Communications and Storage – which reviews the common strategies to collecting data as well as ensuring that the database is properly compiled to allow for easy analyses.
4. Metering Costs and Financing Options – which provides enough information to compile a capital budget for the procurement of meters and an operational budget for the continued analyses of the data.
5. Data Analyses and Usage – which looks at common approaches to performance measurement and guidance on how to utilise statistical tools to better analyse patterns in data.

Case studies and illustrations of how the information is applied are provided throughout the guide and makes reference to companies that the NCPC-SA has worked with over the years.

The schematic on the following page summarises the proposed approach to implementing a metering programme.

2.1 Overview of Metering Implementation Approach

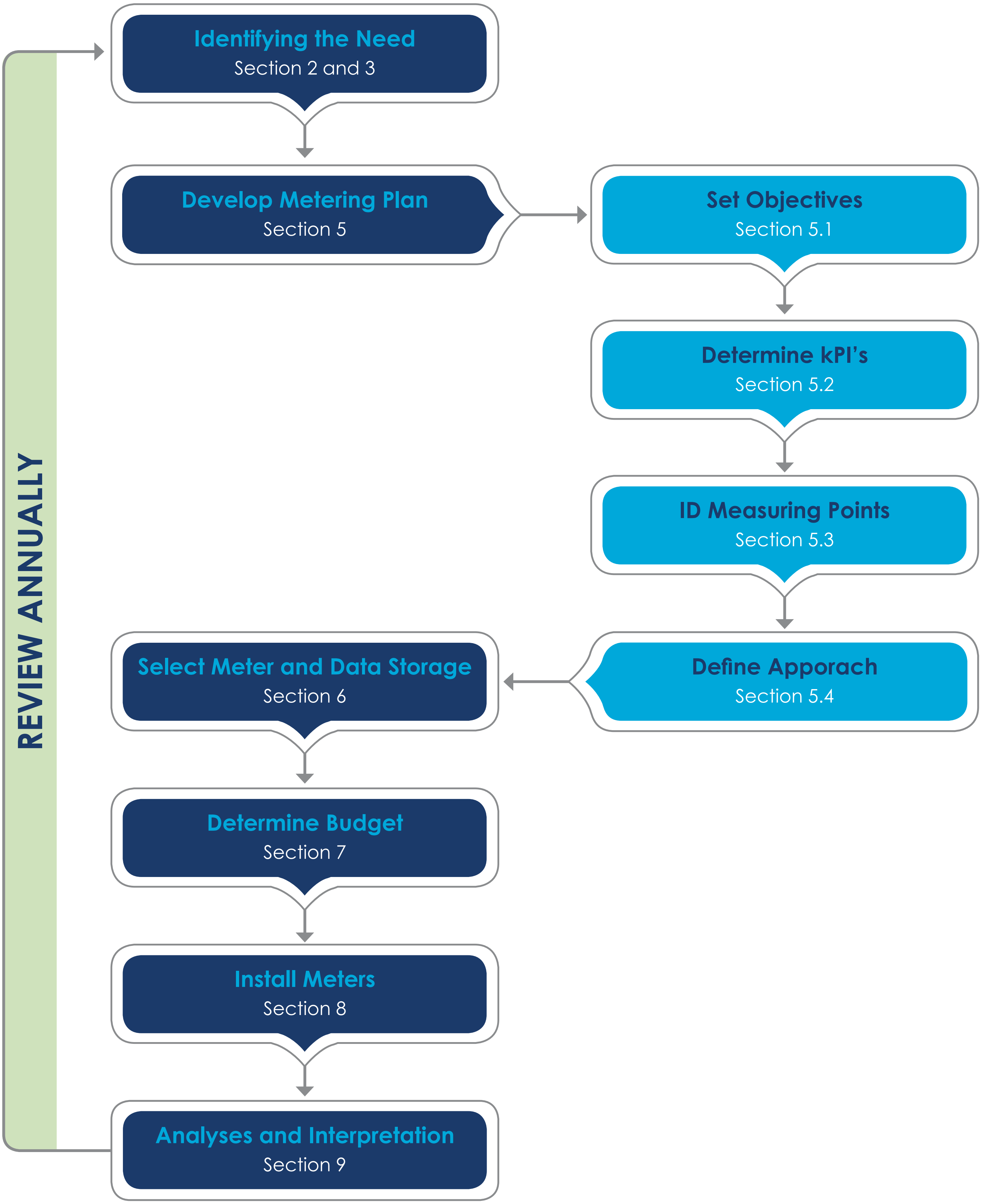

Figure 1. Overview of Metering Implementation Approach.

3. BACKGROUND

South Africa is a water-scarce country, and forecasts indicate that the gap between water supply and demand is expected to increase over the next 20 years. A World Bank 2030 Water Resources Group study projects a 17% supply:demand gap by 2030 which correlates with a prediction by the Institute of Security Studies. A significant contributor to this growth in demand is the industrial sector, of which agri-processing is an important component. In 2019, IFC and the State Secretariat for Economic Affairs of the Swiss Confederation (SECO), launched the Agri-Processing Resource Efficiency (APRE) programme to address this challenge. The programme aims to help the agri-processing sector in South Africa to improve sustainability and competitiveness, emphasising reductions in water use, along with related reductions in energy and fuel. Agri-processing includes sub-sectors such as animal slaughtering, dairy processing, fruit and vegetable processing, paper and pulp, sugar, brewing and malting and wineries.

Several initiatives under APRE have identified energy and water metering and monitoring as a major opportunity for the agri-processing sector to reduce water and energy consumption. For example, several studies have shown that simple metering and monitoring of water inflow can help industries develop water use balances, identify leaks and water wasting procedures that can be fixed in the short term and ensure significant savings on the water consumption and related costs. However, many firms either do not see the full value of metering and monitoring practices or do not know how or where to start implementing metering and monitoring equipment / systems.

This document has been specifically prepared for the agri-processing companies many of whom have very little sub-metering in their plants and still rely on manual inputs of billing data to analyse resource efficiency. To this extent, the guide focuses on what metering system should be in place, what those systems will cost to implement and how to go about analysing the data derived. The guide will not attempt to give detailed information on any one given topic but has referenced resources that have been developed for this purpose. The guide also does not attempt to bring formal Measurement and Verification (M&V) protocols standards required by many of the tax incentives but rather aligns with ISO 50006 approach to performance measurement. Companies looking to take advantage of the tax incentives will need to develop a monitoring programme that has the incentive requirements in mind.

4. BUSINESS CASE FOR METERING

As South Africa's population has grown, the resource and capacity requirements to sustain the growth have not kept up, resulting in supply constraints which inevitably impact on cost, availability and risk of interrupted supply. The electrical energy cost escalations and interrupted supply is a point in case. The chart below is the actual (blue bars) cost per kWh escalation over the past 8 years for a company in the agri-processing industry. Eskom's published information[1] for its industrial clients (brown bars) are also included for reference.

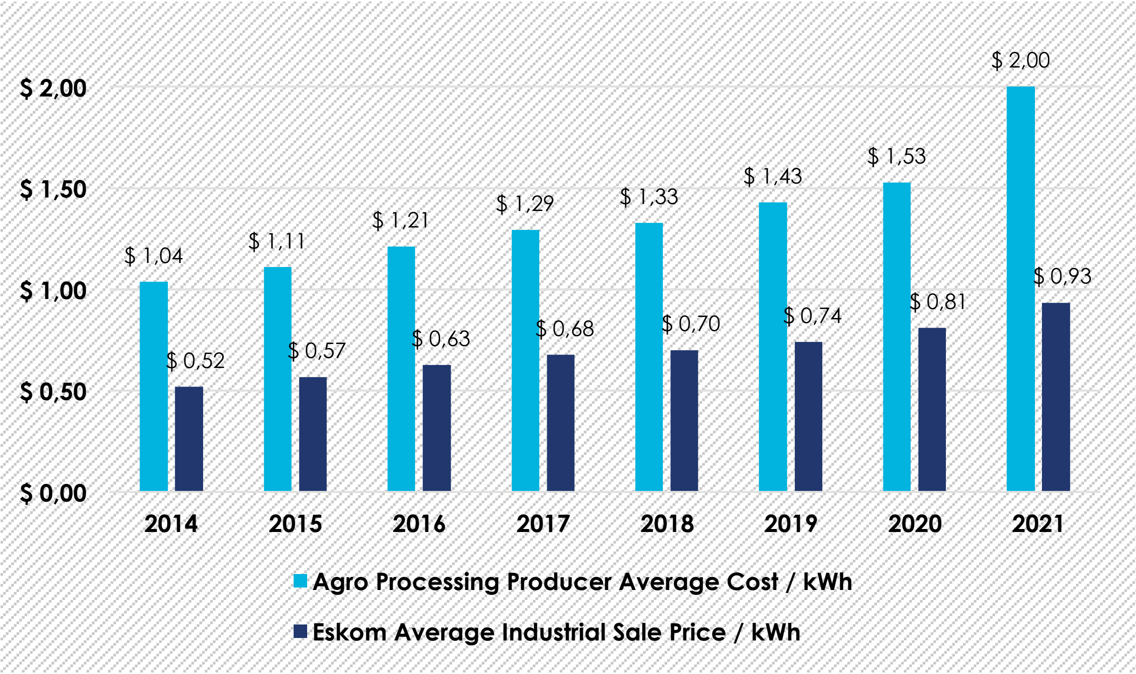

Figure 2. Comparison of cost escalation of electrical energy over the last 8 years.

There are a couple of points to note from the graph.

1. Cost Increase Rate

Electrical energy cost increase has doubled over the past 7-8 years for the company and the trend is likely set to continue.

2. Cost Premium for being in a municipal boundary

Companies purchasing from municipalities are paying a significant premium for being in a municipal boundary. While the average Eskom Industrial user has seen a R0.40 / kWh increase (78%) over the past 8 years the increase from those in municipal boundaries have seen a R0.96 / kWh increase (92%).

3. Re-structuring of tariff

While traditionally the cost escalations related to increases passed on by Eskom, the increase realised by the company in 2021 (~30%) related to a change in the municipal tariff structure. This led to the company having to re-align its cost strategies from an electrical maximum demand based tariff to a time-of-use tariff.

While the example cited above relates to electrical energy pricing, similar cost dynamics are being realised with water and effluent municipal services as supply and water treatment infrastructure capacity constraints are realised. Two of

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[1] https://www.eskom.co.za/CustomerCare/TariffsAndCharges/Pages/Tariff_History.aspx

South Africa's largest Metropoles have faced water supply issues (Cape Town and Nelson Mandela Bay) and many smaller municipalities have had to revert to ground water to supplement surface water supplies. This is highlighted by the graph below which provides an overview of water and electricity cost escalation over the past 24 years as compared to inflation.

South African electricity & water tariffs vs. inflation (CPO)

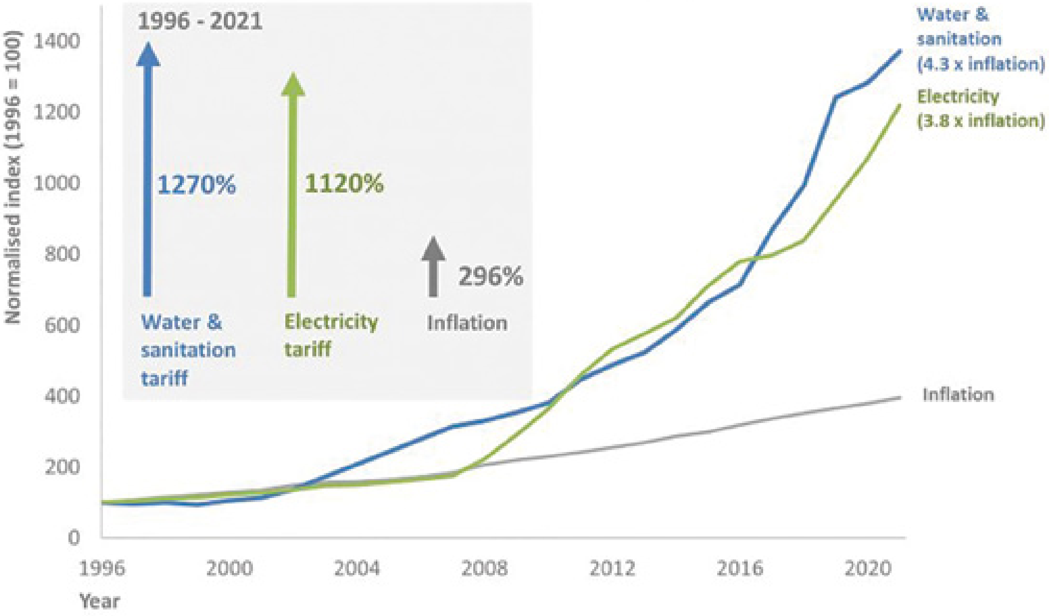

Figure 3. Indication of both water and electricity cost escalation over the past 24 years.[2]

In order to mitigate against the cost escalations, agri processing companies will have to develop strategies that not only embrace efficiency but also take into account tariff billing patterns. These will be discussed in later sections of the guide.

A detailed study of the effectiveness of advanced metering in companies was conducted by the Carbon Trust in the United Kingdom. They found in total a 5% reduction in carbon footprint (proportional to energy consumption) of companies that adopted advanced metering systems[3]. Practically this means that investing 1-2 % of the total utility budget to monitoring and metering should realise a payback of 2 years. While it is important to note that installing meters won't save anything, the information provided (as is demonstrated in many of the case studies in the guide) will often be the basis for decisions that will realise savings without needing additional capital cost. These oppurtunities range from shifting to a more cost effective tariff, identifiying which compressor is operating more efficiently and increase subsequently increasing its utilisation, identifying leaks in the plant or being warned timeously when the plants power factor correction trips.

METERING PAYBACK

Investing 1-2 % of the total utility budget back into metering and monitoring systems should realise a payback of 2 years.

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[2] https://www.poweroptimal.com/the-price-of-water-and-electricity-in-south-africa-a-tale-of-two-tragedies/#chapter

[3] The Carbon Trust (May 2007) Advanced metering for SMEs - Carbon and cost savings

Case Study – ABI Premier Place

A resource optimisation assessment was conducted at ABI Premier Place in 2011 and the site was visited while no production was in place. The main meter was indicating a plant demand of 22.5 litres / minute which upon further investigation was attributable to an underground leak. The savings at the time was in excess of R85 000 / annum. Live logging or a downtime monitoring programme would have detected the leak far sooner. The plant has since put a concerted effort into its water efficiency programme which has seen its specific water usage (litres water per litre product) go from 5.5 in 2011 to 2.3 in 2013 and 1.8 in 2015. More details of this programme are provided in section 8.1 of this report.

Legislative Compliance

While metering programmes often result in significant financial savings, an additional benefit is realised through legal compliance. Companies require metering to be in place in order to obtain water permits and discharge licences which are often renewed on a 3 year cycle. The legislation includes groundwater and river water extraction. Many municipal permits require that a detailed balance be conducted for the submission with a minimisation programme in place to ensure that national water efficiency objectives are being addressed. Similar legislation is being imposed in the energy sector with large users (> 180 000 GJ / year) currently required to report on usage and very large users (>400 000 GJ / year) needing to develop energy management programmes. Some of the relevant sections of legislation are provided below.

