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Implementation of an ISO 50001 energy management system using Lean Six Sigma in an Irish dairy: A case study

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Abstract

Purpose: This article aims to optimise energy use and consumption by integrating Lean Six Sigma methodology with the ISO 50001 energy management system standard in an Irish dairy plant operation.

Design Methodology/Approach: This work utilised Lean Six Sigma methodology to identify methods to measure and optimise energy consumption. The authors use a single descriptive case study in an Irish dairy as the methodology to explain how DMAIC was applied to reduce energy consumption.

Findings: The replacement of heavy oil with liquid natural gas in combination with the new design of steam boilers led to a CO₂ footprint reduction of almost 50%.

Practical Implications/Limitations: A further longitudinal study would be useful to measure and monitor the energy management system progress and carry out more case studies on LSS integration with Energy Management systems across the dairy industry.

Originality/Value: The novelty of this study is the application of LSS in the dairy sector as an enabler of a greater energy-efficient facility, as well as the testing of the DMAIC approach to meet a key objective for ISO 50001 accreditation

Keywords:

Dairy; Energy; DMAIC; ISO 50001 standard; LNG; Lean Six Sigma

Abbreviations:

ANOVA	Analysis of Variance
CHP	Combined Heat and Power
CIP	Clean In Process
COMAH	Control of Major Accident Hazards
CUSUM	Cumulative sum
DHW	Domestic Hot Water
DMAIC	Define, Measure, Analyse, Improve, Control
EED	Energy Efficient Design
EMP	Energy Management Plan
EMS	Energy Management System
HFO	Heavy Fuel Oil
KPI	Key Performance Indicator
KWh	Kilowatt-hour
LNG	Liquefied Natural Gas
LPG	Liquefied Petroleum Gas
LPHW	Low-Pressure Hot Water
MV	Measurement and Verification
MWh	Megawatt hour
SEU	Significant Energy User
SIPOC	Suppliers, Inputs, Process, Outputs, Customers
UHT	Ultra High Temperature
VOC	Voice of Customer
WPC	Whey Protein Concentrate

1.0 Introduction

The Food and Agriculture Organization of the United Nations has forecasted a significant increase in the global consumption of dairy products by 19%, to 99 kg person⁻¹ year⁻¹ by 2050, compared to the consumption in 2005–2007 (Bruinsma and Alexandratos, 2012). The increased consumption of dairy products will create significant challenges regarding the consumption of on-farm energy resources by looking for alternative sources to reduce energy costs and concurrently minimise or eliminate the release of greenhouse gases (GHG) from manufacturing (Shine et al., 2020). With energy costs increasing year on year and the dairy industry coming under increased scrutiny in relation to its CO₂ emissions, reduction in energy use is a key area of focus, by keeping high standards for the product quality at the lowest cost (Trubetskaya et al. 2021). The ISO 50001 EMS was first published in June 2011, and similar to ISO 9000, it follows the PDCA framework for continual improvement (ISO, 2011). This energy management standard aims to help organisations optimise their energy consumption systematically and incorporate management's role in supporting energy projects, incorporating energy in organisational policy, and measuring energy consumption and improvements (Mkhaimer et al., 2017).

Energy-efficient supply chain management using a Lean Six Sigma (LSS) approach is an important organisational philosophy to achieve corporate profit (Egas et al., 2021).

As ISO 50001 incorporates continuous improvement, LSS tools are instrumental in helping to meet the standard. Minimisation of GHG is one of the most cost-effective measures to improve energy efficiency in dairy plants, whereas Six Sigma statistical tools using Design of Experiments

and ANOVA test analysis have been identified as the most influential in obtaining the highest energy saving concurrently reducing the thermal load (Zahraee et al., 2014).

Within the literature, there are many studies related to the application of LSS methods in the food industry. For example, Costa et al. (2018) highlighted that application of LSS in the food industry in the last decade has been increasing but is still sparser than in other areas. There are also some studies on the integration of LSS with energy management improvement (Cherrafi et al., 2016).

Mkhaimer et al. (2017) have written about the compatibility of LSS and energy management within the ISO 50001 framework in a pharmaceutical company.

To the authors' knowledge, this is the first study that considers the integration of LSS with ISO 50001 to become certified to the standard and optimise the energy management system in an Irish dairy plant operation. This research aims to develop an energy management system for a dairy by defining KPIs that will measure this dairy plant's performance in Ireland. This step will allow benchmarking with other similar dairy facilities to meet ISO 50001 standard pre-requisites. Subsequently, Lean Six Sigma tools will be utilised to reduce energy consumption on the Lakeland Dairies site in Killeshandra. Finally, following the natural flow of DMAIC to implement the ISO 50001 standard will give the energy management team clear steps and milestones to ensure a successful outcome.