- Government Notice 141 (2018) Instruction to install water metering devices
- Government Notice 131 (2017) Taking water for irrigation purposes
- National Water Act, 1998 (Act 36 of 1998)
- National Energy Act, 2008 (Act No. 34 of 2008)
- Regulations Regarding Registration Reporting on Energy Management

LEGISLATIVE COMPLIANCE

While metering programmes often result in significant financial savings, an additional benefit is realised through legal compliance.


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5. METERING PLANNING

An effective metering and monitoring system will take years to implement and will require both equipment and human resources. An effective metering system design must avoid the following pitfalls:

- Gathering insufficient data to enable an accurate consumption analysis;
- Gathering too much data that are never used for analysis; and
- Gathering data in a format that cannot be easily used.

Consideration should be given to both what needs to be measured as well as what will be done with the data once it is collected. To this extent, developing a metering plan should be the first step at any site that is initiating a metering program.

The steps for developing an effective metering plan are outlined below.

METERING PLANS

Developing a metering plan should be the first step at any site that is initiating a metering programme.

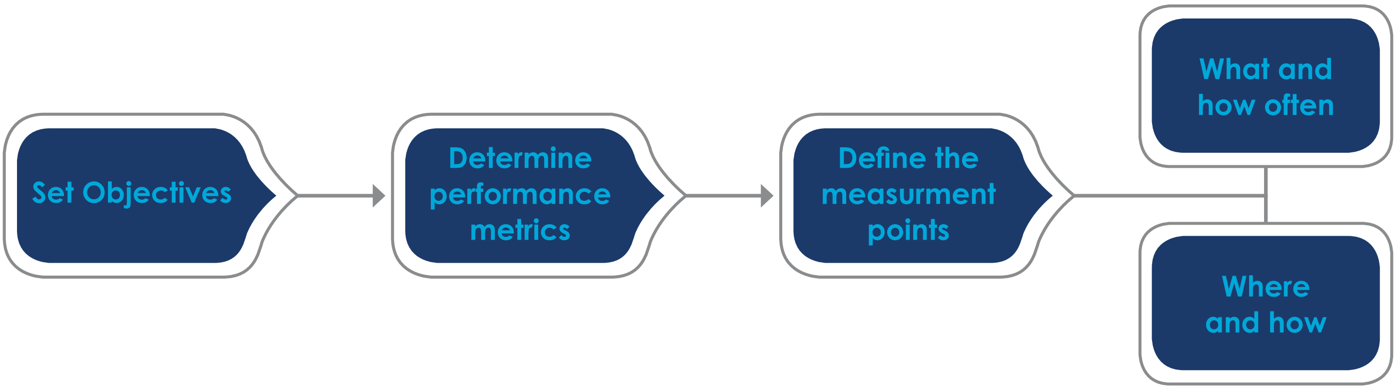

Figure 4. Setting Objectives and Targets.

5.1 Set Objectives

In setting objectives one should consider key areas of resource usage, the variables impacting on the usage as well as the opportunities for improvement.

Figure 5: Steps that feed into objectives and targets.

It is important to differentiate between objectives, targets and action plans as at this point of the project cycle companies are setting long term goals which will underpin the proposed measurement plan. The figure below provides an overview of the key differences.

Figure 6. Relationship of objectives, targets and action plans.[4]

As an example, an objective could be to reduce energy consumption by 20% within 5 years using 2020 as a baseline year. The associated targets would likely be:

1) Install live metering on all significant energy users by December 2021.
2) Replace all electrical heating elements with heat pumps by February 2022.
3) Increase chiller plant coefficient of performance (COP) (i.e., the cooling efficiency of the chiller) from 2.5 to 2.8 by March 2022.

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[4] United Nations Industrial Development Organization (2013) Practical Guide for Implementing an Energy Management System

5.2 Determine Performance Metrics

Performance Indicators (PI's) can be expressed by using a simple metric, ratio, or a model, depending on the nature of the activities being measured. Some examples of performance metrics are provided below:

Table 1. Overview of performance metrics.

Types	Example	Benefit	Disadvantage
Simple metric	• Water consumption per month • Annual Carbon footprint • Production downtime	• Readily available • CFO's historically interested in total spend • Listed companies required to report on total consumption	• Do not account for seasonal variation or changes to production volumes • Not able to benchmark
Simple ratio	• Energy per m^2 • Water per tonne product	• Readily available • Easier to benchmark	• Static factors not taken into account • Rewards increase in production and not necessarily increase in efficiency
Statistical analyses	• A predictive equation based on historical performance	• Provides an accurate indication of savings realised • Allows for developing internal best practice targets • Aligned to International Standards (ISO50006)	• Not easy to benchmark • Requires specific skill set to work with effectively • Statistical correlation not always found

There are usually factors that impact on resource utilisation performance. These typically include:

1. **Static factors** - quantifiable factor that significantly impacts performance and does not routinely change (i.e. facility size, product range, weekly shifts)
2. **Relevant variables** - quantifiable factor that significantly impacts performance and routinely changes (i.e. weather conductions, production output equipment load rates.
3. **Interaction effect** - when the effect of an independent variable on a dependent variable changes, depending on the value(s) of one or more other independent variables.

When developing a metering plan one should identify both the performance metric and the factors influencing consumption as they in turn may need to be measured. In addition, the interaction of the factors influencing consumption on each other (interaction effect) should be considered.

5.3 Identify Measurement Points

Drafting a simple schematic of the site can be a useful way of identifying key metering points. The schematics below provide an indication of the common metering points in an agri-processing plant as well as for advanced systems monitoring (i.e. Boiler, Compressed Air Plant and Chiller Plant).

5.3.1 Electrical Energy Metering

Common electrical metering points in a plant would include the main incomer, each major department as well as each significant energy user (compressed air and chiller plants). Usually submetering of energy intensive processes and compressors would be advised. The main incomer would usually include the monitoring of quality parameters (specifically power factor) which will be discussed in later sections.

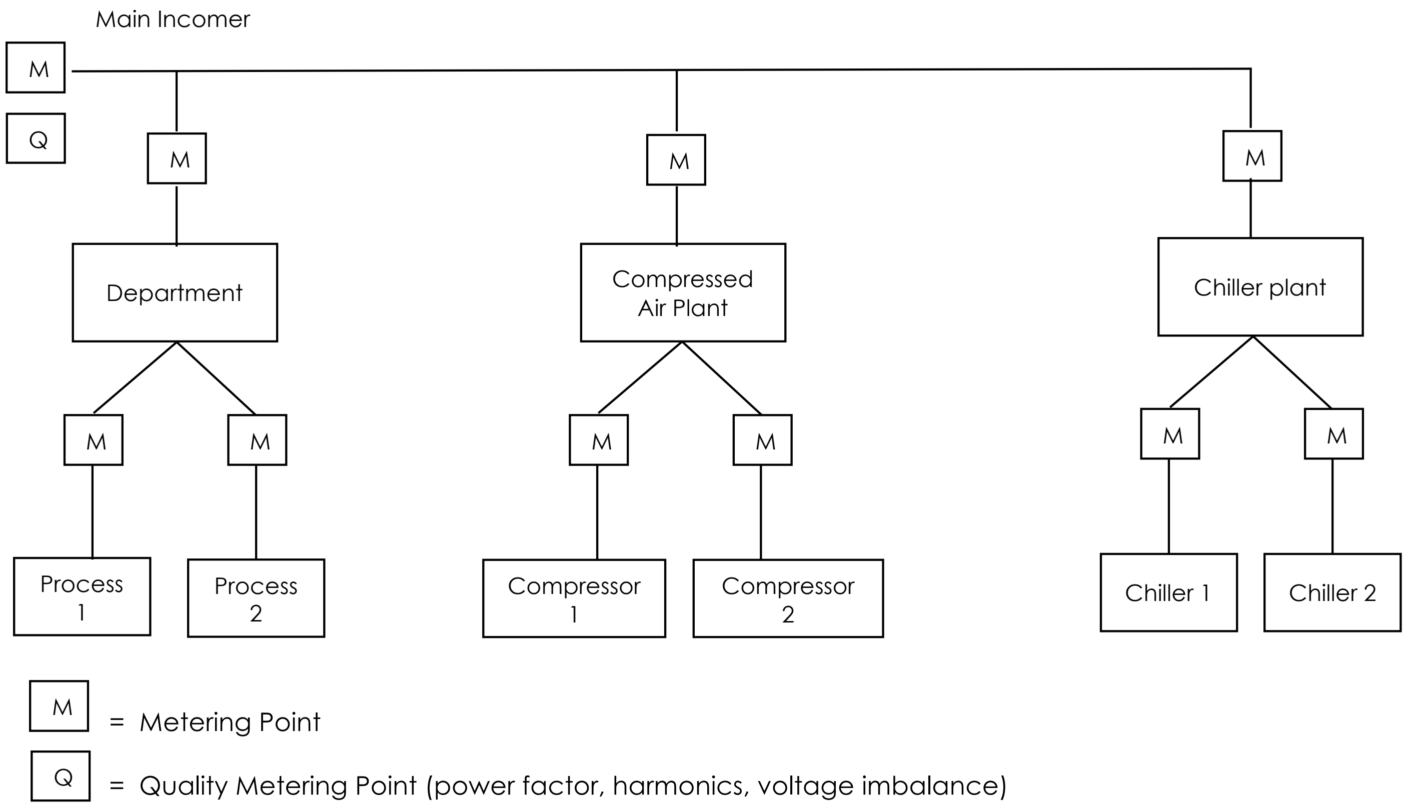


Figure 7: Electrical Metering Schematic.

5.3.2 Water Metering

Water metering systems in plants would usually include the main incoming points (municipal, ground, surface or rain water). Further sub metering would include the main departments and the main water consumption processes which would include the boiler, the cooling towers and the cleaning processes. Qualitative monitoring points would typically include weekly TDS, hardness and microbioligical coliforms tests from non-municipal water sources while water feeding into processes sensitive to water quality would have additional testing paramaters which may include chlorides, pH and the concentration of chemicals added to prevent corrosion or scaling in the boilers and cooling towers.

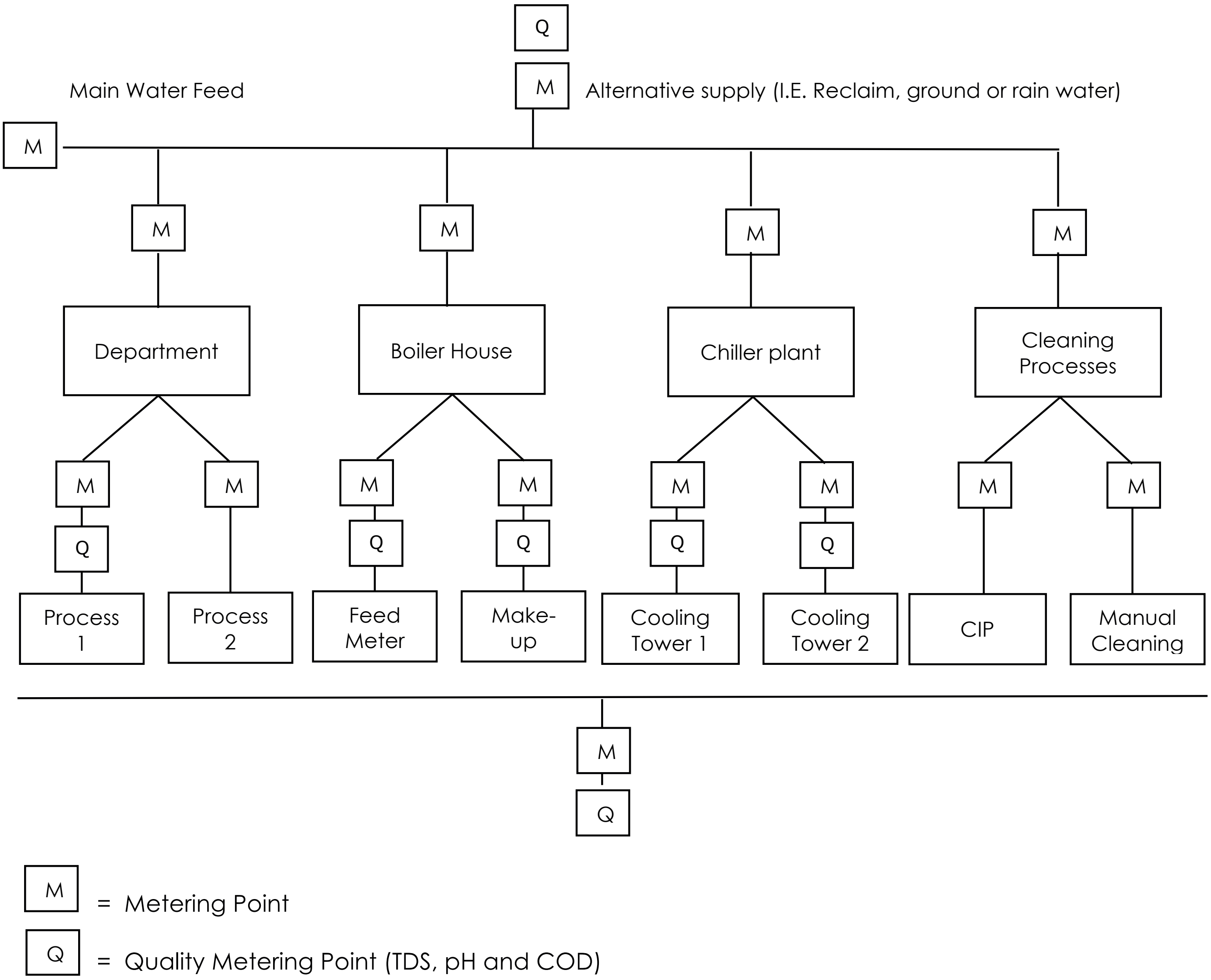


Figure 8: Water Metering Schematic.

5.3.3 Boiler Systems Metering

An overview of the metering points for boiler system would include water metering on the boiler make-up and feed with the associated quality parameter tests as discussed. The TDS of the boiler itself with automated TDS blow-down controller maintaining that parameter at the required set point. Boiler fuel usage is normally metered if it is a liquid fuel but solid fuels are harder to monitor continuously and will usually be based on billing data. A detailed discussion on boiler efficiency is included in section 5.3 as to how to implement a cost effective steam system monitoring program.

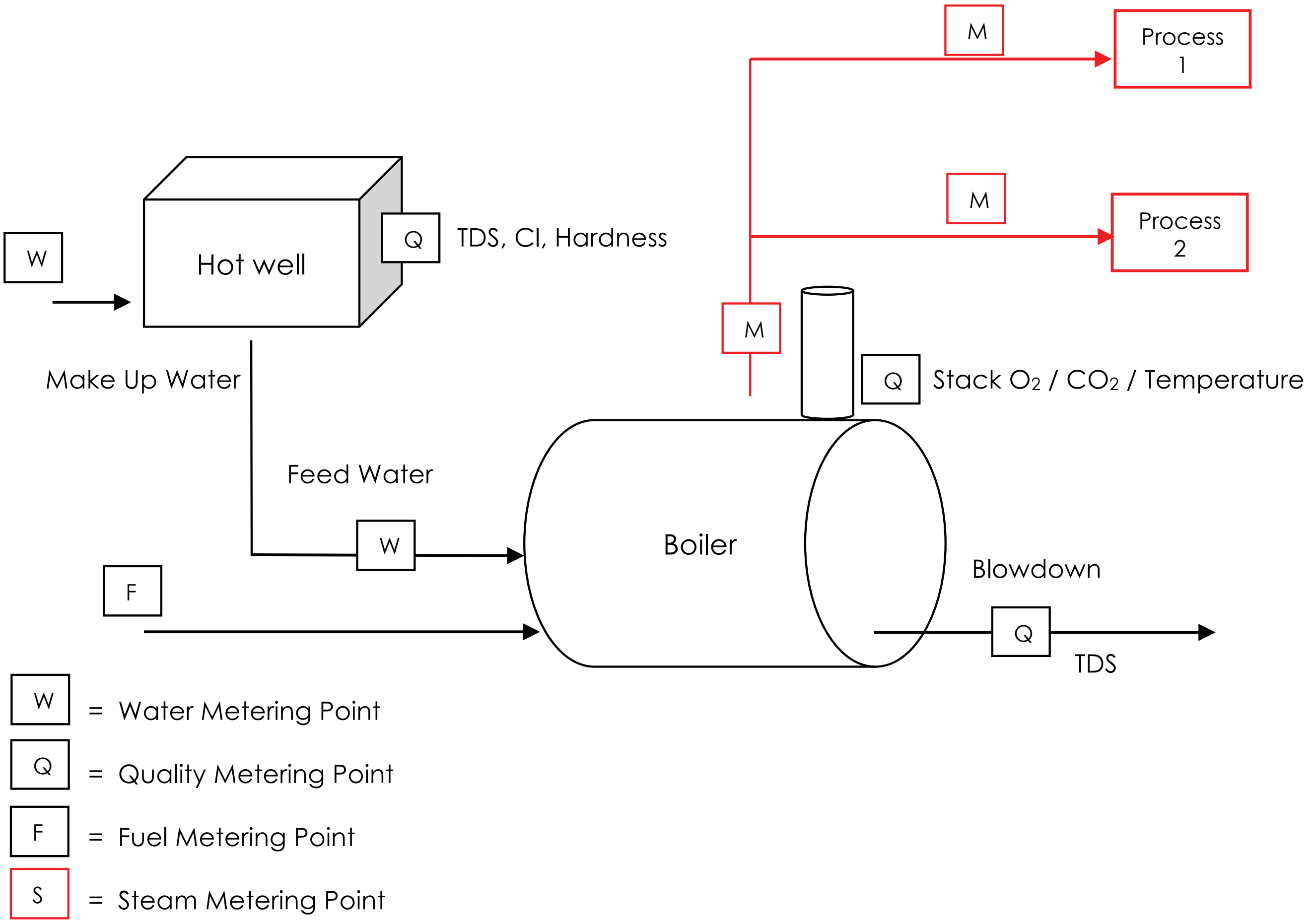
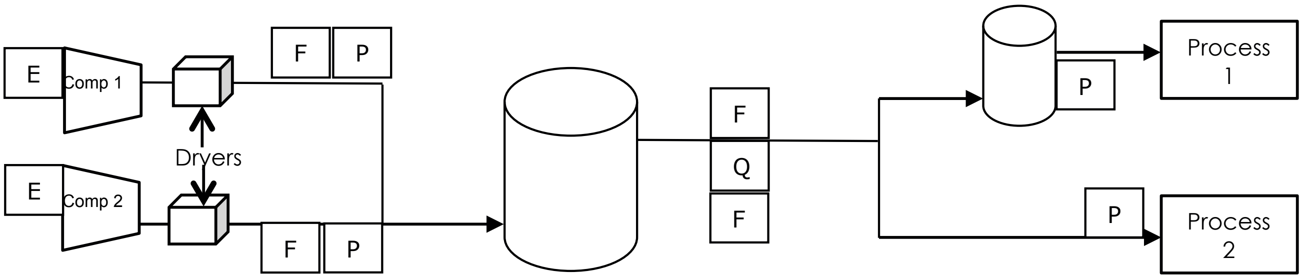


Figure 9: Boiler Metering Schematic.

5.3.4 Compressed Air and Chiller Systems

An overview of the metering points for compressed air and chiller systems are provided in the illustrations below. Both entail live electrical metering of the compressors. Flow and pressure will usually be monitored after each air compressors and after the receiver as well as pressure at key points in the process. Water content in the compressed air will also be monitored after the main receiver in order to confirm the effectiveness of the air drying systems.

Chiller systems would monitor temperature set-points at key points in the process accurately and would also monitor refrigerant pressure both before and after the compressor. Temperature and flow of the chilled water or product would be required to continuously gauge the cooling load requirement. These points will allow for the calculation of the COP (co-efficient of performance) as well as the system COP which are important inputs into understanding the oppurtunities for efficiency gains in the chiller or refrigeration systems. Often a first step in optimisation assessments is a calculation on overall efficiencies based on first principals and system specifications.



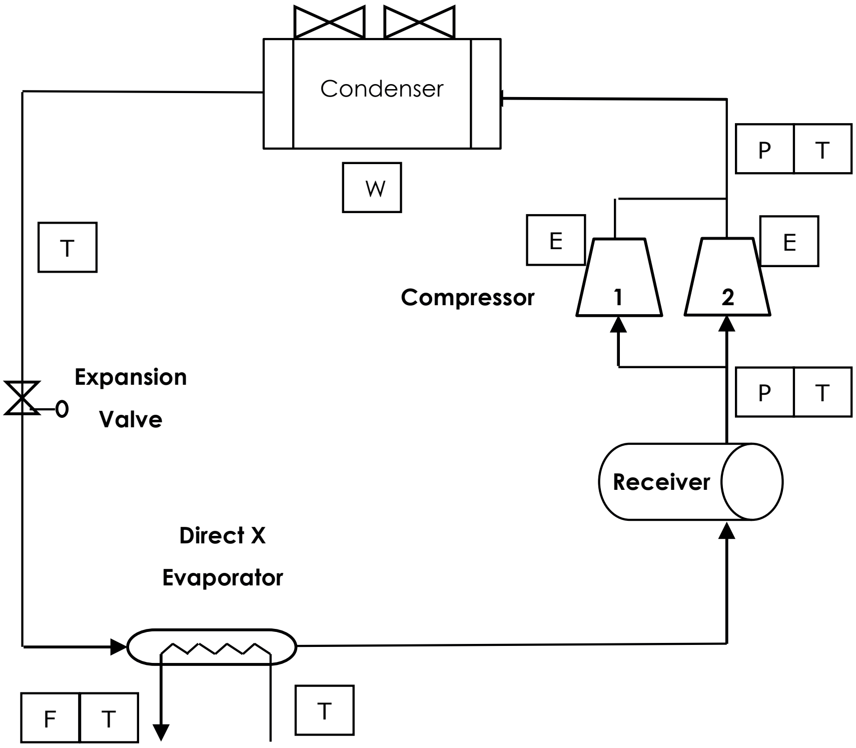
E = Electrical Metering Point

P = Pressure Metering Point

F = Flow Metering Point

Q = Quality Metering Point

Figure 10:Compressed Air Metering Schematic.



E = Electrical Metering Point

P = Pressure Metering Point

F = Flow Metering Point

T = Temperature Metering Point

W = Water Metering Point

Figure 11: Chiller Metering Schematic.

5.4 Measurement Approach

A plant's measuring approach will need to balance capital costs for continuous logging systems and data requirements with potential savings impact. To this extent, there are four levels of resource metering each with their benefits and applications that they will be suited to. These are summarised in the table below.

Table 2. Overview of Metering Period Strategies

	One time / Spot Measurements	Run time Measurements	Short Term Measurements	Long Term Monitoring
Description	Useful in determining "baseline" activities and instantaneous resource use, equipment performance, or loading	Normally used where hours of operation are the relevant variable	Equipment installed for a limited period of time	Term is typically more than a year and often the installation is permanent
Examples	Boiler flue gas analyses Lighting load	Run time of fans or pumps	Fan or pump system efficiency assessment Flow metering on cleaning applications	Incoming electrical and water supply Boiler steam meters
Advantages	Lowest capital cost Equipment usually easy to use Non-intrusive Fast results	Low capital cost Equipment usually easy to use Non-intrusive Useful for constant loads Information can be collected automatically	Mid-level cost Capable of assessing load variations Relatively fast results	Highest accuracy Data can be collected automatically Long term trends can be identified (seasonality and load variance)
Disadvantages	Low accuracy Limited application Typically single operating parameter Information usually manually processed	Useful applications are limited Measures single operating parameter Requires additional calculations/ assumptions	Mid-level accuracy as portable equipment is utilised Seasonal or occupancy variance deficient More difficult to install/ monitor	High cost Most difficult to install Installation process will take longer as CAPEX expenditure approval is usually required.

5.5 Practical Example

The following tables provide templates for a typical agri-processing company with cooling and heating processes as well as water usage in the product itself.

5.5.1 Basic Measurement Plans

Basic measurement plans are likely to achieve savings that require no further capital investment (choice or tariff, efficiency spot checks etc.). The table covers most of the main monitoring points and assumes that the data is manually entered into a local database for comparison purposes. The anticipated cost savings assume the data is incorporated into a resource optimisation plan and actively implemented as discussed previously.

Table 3. Basic Measurement Plan - Expect a 2% saving on costs.

Objective	Utility	Performance Indicator	Static factor	Relevant Variable	Frequency	Measurement Method	Location
Thermal Energy Cost Reduction	Thermal Energy	Steam usage	Steam Pressure	Process demand Weather conditions	Weekly	Direct metering or indirect	Boiler House
Thermal Energy Cost Reduction	Thermal Energy	Boiler efficiency	Boiler Insulation Losses Stack Temperature	Process demand Boiler Load Feedwater temperature	Weekly	Direct metering and indirect	Boiler House
Electrical Energy Cost Reduction	Electrical energy	Site electrical energy	Ventilation Lighting	Production Weather conditions	Weekly	Direct metering	Main Incomer
Water Cost Reduction	Water	Site water usage	Staff usage Leaks	Production Weather conditions	Weekly	Direct metering	Main Incomer
Effluent Cost Reduction	Water	Site water usage Qualitative parameters (COD, PH, TDS)	Daily cleaning schedule	Production	Monthly	Grab sample or composite sample	Effluent Discharge Line

5.5.2 Standard Measurement Plans

Standard measurement plans are also likely to achieve savings that require no or low levels of capital investment (leak determination and high level system enhancements etc.). The table covers most of the main monitoring points and assumes that the data is automativelly entered into a local or a hosted database for analyses purposes. A far higher degree of savings can be expected as more detailed data on an ongoing basis is avaiaible for the analyses. The standard measurement plan assumes that a competent resource is available to analyses the information and put the key observations forward for action by the departments in the plant.

Table 4. Standard Measurement Plan - Expect a 5% saving on costs

Objective	Utility	Performance Indicator	Static factor	Relevant Variable	Frequency	Measurement Method	Location
Thermal Energy Cost Reduction	Thermal Energy	Steam usage	Steam pressure	Process demand Weather conditions	30min	Direct metering or indirect	Boiler House
Thermal Energy Cost Reduction	Thermal Energy	Boiler efficiency	Boiler insulation losses Stack temperature	Stack O2 levels Stack temperature	30min	Direct metering and indirect	Boiler House
Chiller Plant Optimisation	Electrical energy	Chiller plant COP	Circulation pumps and cooling fans	Production Weather conditions	30min	Direct metering	Chiller plant
Compressed Air Plant Optimisation	Electrical energy	kWh / m3 air produced	Compressed air leaks	Compressed air demand	30min	Direct metering	Compressed air plant
Water Cost Reduction	Water	Site water usage	Staff usage Leaks	Production Weather conditions	Hourly	Direct metering	Main Incomer
Water Cost Reduction	Water	Department / Process water usage	Staff usage Daily cleaning schedule	Production Weather conditions	Hourly	Direct metering	Different Departments / Processes
Water Cost Reduction	Water	Cooling system water usage	Cooling tower bleed rates	Refrigeration load Weather conditions	Daily	Direct metering	CIP Plant Feed
Effluent Cost Reduction	Water	Site water usage Qualitative parameters (COD, PH, TDS)	Daily cleaning schedule	Production	Weekly	Grab sample or composite sample	Effluent Discharge Line

5.5.3 Advance Measurement Plans

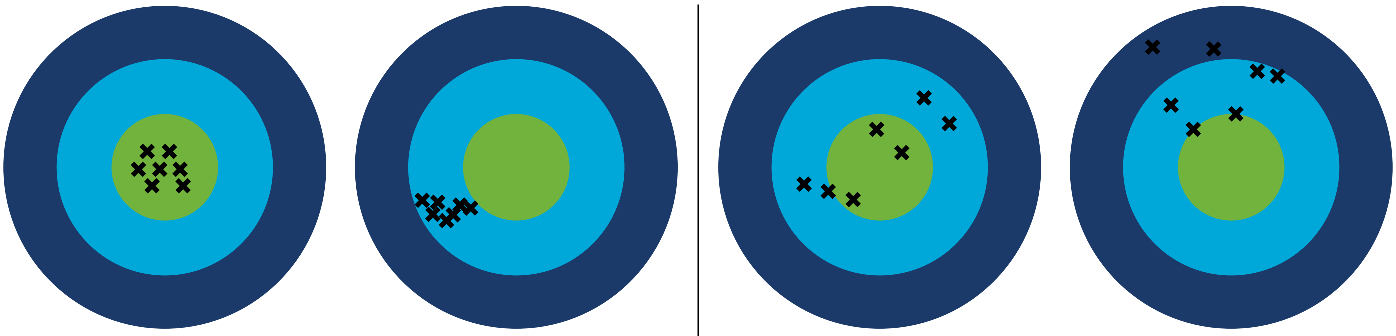
Advanced measurement plans are likely to achieve significant savings that will likely require capital (installation of VSD's, heat recovery systems etc.). External experts will be utilised to assist with conducting detailed system assessments and accompanying recommendations. The metering tools will be important in order to compile baselines which can be used to motivated for the capital required to implement the changes.

Table 5. Advanced Measurement Plan - Expect a 10% saving on costs.

Objective	Utility	Performance Indicator	Static factor	Relevant Variable	Frequency	Measurement Method	Location
Chiller Plant Optimisation	Electrical energy	Chiller COP and System COP	Circulation pumps and cooling fans	Production Weather conditions	30min	Direct metering	Chiller Plant
Compressed air plant optimisation	Electrical energy	Compressor kWh / m3 produced	Compressed air leaks	Compressed air demand	1 second	Direct metering	Compressed Air Plant
Fan system optimisation	Electrical energy	Electrical energy usage	Friction Losses Process pressure	Process air demand	Annual	Temporary metering	Fan Location
Pump system optimisation	Electrical energy	Electrical energy usage	Motor Losses Head Pressure	Process demand	Annual	Temporary metering	Pump Location
Water Cost Reduction	Water	Cleaning water usage	Scheduled cleaning	Production	Daily	Direct metering	CIP Plant Feed
Effluent Cost Reduction	Water	Site water usage Qualitative parameters (COD, PH, TDS)	Daily cleaning schedule	Production	Hourly	Direct metering	Effluent Discharge Line

6. METERING TECHNOLOGIES AND STRATEGIES

When considering meter options it is important to understand key principles and how they apply to different metering technologies.