Thus, the research questions (RQs) are:

1. How can LSS tools be utilised and integrated within the ISO 50001 energy management system to reduce energy management consumption?
2. Identify alternative energy sources to meet the thermal load of the site?

The literature review is presented in section 2, followed by a detailed methodology in section 3. Finally, the results, discussion and conclusion are summarised in sections 4, 5 and 6.

2.0 Literature Review

Along with labour costs and maintenance spending, energy import is one of the three largest cost overheads in a typical dairy operation (Carvalho et al. 2010). Electricity is used to power large motors, e.g., air compressors and large refrigeration systems, and lighting, whilst fossil fuels are burned to meet the thermal loads associated with process heating and Clean in Process (CIP) systems. LSS systems bring Lean and Six Sigma together in a single business improvement approach centred on creating value for the customer (Csikai, 2010; Chay et al., 2015). A lean approach focuses on the minimal exploitation of resources through minimising waste and mitigating the harmful effects on the environment is especially relevant to the dairy sector concept (Saunila et al., 2018). Six sigma tools allow problems to be fully understood in terms of significant factors and quantifying their effects. Continuous improvement in energy efficiency at dairy plants includes many sub-processes that substantially affect the economy of power and heat generation to which Lean Six Sigma tools can be applied.

Six Sigma's DMAIC is more frequently used in the dairy plant operations for established products and processes than the DMADV methodology, mostly used to design and develop new products or services (Trubetskaya and Mullers, 2021). Previous studies have been done in the discussion of optimising food manufacturing parameters, e.g., pH, temperature, concentration, flow rate, etc., aiming to achieve the maximal yield and the highest quality of products (Hakimi et al., 2018; Lee and Lucey, 2004; de Mast and Lokkerbol, 2012; Dora et al., 2013). Six Sigma as a quality tool is

primarily used in manufacturing industries where there is a specific product with specified dimensions and measurable properties at different stages of production (Kaushik and Khanduja, 2009). The optimisation of energy efficiency at the dairy plant includes steam, water, air, hydrogen, and many other streams which are not visible and are typically measured by various instruments mounted on the process hardware in the form of pressure, temperature, and flow (Kumar, 2002). Lean Six Sigma tools have been used in combination with the value stream mapping for the continuous improvement in the environmental sustainability of a food processing plant (Powell et al., 2017). However, the main objective of that study was related to the elimination of raw material waste and increase in environmental sustainability with less focus on energy consumption. Another study demonstrated how the Six Sigma approach following the DMAIC steps could be used to develop an energy management plan (EMP), a systemic way to reduce energy usage and operating costs of a facility simultaneously (Lee et al., 2014). Once this EMP is established, it can be used as part of the ISO 50001 implementation, a benchmark energy management standard. The energy efficiency of a dairy plant can be improved using a standardised taxonomy that allows learning how energy is used in operations by measuring and monitoring energy performance (Kanchiralla et al., 2021). ISO 50006 defines the indicators for measuring and monitoring energy performance to understand the deployment levels of the potential and target levels for improvement (International Organisation for Standardization ISO 50006, 2014). As per ISO 50001 standard, energy planning should lead to activities that continuously improve energy performance concurrently following the energy policy at the dairy plant. ISO 50001 provides a conceptual map for energy planning by saving energy and costs (International Organisation for Standardization ISO 50001, 2011). The Six Sigma DMAIC approach can be a powerful way to reduce energy usage within a system and refine the variation that drives energy consumption

(Ahmad et al., 2022). Statistical tools allow users to identify and quantify interactions between variables that may not be well understood. The DMAIC process guides practitioners toward creating processes with far fewer defects and excursions that are usually at the core of wasted energy. Many energy savings are obvious. However, the Lean Six Sigma methodology integration can be applied in cases where multiple variables are involved, and cause and effect relationships are not readily apparent. The results of previous studies using the DMAIC approach demonstrated energy savings of 50 % (approx. €1.8M in 2021) through the reduction in scrap and avoidance of additional energy usage (Singh and Bakshi, 2018). The other study is an example of DMAIC integration to change a company culture with respect to the energy savings in the company building (Kane, 2019). Substantial savings (about \$4.9 million per year) were observed with little or no capital investment. A cross country analysis of dairy plants' energy consumption and energy efficiency was performed using the DMAIC methodology by defining two different KPI types (Ramirez et al., 2006). Before the abolition of the European milk quota system, a more recent study looked at direct energy use in the Irish dairy processing industry (Finnegan et al., 2013). This study determined the overall energy usage in the Irish dairy processing industry to be 474 kWh/m³ of milk, with an overall increase in energy efficiency from 2005 to 2013. This is due to an increase in electrical energy offset by decreased thermal energy. In the recent article, a benchmarking was performed to bridge a gap in information with respect to energy efficiency by giving particular emphasis to steam generation and usage (O'Reilly, 2017). Dairy processing is one of the most energy-intensive sectors within the food industry, e.g., combined casein and lactose energy use (electricity: 0.92MJ/kg; fuel: 4.12 MJ/kg), respectively (Ladha-Sabur et al., 2019). Between 2006 and 2009, the Irish dairy sector has invested significantly in energy conservation, including the recovery of heat from condensate / evaporate/ effluent/pasteuriser