Accurate, Repeatable **Inaccurate, Repeatable** **Accurate, Non-repeatable** **Inaccurate, Non-repeatable**

Figure 12: Illustration of accuracy and precition.

Accuracy – this is usually the first metric used to determine applicability of a meter to a particular system. No meter is 100-percent accurate and most manufacturers provide a range of accuracies in their product line and corresponding prices. Accuracy could be thought of as the difference between a measured value and that of the actual value. Published accuracies often will, and should, be referenced to specific calibration procedures including equipment-traceability according to SANS 1529 equipment and procedures. A meter's accuracy will vary over the specified flow range of the meter. SANS 1529 requires that a meter's reading inaccuracy is limited to ±5% at low flow and ±2% at high flow. Meters C and D in the figure below would not receive certification against the SANS 1529 standard. Meters should not only be selected according to required accuracy but also verified performance over the expected flow range.

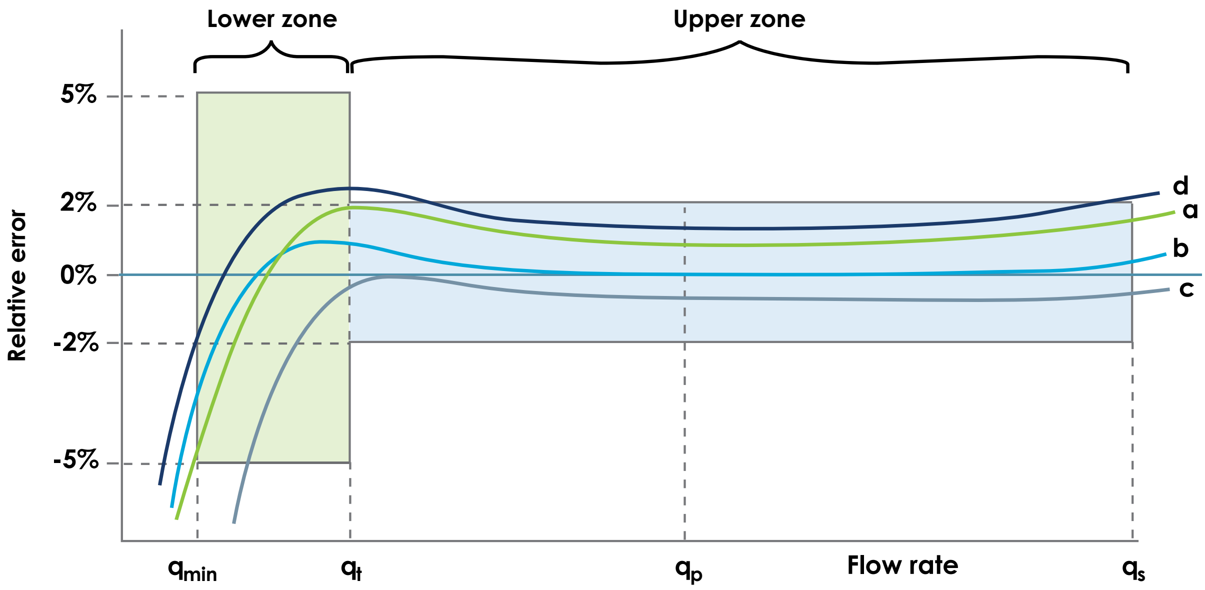


Figure 13. SANS 1529 Accuracy requirements for meters over their specificied flow range.

Precision/Repeatability – the precision or repeatability of a measurement entails the ability to reproduce the same value (e.g., temperature, power, flow rate) with multiple measurements of the same parameter, under the same conditions.

Turndown ratio – the turndown ratio refers to the flow rates over which a meter will maintain a certain accuracy and repeatability. For example, a steam flow meter that can measure accurately from 1 tonne/hr to 25 tonne/hr has a turndown ratio of 25:1. The larger the turndown ratio, the greater the range over which the meter can measure the parameter.

Ease of installation – When making specific make-and-model decisions, it is important to understand any size and weight constraints, needs for specific diameters (or lengths) of straight pipe upstream and downstream of the meter, specific electrical and communications needs, and the overall environment the meter will operate in.

Ongoing operations and maintenance – the lowest cost metering technology may not be the best choice if it has high associated maintenance costs (e.g., frequent service, recalibration, sensor replacement). As with most capital purchases, a life-cycle cost approach (including all capital and recurring costs) is recommended for decision making.

Installation versus capital cost – in some situations, the cost to install a meter can be greater than the capital cost; this can be true where system shutdowns are necessary for meter installations, or where significant redesign efforts are needed to accommodate a meter's physical size, weight, or required connection. In these cases, decision makers should consider alternative technologies that may have a high first cost but a much lower installed cost. A good example of this is the use of non-intrusive metering technologies (e.g. ultrasonic flow meters) that typically have a high capital cost but often a reduced installed cost.

6.1 Fluid Metering – Volumetric

An exhaustive review of types of meters is beyond the scope of this guide and useful information in this regard has been published by the Department of Water Affairs (JE Van Zyl, 2011) . Important considerations for the selection of the meter are discussed below.

6.1.1 Meter Selection

An overview of the different categories of water meters and the proposed application points are provided in the table below. The table compares water metering technologies with practical issues a plant may encounter. If the table is shaded red it indicates that it is less desirable and if green that indicates it is suitable given that specific parameter. The plants choice will depend on the specific application as well as the water utilised. For example, the "electrical" meter will monitor the amp load on the motor and the pressure on the pipeline and use the pump curve to determine the expected flow rate. This metering technique is suited to dirty water metering of large pipelines. It is not likely to be as accurate as some of the other meters however and would not be suited to billing applications. In certain circumstances high precision is required for product make-up purposes and so the capital cost of a Electromagnetic meter is warranted. The table also provides common points where the meters will be used for ease of reference. Most plants will utilise good quality water which make mechanical-turbine flow meters a cost effective choice for higher volume applications and mechanical-volumetric for the lower flow applications.

Table 6. An overview of the different water meter types and their characteristics.

Type	Mechanical – Volumetric	Mechanical - Jet	Mechanical - Turbine	Electro-magnetic	Ultrasonic	Electrical
Common pipe sizes (mm)	15-40	15-40	40-500	300-2 000	400-4 000	Any pumped application
Sensitivity to flow variation	Very Low	Low - Medium	High	Medium	High	Low
Sensitivity to water quality	High	Medium	Low	Very Low	Low	Insensitive
Pressure loss	High	Low - Medium	Medium	Very Low	Very Low	Very Low
Installation limitations	Low	Low - Medium	Medium	High	High	Low
Electricity	No	No	No	Yes	Yes	Yes
Installed Cost	Low	Low	Medium	High	High	Low
Proposed Application	Cooling Towers Hot well Admin block Ablutions	Cooling Towers Admin block Ablutions	Main line Borehole Boiler Feed	Process supply	Not typically used	Effluent Irrigation Borehole /River

6.2 Fluid Metering - Qualitative

Water qualitative parameters are important both for process water usage as well as effluent discharge. Key parameters and strategies to monitor these are discussed below.

Incoming Water

The incoming water quality should typically be analysed on an annual basis if supplied by a local municipality or on a monthly basis if the water is extracted from a natural water source or if the municipal supply quality varies. Typical tests of incoming water would include:

- pH
- Dissolved solids (TDS)
- Alkalinity
- Coliforms
- Hardness levels

Boiler and Cooling Towers

Weekly or monthly testing of water quality feed water would be conducted where used as a make-up for the boiler and or evaporative cooling systems. Boiler systems should be fitted with TDS controllers to ensure correct cycles of concentrations of the boiler at all times. Cooling tower and hot well make up systems are usually fitted with pulse output meters that are linked to the chemical dosing systems, controlling scale and corrosion in these systems.

BOILER BLOW DOWN

Boilers should be fitted with TDS controllers to control blow down and cycles of concentration.

Effluent

Very few companies continuously monitor their effluent discharge and both the council and the company rely on a single grab sample to determine the quality discharged. The discharge costs will often exceed the consumption costs as penalties are imposed for breaching the quality set-points prescribed by the local authorities. The table below provides an indication of the main discharge parameters tested for, but should a company be found to breach these, then additional tests and analyses would be undertaken and additional charges levied based on the defaulting parameter.

The standard effluent charge calculation is usually a function of the quanitity of of water discharged, the organic load in the water discharged (COD) as well as a penalty for breaching the discharge parameters as quantified in the table below. Generally, if companies can show that their effluent discharge COD is consistently below 1000 mg / litre then the effluent quality cost parameter will not be levied. Similarly, municipal councils' instead of installing metering on the effluent line will assume that 95% of the water supplied to the company is discharged to effluent unless metering can show otherwise. The actual calculations can generally be found in the by-laws published on the municpal web-site as indicated below. These tables would not be applicable to companies in rural settings discharging directly into waterways.

Table 7: Example of municipality by-laws

Municipality / Metropolitan	Link to by-laws webiste
Cape Town	https://www.capetown.gov.za/Work%20and%20business/City-publications/policies-and-by-laws/policies-by-laws-and-publications
Ekurhuleni	https://www.ekurhuleni.gov.za/council/by-laws-policies/by-laws/ekurhuleni-by-laws-1.html
Durban	http://www.durban.gov.za/Resource_Centre/Pages/By-Laws.aspx

The table below provides an indication of the qualitative thresholds municipalities adhere to when analysing effluent grab samples.

Table 8. Extracts from City of Cape Town Waste Water By-law.[5]

Section a: General	Not less than	Not to exceed
1. Temperature at point of entry	0°C	40°C
2. Electrical conductivity at 25°C		500 mS/m
3. pH Value at 25°C	5.5	12.0
4. Chemical oxygen demand		5 000 mg/l

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[5] City of Cape Town Wastewater and Effluent By-Law, Promulgated 7 February 2014.

Section b: Chemical substances other than heavy metals – maximum concentrations	
Settleable solids (60 minutes)	50 mg/l
Suspended solids	1 000 mg/l
Total dissolved solids at 105°C	4 000 mg/l
Chloride as Cℓ	1 500 mg/l
Total sulphates as SO_4	1 500 mg/l
Total phosphates as P	25 mg/l
Total cyanides as CN	20 mg/l
Total sulphides as S	50 mg/l
Phenol index	50 mg/l
Total sugars and starches as glucose	1 500 mg/l
Oils, greases, waxes and fat	400 mg/l
Sodium as Na	1 000 mg/l

Case Study – Effluent Metering

All of the parameters in Section A can be continuously monitored in order to determine not only compliance with the by-laws but also times where product has been introduced into the effluent system. A company in Cape Town was constantly in breach of the local discharge limits pertaining to TDS and pH and as a result installed continuous monitoring equipment to verify the council bills. The metering not only indicated that there was significant variation in the discharge quality over the month but that a number of isolated cases had a major impact on both the conductivity and the pH. As product was dumped into the effluent system the TDS would increase and the pH would drop. The metering system allowed the company to identify the day and time of the incidents and rectify the issues accordingly.

A composite sampler was installed so as to ensure that the municipality's sample was representative for the month rather than coinciding with one of the process lapses. A further indirect benefit was the ability to reduce raw material and product losses which were the cause of the effluent quality discharge spikes.

EFFLUENT MONITORING

The metering system allowed the company to identify the day and time of the incidents and rectify the issues accordingly

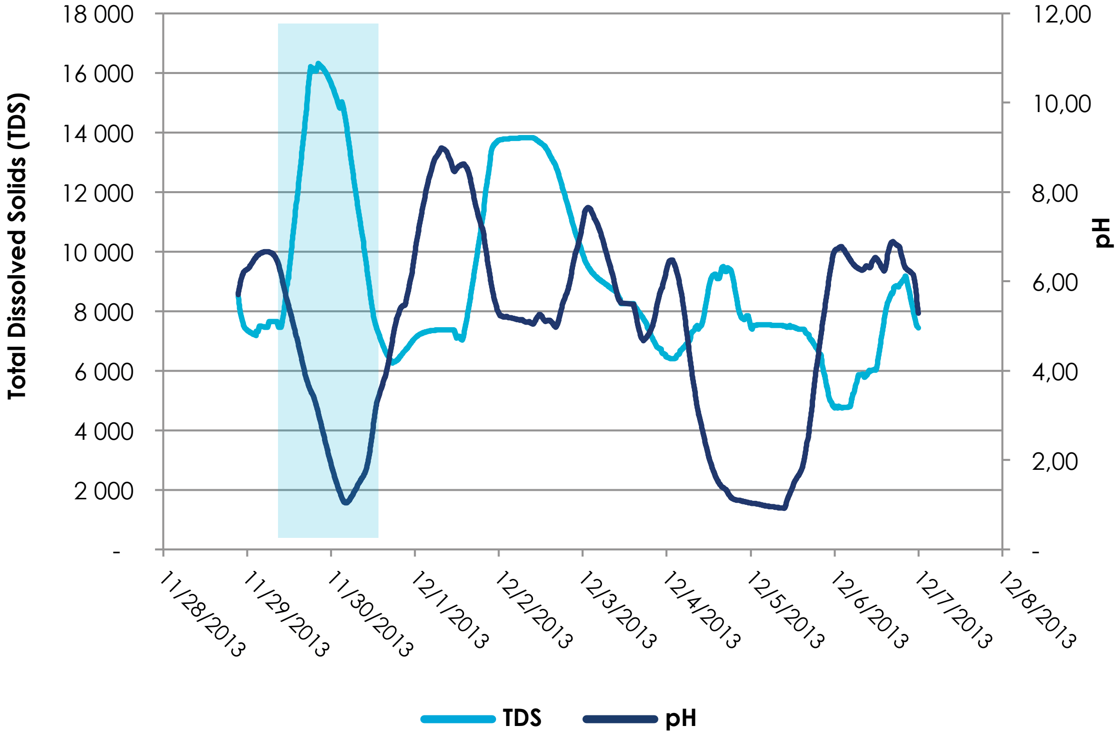


Figure 14. Effluent Quality Monitoring Project.

A magnetic flow water meter was also installed and the actual discharge was monitored over a 12 month period. Council's billing department calculation assumed that 95% of the water consumed was discharged to effluent. The actual metering indicated that this was only 79% (see table below).

Table 9. Overview of water utilised and discharged over the course of a year.

Total usage – kl	46 115
Total discharge - kl	36 430
% Discharge	79%

The revised figure was submitted to council and their billing system adjusted accordingly. The company was also able to back-date the savings (>R1Million) from the beginning of the monitoring period which more than covered the costs for implementing the metering (<R100 000). The programme took over a year to implement as council required twelve months data before they were prepared to adjust the discharge formulae on the account.

6.3 Boiler Efficiency and Steam Metering

6.3.1 Direct Steam Metering

There are a number of different types of steam flow meters which have advantages and limitations. Typically steam meters are expensive relative to their water and electrical counterparts and as such the lower cost orifice and annubar types are often installed. These meters suffer from low accuracy levels at low flow levels which is indicated by the turn-down ratio. A turndown ratio of 5:1 indicates that at flows lower than 20% of the design specification the metering results will be inaccurate. Selecting the correct meter for the correct application is a specialist requirement especially considering the budget being spent as steam meters are costly. We would recommend working closely with the supplier in profiling the metering point in this regard. The meter types and a summary of the advantages and disadvantages are provided in the table below.

Table 10. An overview of the different steam meter types.

	Orifice	Annubar	Turbine	Vortex Shedding
Accuracy	Moderate	Good	Good	Good
Turndown Ratio	<5:1	5:1	10:1	20:1
Repeatability	Good	Good	Low	Very good
Installation Ease	Easy	Easy	Challenging	Moderate
Pressure Loss	Moderate	Low	Moderate	Low
Recalibration Needs	Frequent	Infrequent	Frequent	Infrequent
Capital Cost	Low	Low	Moderate	Moderate
Installed Cost	Low	Low	Moderate	Moderate
Maintenance Cost	High	Low	Moderate	Low

Our recommended approach for the boiler steam generation metering is the indirect metering approach which is described below.

6.3.2 Indirect Steam Metering

Boiler steam production can be indirectly ascertained based on the boiler feed water volumes and the boiler blow down rate at a far lower cost and with similar accuracies. The approach assumes the boiler feed water volume and the TDS of both the feed water and the blowdown are being measured.

The blow down rate can be calculated by measuring the TDS of the blow down and TDS of the feed water. The equation below can be applied to calculate the % blow down.

$$\%\ \text{Blow down} = \frac{\text{TDS blow down} - \text{TDS feed}}{\text{TDS blow down}}$$

STEAM METERING - INDIRECT

Boiler steam production can be indirectly ascertained based on the boiler feed water volumes and the boiler blow down rate at a far lower cost and with similar accuracies.

Once the blow down rate is determined the steam rate can be determined by subtracting the blowdown from the feed water volumes as indicated below.

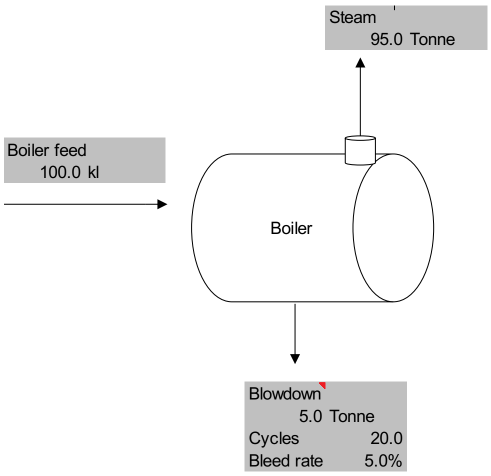


Figure 15. Indirect method for determining steam production.

6.3.3 Indirect Condensate Return Metering

As is the case for steam metering, condensate return can be difficult to meter as there can be two phases in the condensate return lines (flash steam and condensate) as the temperatures can be over 100oC. The condensate return can be indirectly measured by using the hot well make up water meter reading, the steam meter reading (direct or indirect) and making an assumption on flash losses (usually between 2-5%) and direct steam injection in the process. The figure and equation below provides an overview of this approach with the condensate return being calculated as follows:

$$\textit{Condensate Return} = \textit{Steam Generated} - \textit{Direct Steam Injection Estimate} - \textit{Flash Steam Loss Estimate}$$

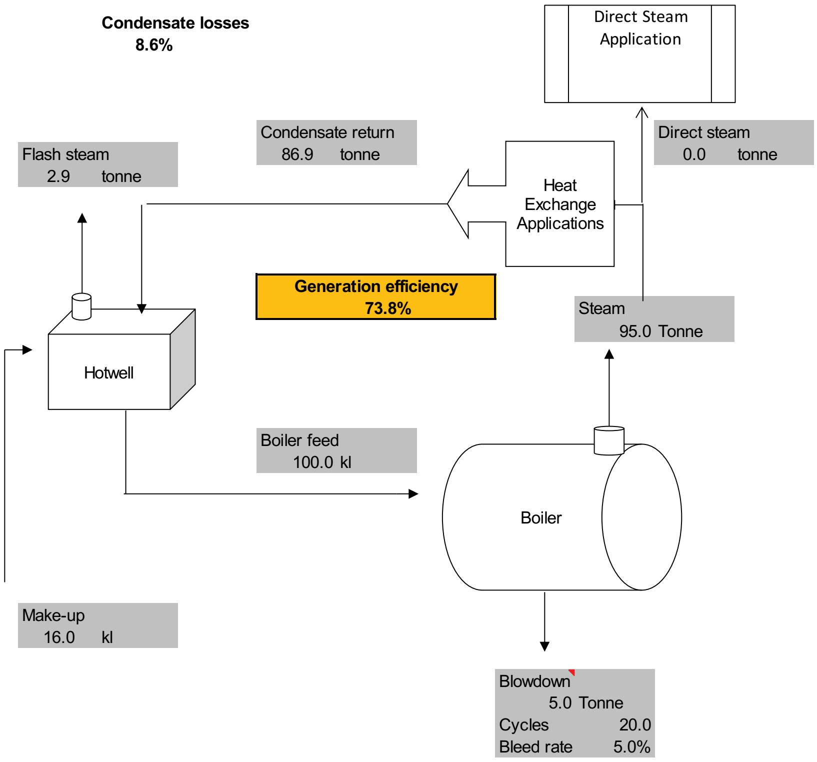


Figure 16. Steam Generation Efficiency calculated using a mass balance approach.

While the margin of error in this approach is high (>10%), condensate monitoring and optimisation systems can be based on historical trends if a plant has direct steam injection processing systems in use. If no direct steam injection systems are in place and impurities in condensate are not present, then a good target for condensate return would be anything in excess of 85%.

6.3.4 Generation Efficiency

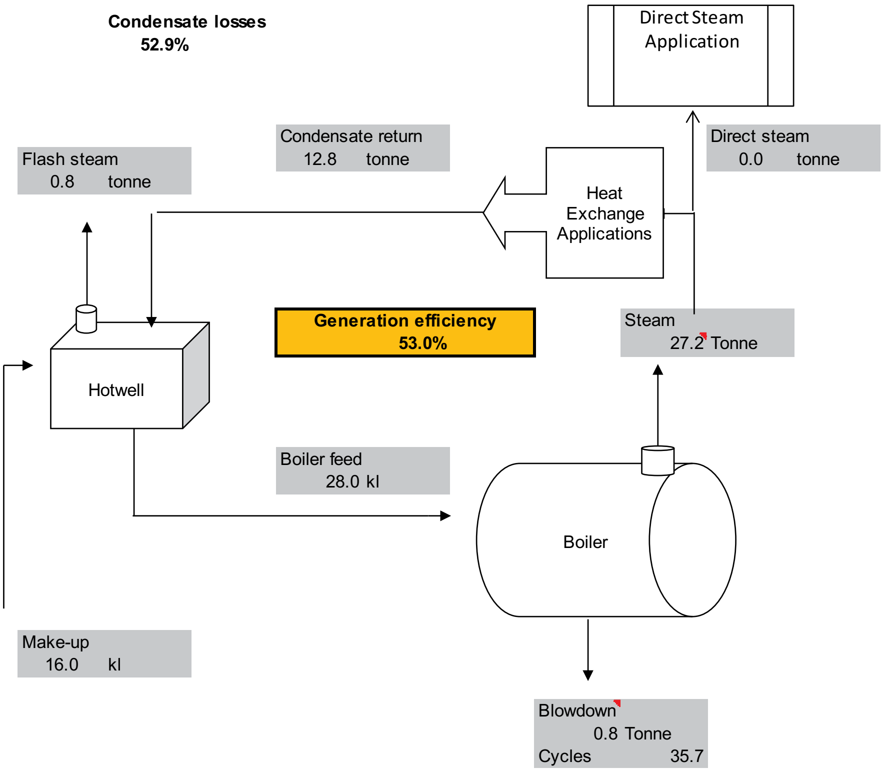
A further important step would be to determine the generation efficiency using the mass balance approach which would typically be applied to monthly data collected for the boiler systems. This can be done by using steam tables in order to understand the energy content in the boiler feed and in the boiler steam which would then be used in conjunction with the fuel energy utilised for the system. The equation below summarises the calculation.

$$\text{Boiler Gneration Efficiency} = \frac{\text{Steam energy Content-Feedwater Energy Content}}{\text{Fuel Energy Content}}$$

Flue gas analyses, while useful, should always be read in conjunction with the overall generation efficiency as isolated measurements do not necessarily capture losses related to low load conditions or start up.

Case Study – Steam System Optimisation

Klein River Cheese (Standford – Western Cape) utilized a 4 tonne / hr boiler to supply their processes. A steam assessment conducted by the National Cleaner Production Centre was conducted and the process steam load was calculated indirectly based on the boiler feed and blow down TDS readings. The generation efficiency of the steam could be calculated based on the calculated steam production and the boiler fuel utilised and was found to be low at 53%. Once the system losses were included, the overall system efficiency was in the vicinity of 33%. This should theoretically be over 75%.



Area	Boiler
Boiler losses	
Radiation loss / Boiler design*	2.0%
Flue gas loss	16.7%
Unaccounted for loss	27.7%
Bleed*	0.6%
Generation efficiency	**53.0%**
Steam losses	
Radiation loss	21.3%
Leakage	5.6%
Condensate return loss	8.5%
Flash steam loss	2.4%
Heat recovery	0.0%
Sub total	**37.8%**
Overall thermal efficiency	**33.0%**

Figure 17. Klein River Cheese steam system generation and system efficiency.

The solution was to revert to a point-of-use hot water system even though the input fuel costs were more expensive than the previous boiler fuel source. As a whole, significant savings were realised in addition to reduced maintenance costs as the steam system was decommissioned. The annual savings amounted to R290 000 (50% saving) with an investment cost of roughly R100 000.

6.4 Electrical Metering

Some common terms used in electrical metering and important for understanding utility bills are provided below.

Volt (V): The measure of electric potential between two points in a circuit and typically measured with a voltmeter or potential transformer.
Apparent Power (Volt- Ampere - VA): The measure of "apparent" rate of energy supplied to an electric load. The volt-ampere (designated VA) is defined as the voltage multiplied by the current. The volt-ampere is the metric used to rate many forms of electrical equipment.
Real Power (Watt): A measure of the "real power" delivered to an electric load. Watts are defined as volt-amperes multiplied by the "power factor". As such, the real power will always be less than or equal to the apparent power. Real power is sometimes referred to as "active Power" or "true Power".
Reactive Power (Volt-ampere reactive - VAR): A measure of the system's reactive power – or power stored in a system's inductive or capacitive loads – and is mostly used for identifying power factor correction needs.
Power factor: The ratio of "real power" (watts) to "apparent power" (volt-amperes) and defined as the cosine of the phase angle between voltage and current. For resistive loads (in ac circuits), the voltage and current are in phase and, therefore, the cosine of the angle is unity (i.e., 1.0), resulting in a power factor of unity. For loads with reactive components (e.g., motors, electrical ballasts), the voltage and current are not in phase resulting in a power factor of less than unity. Power factors significantly less than 1.0 (e.g., 0.85) can result in surcharges from the utility due to their need to make up the balance resulting from the improper power factor. The significance of power factor is that the electric utility supplies customers with Apparent Power (VA) but bills the customer for Real Power (Watts). A power factor below 1.0 requires the utility to generate more than the minimum volt-amps to supply the load.
Demand: A measure of the average real power over a specified time interval. Depending on the utility, the specified interval is between 5 minutes to 1 hour, with the 30-minute interval being the most common.
Maximum demand: The highest average demand measured in kVA or kW at the point of supply during a 30 minute integrating period in a billing month. It is important to understand how your utility assesses maximum demand, and the associated kW charge, to be able to manage for operational and economic efficiency.
Harmonics: A measure of the electrical frequencies beyond the fundamental frequency of 50 hertz and usually labeled as the first harmonic (50 hertz), second harmonic (100 hertz), and so on. Harmonics are created by non-linear loads (e.g., computer power supplies, electronic ballasts) that draw current in short pulses rather than the traditional smooth ac sine waveform. Among other problems, harmonics can cause excessive heating of metal wires and certain types of electrical interference.
Total harmonic distortion (THD): THD is a measure of the content of all major types of harmonic frequency current or voltages in relation to the fundamental current voltage frequency. This content is usually expressed as a percentage of the fundamental frequency and is defined as the square root of the sum of the squares of the harmonics divided by the fundamental frequency.

6.4.1 Meter Selection

Typically monitoring of power is based on supplementing strategies to reduce energy costs (i.e., maximum demand strategies) as well as verifying monthly bills. Increasingly, with the adoption of energy management systems, digital electrical metering is being rolled out to departments and to large electrical energy users as the norm in plants. The installation cost relative to the ability to obtain a large amount of useful information as well as control equipment can be considered to be very low when compared to water and steam metering applications. The table below provides an indication of the advantages and disadvantages of the different types of meters but with the cost of digital meters coming down significantly the only consideration would be for Mechanical or Electro-mechanical meters if they feed into an existing SCADA system.

Table 11. Overview of electrical energy meters and their characteristics.

	Advantages	Disadvantages	Application
Mechanical	• Low Cost • Reasonably Accurate	• Typically manually read • No time based recording • Not able to monitor quality	• Monitor utilisation on air / cooling compressors
Electro-Mechanical	• Low Cost • Reasonably Accurate • Can produce a pulse output for logging	• Not able to monitor quality • Separate data logger needed to collect information	• Remote monitoring applications (i.e. borehole) • Large Energy Users (compressors)
Digital Meters	• Accurate • Data storage with time stamp • Accommodate multiple inputs • Two way communication • Built in alerts • Flexible data intervals	• Moderate to high cost • More complicated data management requirement • Additional systems for data transfer and use	• Site Feed Departments Large power users / areas

Case Study – Compressed Air

A blow moulding operation in Gauteng supplying HDPE and PET bottles to the dairy industry utilised a 200kW and 250kW compressor for their 700 psi line and alternated the compressors on a weekly basis for maintenance purposes. Power, flow and pressure monitoring equipment was installed over a period of two weeks. When the 250kW compressor was utilised there was a 30kW increase in power consumption with no significant change in the pressure or flow requirement. Utilising the more efficient compressor would realise a 130 000kWh saving per annum (~ R200 000 /annum) for the plant.