water, low energy cleaning/disinfection systems, insulation of pipes and tanks, economisers, lighting control, variable-speed motor drives, etc. and the implementation of energy management systems. This resulted in a 20% reduction in mean annual energy use per plant (204,682 MWh to 163,771 MWh), equating to a mean emission reduction of 11,000 tonnes of CO₂ per plant (Enterprise Ireland, 2011). The largest share of fuel consumed by the dairy industry (80%) is used for direct process heating and steam generation via boiler systems, whereas the US dairy sector uses almost exclusively natural gas to meet this thermal energy demand (Brush et al., 2011). The previous research has underlined the importance of system design and process control in steam efficiency during dairy plant operation. Heat recovery offers significant opportunities to reduce energy consumption, and suggested improvements include preheating products and utilising condensate return by increasing storage capacity for this condensate for use in the pre-washing of equipment (Makaliunas and Nagevicius, 1998; Brush et al., 2011). Other forms of heat treatment are emerging and have shown promise, e.g., pulsed electric field pasteurisation and radio frequency drying, with strong potential for energy savings (Lung et al., 2006). Where gas is used, then a combined heat power plant (CHP) may be considered, as well as the energy savings due to an overall efficiency increase (thermal and electrical); CHP units give a flexible power option and come in a standard design with a relatively small carbon footprint (Brahmanand, 2018). LNG (Liquefied Natural Gas) is growing in importance across the globe (Laciak et al., 2019). Where natural gas pipelines are not feasible or do not exist, liquefying natural gas is a way to move natural gas from producing regions to markets (US Energy Information Administration, 2021). LNG is also more environmentally sustainable than any other fossil fuel. Burning natural gas produces dramatically less CO₂, NO_x, and SO₂ than fossil oil and almost no ash, dust, smoke, or particulate

matter (Pavelenko et al., 2017). As well as allowing the use of CHP, LNG regasification may be recovered and used for electricity generation.

3.0 Methodology

3.1 The Case study methodology

The research methodology of this paper is case research using the DMAIC methodology. As the RQs in this study are based on "how to use LSS methodology to improve energy management", Yin (2014) recommends that this "how" research question lends itself to the case study approach. Many studies utilising DMAIC methodology to solve problems and answer "how" and "why" RQs have utilised the case study approach to aid understanding of the problem and its context (Byrne et al., 2021; McDermott et al., 2022; Sony, 2019, Li et al., 2019)

Based on the research type and conditions and using DMAIC, a mix of qualitative and quantitative tools, the authors use a single-case study approach utilising a dairy. The single case approach focusing on a single phenomenon aids understanding of the areas being studied in the context of RQs (Lee, 1999).

Yin (1981, 2009) defined the case study as an empirical investigation investigating a contemporary phenomenon in a real-life context. The extent to which one can generalise from a single case study is limited, but by the documenting of the case study story, each case adds to the state of the art available for future practitioners and researchers (McDermott et al., 2022; Antony et al., 2012b).

3.2 Roadmap and DMAIC

The team at the Lakeland dairy plant in Killeshandra has identified energy as the second-largest overhead on-site, just behind labour spend; electricity is equivalent to 30% of total kWh use, 70% being the site thermal load. Electricity, in 2019, accounted for 52% of the energy spend, i.e., although 30% of the kWh total for the site. Electricity in 2019 was considerably more expensive than the thermal sources of Heavy Fuel Oil (HFO) and Liquid Petroleum Gasoline (LPG). Due to its relatively remote location, Killeshandra dairy is "off-grid" when it comes to meeting its thermal load, there is no accessible natural gas line, and there is none planned in the foreseeable future. Relatively expensive HFO was the fuel burned to produce steam to provide the heat for all parts of the factory. Not unlike most dairies, the processes utilised in Killeshandra are very energy-intensive with considerable heating and cooling loads. For the basis of this project, 2019 was chosen as the base year, and any savings in 2022 will compare against 2019 energy consumption. This project coincided with the COVID-19 pandemic, 2020/21 are considered abnormal years with much reduced volumes in some areas, thus a unique product mix across the facility. The optimisation of the energy use, i.e., the electrical and thermal loads at the dairy plant, is performed using the DMAIC methodology, as shown in Figure 1.