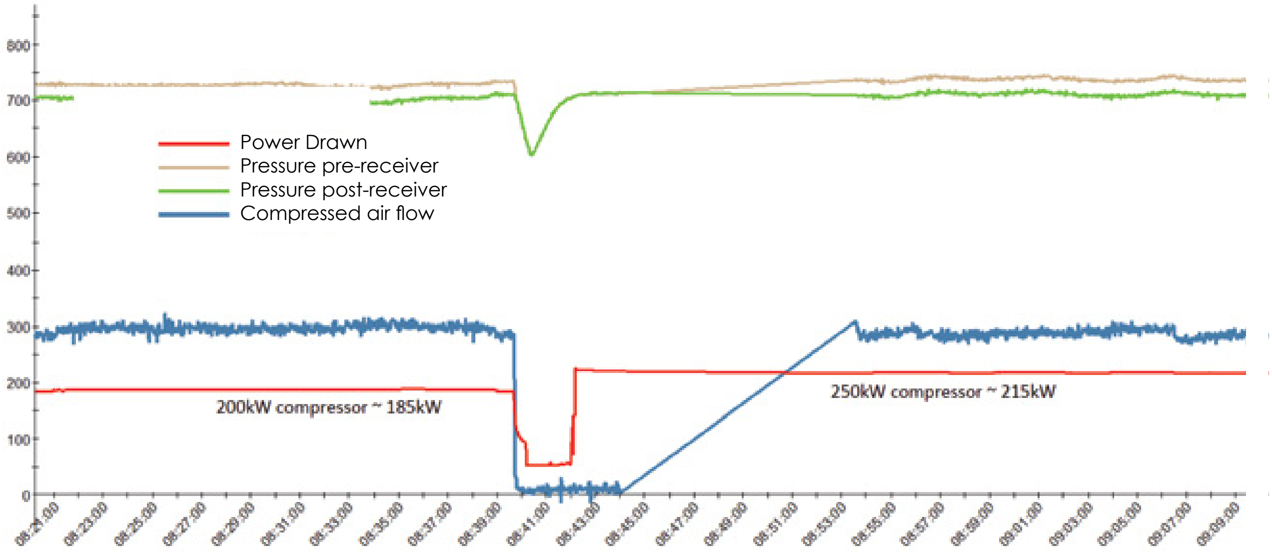


Figure 18. Logging data for the compressed air system including power, pressure and flow.

7. METERING COMMUNICATIONS AND STORAGE

Traditional metering systems in South Africa still dominate the Agri-processing industry with the bulk of non-electrical metering still being manually collected and then typed out onto a spreadsheet for review. For those companies who aggressively collect data, the opposite extreme exists where the information is in a format that is hard to analyse (e.g. 10 second data) or difficult to extract from the existing databases. The figure below summarises the different approaches to data collection and storage.

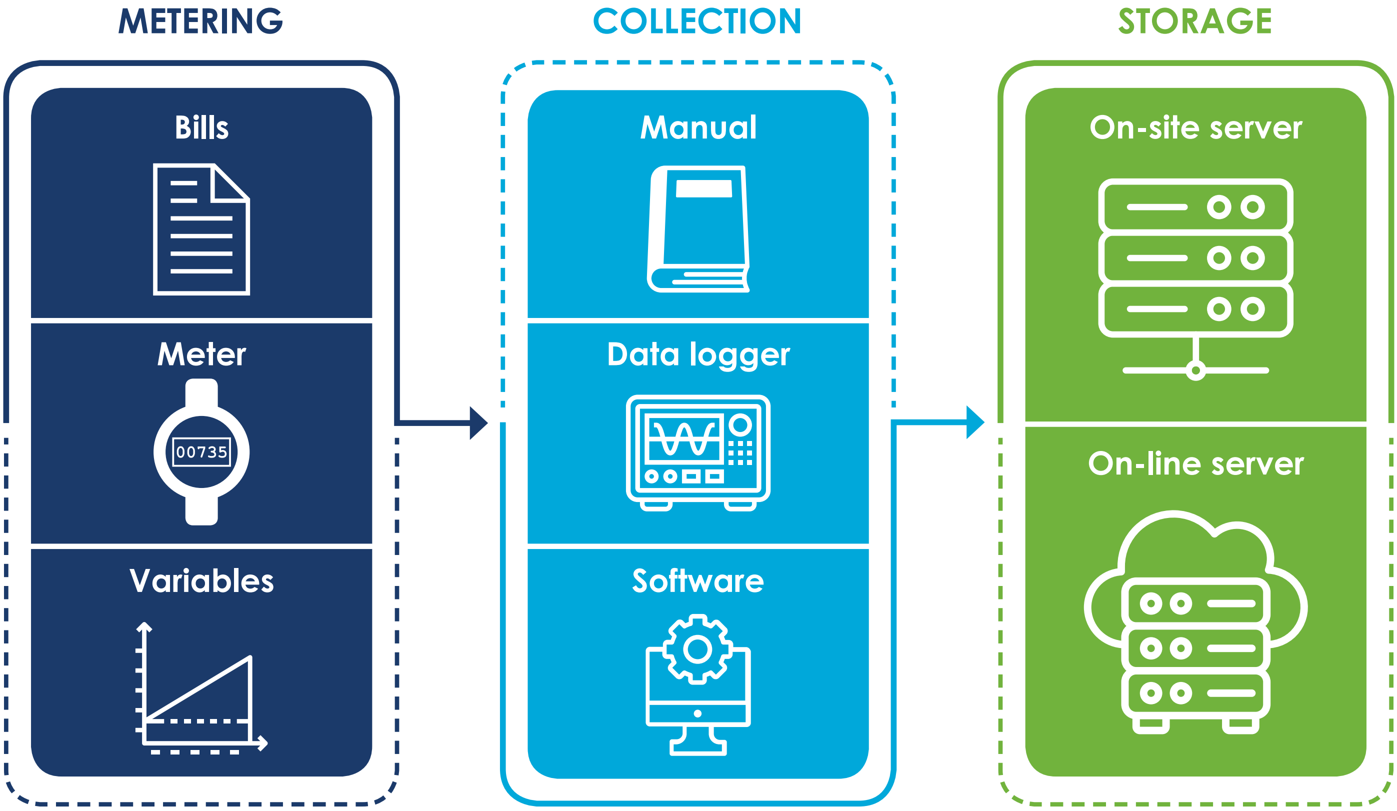


Figure 19. Overview of data collection approach.

Some key considerations should be kept in mind when considering the data collected:

Manual Reading – Data integrity issues as will be discussed below.

Automated Reading - Equipment should be fitted with automated reading options. These could be in the following outputs.

a) Analog output – typically, 4 to 20 mA or 0 to 5 volts dc
b) Contact closure – pulse type output
c) Digital output – digital pulse
d) Digital signal – outputs using networked communications (e.g., Ethernet, Modbus, HART).

Storage and storage period – high sample rates stored for long periods will see high data storage requirements.

Proprietary Communication Protocols – most companies have a range of different types of meters across the plant and care should be taken to avoid installing meters that make use of proprietary and encrypted communication protocols. This will make centralised collection of data at some point in the future costly as bespoke systems will need to be installed.

7.1 Common Mistakes Made

Care should be taken to avoid common mistakes in collecting data. These include:

- The date 02/02/20 could be the 2 February 2020 or the 20 February 2002. Care should be taken to ensuring the date stamp is not ambiguous. For example, it is difficult to ascertain whether the data points to the right indicate the start of the week or the end of the week.
- Avoiding rows in the middle of a data set (discontinuous data) that are not a part of the data set needing to be analysed. These will need to be removed before analysing. From the table on the left the weekly data for 2013 is summed as well as the monthly data for January and is included in the data set.
- The data intervals / periods should be consistent. This can frequently be a problem when working with municipal bills which have differing number of days in each billing month that can range for 25 to 31 depending on the billing cycle. In this data set, the point 28/02/2014 has only 5 days in the week (starting 23/02/2014).
- Estimates should be avoided and omitted from the data set before analysing. In this example, the data points for the 16 and 23 March 2014 were not taken and a zero figure was used in the data set which would significantly skew any analyses conducted .
- Finally, if data is manually entered, the data readings should be taken at the same time of day.

Week/Year	Date	Total KWh	KWh used
46	17/11/2013	410517	**12484**
47	24/11/2013	422377	**11860**
48	01/12/2013	432119	**9742**
49	08/12/2013	44 3846	**11727**
50	15/12/2013	455635	**11789**
51	22/12/2013	467424	**11789**
52	29/12/2013		
			540433
1	05/01/2014	475490	**8066**
2	12/01/2014	487088	**11598**
3	19/01/2014	498602	**11514**
4	26/01/2014	510154	**11552**
		517633	**7479**
5	02/02/2014	520624	**2991**
6	09/02/2014	533721	**13097**
7	16/02/2014	541942	**8221**
8	23/02/2014	554224	**12282**
	28/02/2014	564103	**9879**
9	02/03/2014	568055	**3952**
10	09/03/2014	578027	**9972**
11	16/03/2014		**0**
12	20/03/2014		**0**
13	30/03/2014	589386	**11359**

7.2 Best Practice For Datasets

Datasets should ideally be:

- Automatically collected.
- Have reporting options that allow output with set time intervals including:
    - » 30 minute
    - » 60 minute
    - » Daily
    - » Weekly
    - » Monthly
    - » Annually
- Automated reporting and alerts.

7.3 Case Study – Power Factor

An energy audit was conducted at a food plant based in Johannesburg. Power factor correction equipment was installed but the unit had tripped. The resulting power factor of 0.86 equated to an additional demand of roughly 120kVA which would amount to R20 000 / month additional cost. This plant was well run and had installed continuous logging systems but had not set up monitoring systems which would notify management when conditions were not in specification. In this instance the cost of the kVA excess to the plant was in the vicinity of R40 000 for the two months that the trip went undetected.

This shows the importance of not only metering key points effectively but ensuring that a monitoring programme is implemented with feedback mechanisms in place to notify staff of conditions out of the operational specifications.

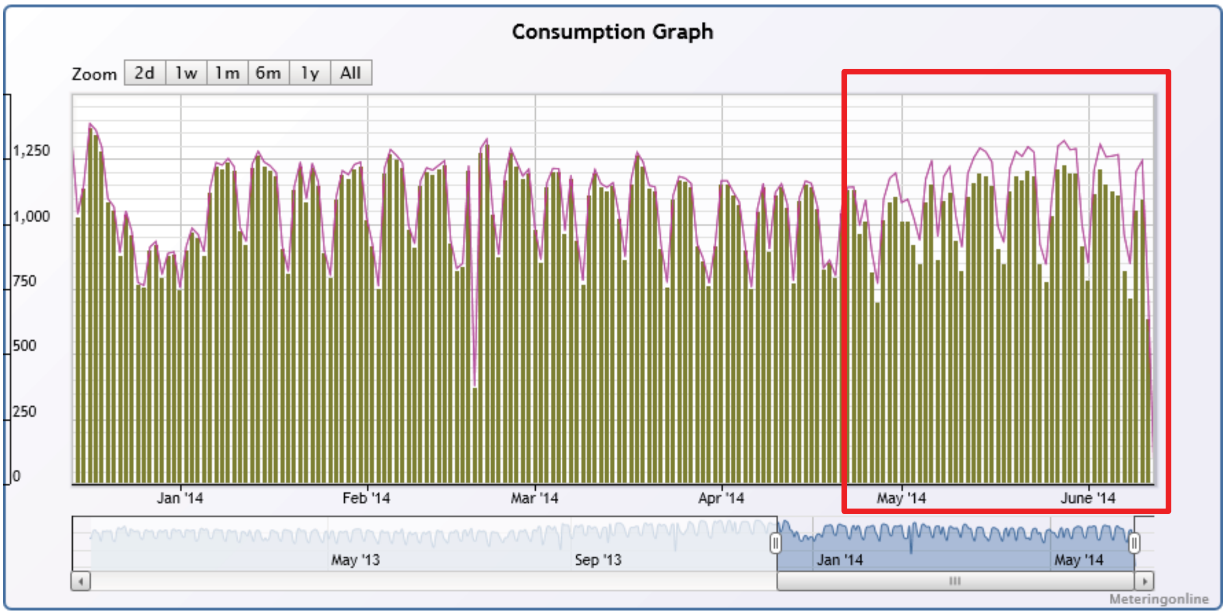


Figure 20. Demand graph illustrating the difference between kVA supplied and kW drawn when the power factor equipment had tripped.

8. METERING COSTS AND FINANCING OPTIONS

The costs for meter installation for most of the systems found in the Agri-Processing sector are provided in the sections below. These costings assume that the site is in a major metropolitan area and that the installation has no practical complications relating to the installation. The costings are also an indication of the pricing as of November 2021 and should be escalated when used. Ongoing maintenance and calibration can be budgeted annually at 10% of the cost of equipment installed.

8.1 Water Metering

In many cases there are existing water meters in place that can be used to capture continuous flow data. Should this not be the case then the table below can be used as a budget price for replacement of the meters or for a new installation. Many companies manually read the meters and compile the information on spreadsheets. We would recommend automating this process and a budget for this is also provided in the table below. The monthly subscription would apply should the data be hosted by a third party service provider.

Table 12. Budget price for the installation of a water meter.[6]

Nominal Diameter (MM)	Installed Cost	Data link per point	Monthly subscription per point
15	R 3 400	R 3 000	R 60
20	R 3 600	R 3 000	R 60
25	R 4 000	R 3 000	R 60
40	R 4 400	R 3 000	R 60
50	R 7 600	R 3 000	R 60
80	R 10 000	R 3 000	R 60
100	R 15 000	R 3 000	R 60
150	R 25 000	R 3 000	R 60
200	R 50 000	R 3 000	R 60
250	R 75 000	R 3 000	R 60
300	R 125 000	R 3 000	R 60
400	R 250 000	R 3 000	R 60
450	R 400 000	R 3 000	R 60

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[6] Personal Communication (August 2021) G.W. TRAUTMANN BK and Livewire Engineering (www.livewire.co.za)

Table 13. Budget price for the installation of quality meter types.

Metering Point	Installed Cost	Data link per point	Monthly subscription per point
Effluent - pH	R 15 000	R 3 000	R 60
Effluent - TDS	R 15 000	R 3 000	R 60
Effluent - COD	R 30 000	R 3 000	R 60
Custom Composite Sampler*	R 100 000		
Total	**R 160 000**		

* Custom composite sampler using flow to activate a peristaltic pump discharging into a refrigerated container with a manual overflow pipe fitted.

8.2 Electrical Energy Metering

Electrical meter costs would vary depending on the size of the installation and the number of feeds into the plant. As a budget cost for a 1MVA installation, the following costs would apply.

Table 14. Budget price for installing an electrical energy meter.[7]

Item	Cost
Meter	R 7 500
Data Link	R 5 000
Installation	R 2 500
Total	**R 15 000**
Monthly subscription per metering point	R60

8.3 Compressed Air Systems

Compressed air systems are a lot more costly to monitor as they require data measurement intervals in the second range and the data logger requires multiple inputs with a visualisation screen for trouble shooting at the compressor room itself.

Table 15. Budget Cost for installing a compressed air system metering programme.[8]

Item	Cost
Data logger with visualisation capability*	R 75 000
Compressor monitoring (power, flow, pressure and moisture)	R 75 000
Remote pressure and flow monitoring point linked to data logger	R 30 000
Total	**R 180 000**
Monthly subscription per metering point	R60

* Not required if data is captured to a SCADA system

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[7] Personal Communication (August 2021) Livewire Engineering (www.livewire.co.za)

[8] Personal Communication (August 2021) CS Instruments (www.cs-instruments.co.za)

8.4 Refrigeration / Chiller Systems

Cooling compressors can be cost-effectively monitored using conventional electrical and temperature metering systems although the temperature probes should be of a good quality and regularly calibrated. Flow data can be determined from pump curves and design data should flow metering prove to be cost prohibitive.

Table 16. Budget Cost for installing a chiller system metering programme.

Item	Cost
Electrical meter per compressor x 2	R 20 000
Temperature probes for feed and return lines per cooling loop x 2	R 10 000
Pressure probes for refrigerant lines x 2	R 10 000
Flow meter per cooling loop	R 20 000
Data link for compressor room	R 10 000
Total	**R 70 000**
Monthly subscription per metering point	R60

* Optimisation software not included in the costings above.

8.5 Boiler Systems

The boiler system costing assumes the indirect approach to metering will be utilised which would require the installation of an automated TDS blowdown controller. TDS controllers will usually realise operational and maintenance cost savings as the water treatment controls are improved. The TDS controller and O2 probes can be excluded from the monitoring system as the main objective will be to measure generation efficiency which can be done with the feed meter and fuel consumption figures, as well as spot checks on the boiler blowdown TDS. The table below assumes a two boiler configuration in the plant.

Table 17. Budget Cost for installing a steam system metering programme.

Item	Cost
TDS Controller x 2	R 100 000
Temperature Probe x 2	R 10 000
O_2 or CO_2 probe x 2	R 100 000
Hot Water feed meter – 80mm	R 20 000
Make up meter – 40mm	R 5 000
Liquid fuel flow metering system – 40mm	R 20 000
Boiler House data link / logger	R 5 000
Total	**R 260 000**
Monthly subscription per metering point	R60

* Optimisation software not included in the costings above.

8.6 Overview Budget

The following budget can be utilised for a plant with the following requirements:

- Refrigeration plant with two chillers
- Two boilers
- One municipal water feed and five sub-metering points requiring continuous logging
- One electrical feed with five sub-metering points
- One compressed air system with two compressors and one remote logging point
- An effluent monitoring point (TDS, COD and pH) with a composite sampler

Comprehensive metering programmes will usually have a payback of less than three years. A budget for this sort of programme is provided in the table below.

Table 18. Budget Cost for installing a comprehensive metering programme.

Item	Cost
Water Metering Programme (6 points)	R 100 000
Electrical Metering Programme (6 points)	R 100 000
Compressed air plant with one remote point (10 points)	R 180 000
Refrigeration Plant (7 points)	R 60 000
Boiler plant (9 points)	R 260 000
Effluent monitoring point and composite sampler (4 points)	R 160 000
Total Capital Costs	**R 860 000**
Monthly subscription for hosted solution	R2 500

9. DATA ANALYSES AND USAGE

The previous sections reviewed the common metering types and locations in a plant but attention must be given to interpreting the data that is generated. The following sections review common performance measurement approaches and introduce statistical analyses as a best practice tool for reviewing data.

9.1 Performance Measurement

Performance metrics are historically determined by simple metrics or ratios primarily as a result of finance departments needing to set budgets and assess performance against the set budgets. The different types of metrics are discussed in section 3.2. This section will look to expand on the concepts and provide tools to be able to analyse data more effectively.

1. Simple trend of monthly electricity use

Simple assessments of trends are not easy to judge from month to month especially if the process is seasonal. They can be useful to use if production is stable (little variation in production) volumes. The figure to the right is a graph of the plants total energy consumption per month likely derived from billing data. One will note the seasonal variation with peaks during the winter period.

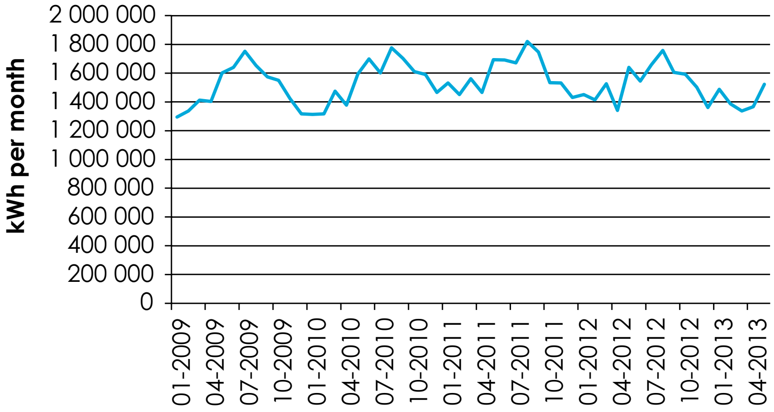


Figure 21. Monthly kWh data for a factory.

2. Annualised energy trend

A method to negate the impact of seasonality is to utilise an annual rolling average. Increasing or decreasing trends can be easily identified over a number of years. These trends do not incorporate relevant variables that may influence production. The rolling average for each month is the sum of the previous 12 months (including the month in question) divided by 12.

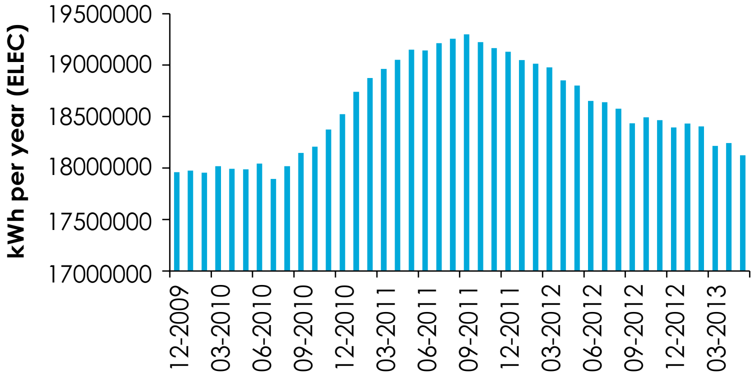


Figure 22. Annual rolling average of the same data.

3. Annualised energy and cost trends

A difficulty with savings initiatives is that, while there may be a saving in energy or water consumption, the actual financial savings may not be seen if the rates increase exceeds the actual energy savings realised. This can often give the sense that the savings programme is not effective. The savings reflected by the rolling average for kWh is not translated into the rolling average for costs for the same period.

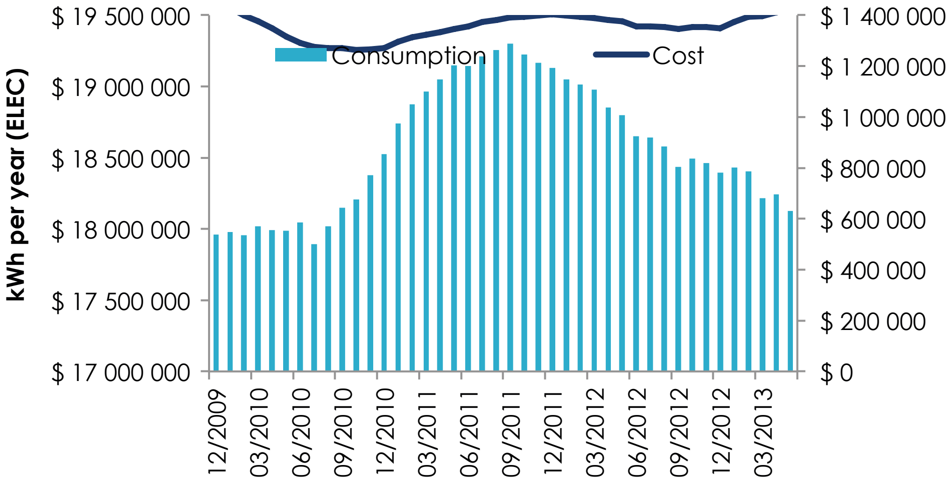


Figure 23. Annual rolling average and cost.

4. Specific ratios

A common method to factor in the impact of increased or decreased production is to utilise a ratio between the resource consumed and the amount of production. In this example the total kWh / month divided by the total production (in kg) for the same month. While this method accounts for changes in production, it does not take into account the effect of seasonality or baseload (consumption not related to production) and as a result have distortions in low production months or seasons.

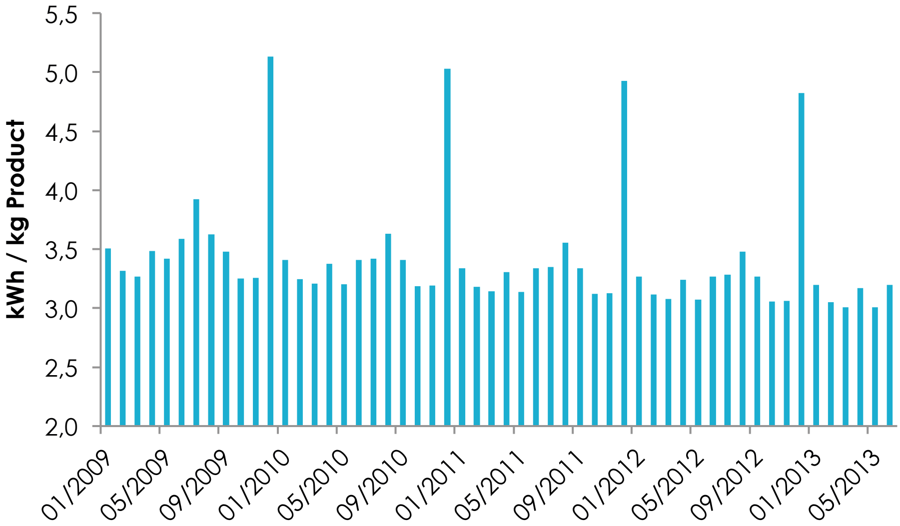


Figure 24. Ratio of kwh to production.

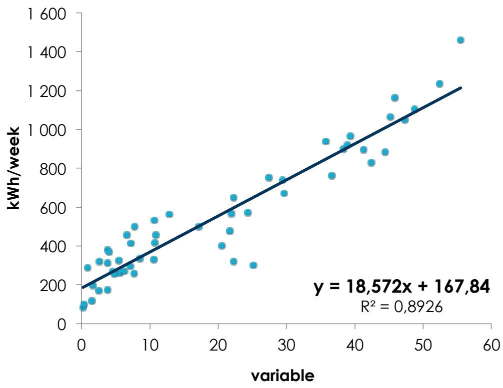
5. Statistical Tools

The material used in this section draws on the National Cleaner Production Centre South Africa's (NCPC-SA) two day course on Performance Measurement Indicators which goes into more detail and rigour on using statistical models.

A linear regression model can be developed which develops a predictive formula for resource usage performance given one relevant or influencing variable. Most spreadsheet programmes provide the option to insert a linear regression from a standard X-Y plot when developing a chart. MS Excel also provides formulas to provide the values without having to generate the chart as indicted in the slide to the right. The model provides an equation (y=Mx+C) which allows one to calculated consumption given a level of production (or other relevant variable). The equation below would apply.

Expect Consumption = Production x M (slope model constant) + C (y-axis intercept model constant)

Scatter Diagram



- You can also use formulae in excel
  - ✓ **c:** =INTERCEPT (known_y's,known_x's)
  - ✓ **m:** =SLOPE (known_y's,known_x's)
  - ✓ **R2** =RSQ(known_y's,known_x's)
- ✓ Remember: y= Mx+C
  - C and m are constants
  - X is a measured "relevant variable"

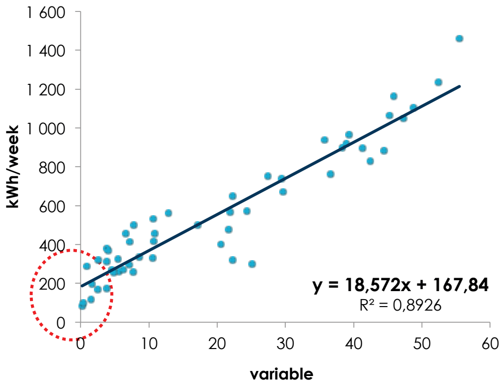
Figure 25. Example of a scatter plot with linear regression through the data points.

The statistical model provides an indication of the expected resource consumption should the production (or relevant variable) be zero. This is indicated in the slide to the right as the point where the X axis is zero. Examples of contributors to baseload are:

- Lighting systems
- Radiation losses
- Water leaks
- Cold storage

In any efficiency programme, focus should be on optimising the efficiency of the programme (i.e. the M in the y=Mx+C equation) as well as reducing the baseload (the C in the y=Mx+C equation).

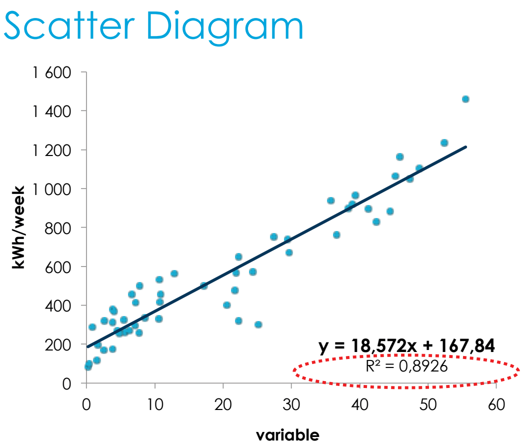
Scatter Diagram



- **Intercept:**
  - Consumption when the variable is 0.
  - It can be considered as the baseload in most of the cases.

Figure 26. Illustrates how to determine the plants baseload.

Statistical tools provide an indication of how much confidence one can put into the formula generated. One of these is the Coefficient of Determination or R-Square correlation (R2) which is a value between 0 and 1. The R2 value indicates how much of the variation in the data can be explained by the influencing variable used. A high R2 value (>0.75) indicates that the equation can be used to predict consumption. Conversely, a low R2 (<0.5) also provides an indication poor control and internal inefficiencies or the possibility that the selected independent variable is not the correct or sole influencer of the the resource consumption.



- **R^2:**
  - % of variation explained by variables
  - **High R2:**
    - a) Strong correlation. Not necessarily good performance.
  - **Low R2:**
    - a) There are other variables.
    - **b) Saving Opportunities in operational control.**

Figure 27. How to determine the R2 value.

9.2 Case Study

Data over a period of time can be difficult to analyse especially if the production is seasonal and the energy or water consumption is strongly influenced by external weather conditions. The table below is of an actual plant's coal usage and production in 2020. The plant utilises the simple ratio (tonne Coal / tonne production) to measure performance. Anything below 1 is deemed to be good performance whereas everything above 1 is deemed to be poor.

Table 19. Overview of 12 month data for the plant.

	Coal Consumption (Tonne / month)	Production (Tonne / Month)	Heating Degree Days (HDD) (13.5 °C)	Simple Ratio
Jan-20	969	1 032	0	0.9
Feb-20	1 021	1 235	0	0.8
Mar-20	868	949	0.4	0.9
Apr-20	0	0	11.5	Err
May-20	798	328	64.3	2.4
Jun-20	943	752	129.4	1.3
Jul-20	1 441	1 249	115.9	1.2
Aug-20	1 184	1 207	70.1	1.0
Sep-20	1 085	1 259	13.1	0.9
Oct-20	1 221	1 265	1.9	1.0
Nov-20	1 049	1 253	0.7	0.8
Dec-20	644	741	0	0.9
Average	**935**	**939**	**33.9**	1.0

One will note the impact of the COVID lockdown on their production volumes over the period April 2020 – Jun 2020. One would typically expect the performance to be poor when using intensity targets. In this case the intensity target could not be used as the there was no production in April 2020. July 2020 stands out though as it is a high production month yet it still performs poorly based on the intensity target method. Similarly, December 2020 stands out as being a good performing month even though it is the second lowest production month in the year. Conventional intensity targets are useful for quick assessments but are significantly distorted when a plant has a high baseload (non-production consumption) or if there are factors that strongly influence energy consumption that are not directly related to production. Statistical tools are a better way of measuring actual performance. In this instance, the company generated a simple X-Y plot in excel and opted for a liner regression.

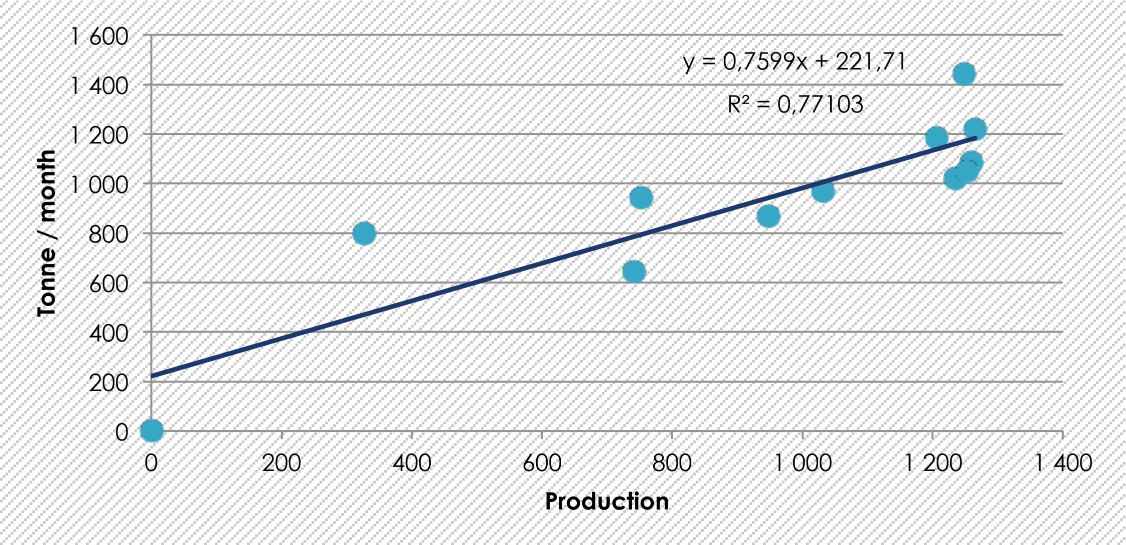


Figure 28. X-Y plot with a linear regression.

The statistical tool has determined the baseload to be 221 tonne coal per month (fuel consumption not dependent on production) and the simple ratio of 0.76 tonne coal / tonne production can be an effective measure of performance once the baseload has been taken into account. In this case, the baseload can potentially be ascribed to radiation losses, firing losses and leaks (condensate and steam). The equation provided below calculates the expected coal consumption once the baseload has been taken into account.

$$\text{Expect Coal Usage (Tonne)} = 0.77 \times \text{Production (Tonne)} + 221 \text{ tonne coal (baseload)}$$

While the above regression provided a better method for measuring efficiency, other factors had a significant impact on coal consumption. From the table, it was clear that the winter months tend to be the poorer performing months. An online tool (www.degreedays.net) was used to determine the impact that average ambient temperatures have on coal consumption. The site expressed this in the form of Heating Degree Days (HDD) which is a measure of how much (in degrees Celsius), and for how long (in days), the outside air temperature was below a certain level. The data was used to compile a regression with more than one relevant variable (HDD and production) and an equation was generated. The new model had a statistically more reliable prediction of expected coal consumption based on weather and production.

$$\text{Expect Coal Usage (Tonne)} = 0.78 \times \text{Production (Tonne)} + 2.78 \times \text{HDD} + 106 \text{ tonne coal (baseload)}$$

In the following table, tThe cells highlighted in green depict better than expected performance when using the different models. One will note that the simple ratio and the statistical model only using production as a relevant variable misinterpret performance specifically in summer months. The regression model using production and average ambient temperatures provides a very different view on the better performing months.

Table 20. A plant's 12 month data including regression analyses outputs.

					Production		Production and Weather	
	Coal Usage [tonnes]	Production [tonnes]	HDD (13.5 oC)	Simple Ratio [Coal Usage / Production]	Expected Coal Usage [tonnes]	Difference [tonnes]	Expected Coal Usage [tonnes]	Difference [tonnes]
Jan-20	969	1 032	0	0.9	1 006	-37	913	55.6
Feb-20	1 021	1 235	0	0.8	1 160	-139	1 072	-50.9
Mar-20	868	949	0.4	0.9	942	-75	849	18.6
Apr-20	0	0	11.5	Err	222	-220	139	-137.1
May-20	798	328	64.3	2.4	471	328	542	256.7
Jun-20	943	752	129.4	1.3	793	150	1 055	-111.6
Jul-20	1 441	1 249	115.9	1.2	1 171	271	1 405	36.0
Aug-20	1 184	1 207	70.1	1.0	1 139	45	1 245	-61.2
Sep-20	1 085	1 259	13.1	0.9	1 179	-94	1 128	-43.0
Oct-20	1 221	1 265	1.9	1.0	1 183	37	1 101	119.5
Nov-20	1 049	1 253	0.7	0.8	1 174	-125	1 088	-39.3
Dec-20	644	741	0	0.9	785	-141	686	-42.0

Regardless of what tool is used, data should never be utilised without a practical understanding of the influencing factors. The utilised coal consumption figures are based on purchasing records rather than actual consumption which could lead to inaccuracies in the input data. To this extent, a model was developed utilising the boiler feed water supply (indirect measure of steam generated), production and Heating Degree Days. The model provided an acceptable correlation with a high degree of data accuracy and 52 data points (weekly) instead of 12 (monthly).

While utilising regression data will be able to provide insight into the process controls as well as a predictive tool for setting realistic targets taking all influencing variables into account, additional detailed process and system analyses should still be conducted to understand if efficiency opportunities exist as well as the savings potential. The United States Department of Energy Open Source software tool called "MEASUR" has many useful functions for analysing both historical data and trends as well as system data (i.e. steam, pumps, fans and compressed air systems). https://www.energy.gov/eere/amo/measur

The Website www.degreedays.net provides a useful platform to obtain weather data for various locations across the world. The web-site also provides a regression tool which you can paste data and it will find the best temperature set-points for a regression.

10. CASE STUDIES

10.1 Atlantis Water Supply Scheme

The Atlantis Water Supply Scheme (AWSS)[9] and the associated groundwater recharge scheme is a good example of how improved monitoring has allowed for sustainable water extraction from the groundwater reserves. The scheme was initially augmented with treated waste water and storm water however the quality of the two streams resulted in a steady increase in the salinity of the ground water. The waste water stream was subsequently excluded from the augmentation scheme but as a result there was a reduction in ground water reserves. Treated domestic effluent was included and then subsequently, low salinity industrial streams. The interventions not only resulted in an increase in the water levels but also resulted in a decrease in the overall salinity concentration. While the case study relates to a municipal scheme, the learnings are important for companies interested in long term sustainable extraction of resources from a water catchment area, and especially if ground water is utilised in lieu of limited municipal potable water supplies.

SUSTAINABLE WATER EXTRACTION

Implementing effective metering and monitoring systems is crucial for long term sustainable management of resources.

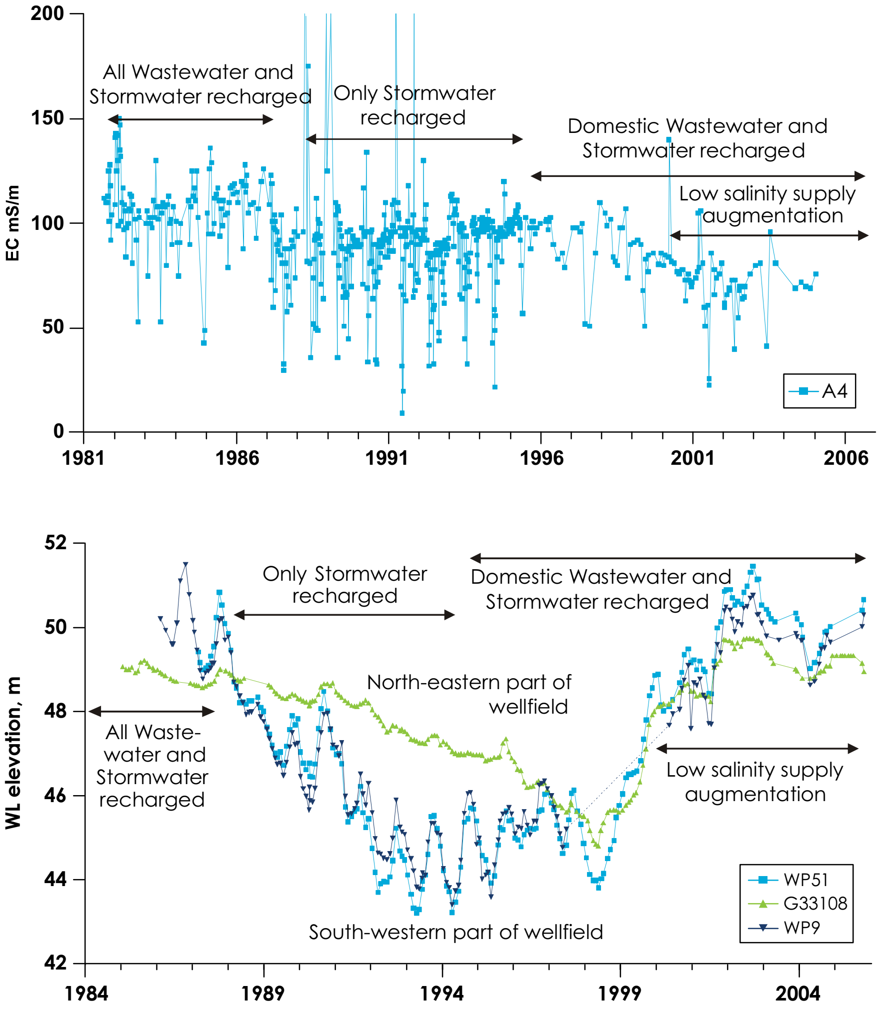


Figure 29: Atlantis Recharge Quality and Level Sampling Record

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[9] Department of Water Affairs (2010), Strategy and Guideline Development for National Groundwater Planning Requirements. The Atlantis Water Resource Management Scheme: 30 years of Artificial Groundwater Recharge, P RSA 000/00/11609/10 – Activity 17 (AR5.1)

10.2 ABI Premier Place – Pheonix (McComb, 2016)

20 NCPC Years
INDUSTRIAL EFFICIENCY IN SOUTH AFRICA

Amalgamated Beverage Industries (ABI) is the leading soft drink business in the international SABMiller plc group of companies. The ABI Premier Place manufacturing plant is approximately 20 years old and functions mainly as a returnable glass bottling (RGB) beverage facility. The beverages are filled into 300ml, 500ml and 1.25l bottles.

The company had been on an aggressive water savings drive which had seen its specific water consumption drop from 5.5 in 2011 to 2.3 in 2013.

One of the savings interventions over this period was the installation of a tank to recover the back wash and reject water in the water treatment systems. This water was used on non-product surface cleaning and applications (i.e., crate washing, lubrication systems and manual cleaning). The initial investigation indicated that the recovered water would be sufficient for the recovered water demeand. A meter was installed on the municipal make-up line to the plant and it was found that the recovered water demand outstripped the supply, and in addition, that the municipal water supply control valve was faulty resulting in municipal water displacing the recovered water.

The faulty valve was repaired and additional water from the cleaning-in-place (CIP) systems was recovered. After the intervention, no further municipal make-up water was required for the recovery tanks. Furthermore, a programme was implemented to improve the efficiency of recoverd water usage to reduce the demand to ensure no additional municipal water was required.

WATER RE-USE SYSTEM SAVINGS

Interventions included CIP rinse water recovery and improved recovered water utilisation.

IMPACT OVER 3 MONTHS

Actual Cost Savings	**R190,697**
Actual Water Savings	**7,008 kl**
Cost of Project	**R32,000**
Payback Period	**1 Month**

Figure 30. Picture of the recovery and blending tanks.

10.3 RFG Foods – Groot Drakenstein

RFG Food has 14 state-of-the-art production facilities and two farms – dairy and pineapple. The production facilities are equipped with modern technology and certified according to international standards. The RFG Foods complex in Groot Drakenstein is located in Pniel Road near Franshhoek outside Cape Town. The complex comprises of Ready Meals, Puree Plant, Dairy, RFG Head Office and the Ayreshire Stud Farm as well as Services Departments.

An energy assessment previously carried out in January 2013 The methodology included compiling detailed electrical energy balance and identifying opportunities for increased optimisation. Areas for resource saving identified included a 25% reduction in electrical energy costs and an 18% reduction in steam generation costs. Savings in excess of R 4,000,000 per annum were identified. During the audit a detailed analyses was conducted on the electrical energy consumption over the period of a year. The existing RFG tariff from Groot Drakenstein Municipality was a standard consumption (kWh) and maximum demand (kVA) tariff. The option to switch tariffs was reviewed and a Time of Use (TOU) tariff in was adopted in July 2013. There were no capex requirements. The savings provided immediate payback and significant reduction in electricity costs.

TARIFF MANAGEMENT

Shift from demand tariff to a time of use tariff.

Cost Savings	**R2.3 Million**
Cost of Project	**R0**

Being a 24 hour operation, RFG were able to derive significant benefit from the lower off-peak tariff as well as the lower kVA charges.

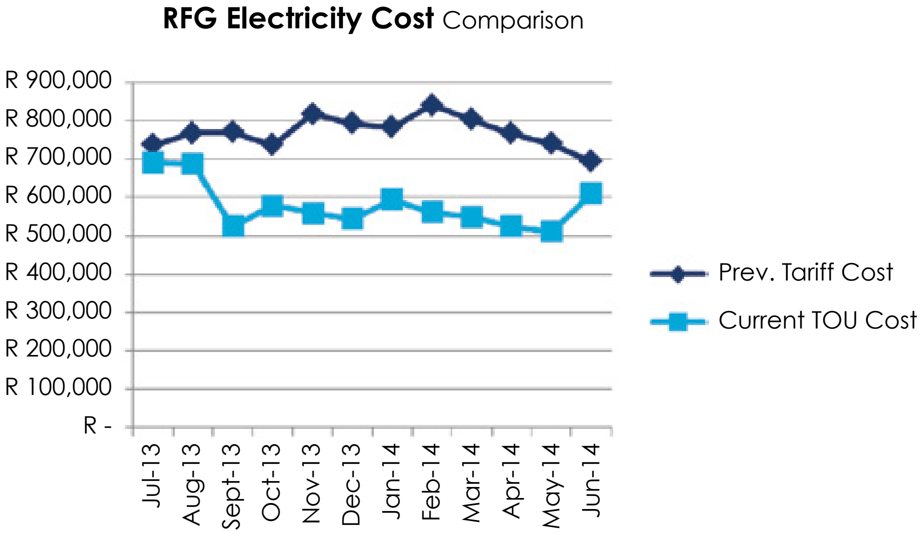

Figure 33. RFG Electricity cost comparison July 2013 - June 2014

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