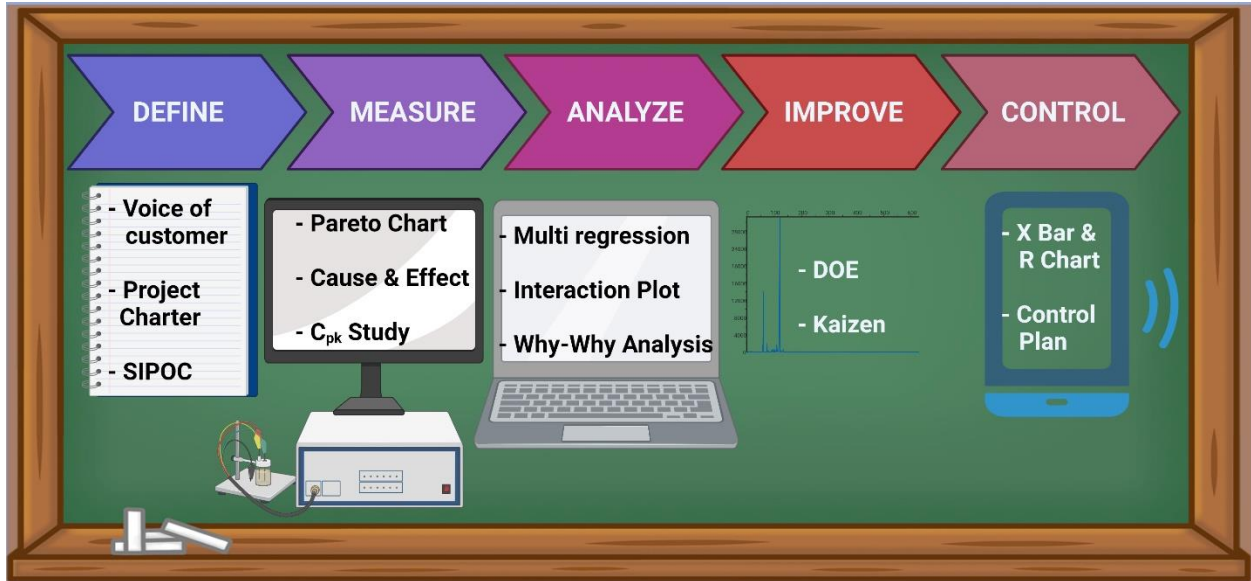


Figure 1: DMAIC methodology implemented at the dairy plant.

This was planned to design a roadmap for reducing energy consumption and further process accreditation according to ISO 50001 standard. The energy management system to be awarded ISO 50001 accreditation must meet the pre-requisites whilst demonstrating the annual improvement in energy efficiency at the dairy plant. The energy management team was familiar with the DMAIC concept through completed projects as part of Lean Six Sigma green belt training.

3.3 Define the Project Goals and Customer Deliverables

The *Define* phase in the problem-solving approach scoped the problem statement and gathered the voice of the organisation and customer. In this case, the team captured the problem statement in the form of a project charter that outlines the scope of the DMAIC project. This team charter, which feeds into an energy policy for the site, was created and agreed upon by the energy management team, as shown in Figure 2.

The charter calls out the objective, stakeholders, risks etc. The Voice of the Customer (VOC) is also sought, and an overall SIPOC is created to ensure that the project charter and scope meet the needs of the various stakeholders within the business. Stakeholder analysis is vital as the goals and objectives of the project should be supported by the stakeholders, that is, those who will be either impacted by the project or who may influence the project (Taghizadegn 2014).

Step two of the define phase consisted of a stakeholder analysis formulated in line with a communication plan to engage and communicate with the stakeholders throughout the project lifetime and became a part of the project charter. It has been shown in the previous studies that the charter defines the communication plan and tools, which are the key parameters throughout the life of the project. It enables employees and cross-functional stakeholders to understand how their operating environment performed and how it may transform in the future.


<p>Lakeland Dairies 6o</p> <p>Charter for: Energy Reduction, Lakeland Dairies Killeshandra</p> 	
<p>Problem Statement: Energy spend on the Killeshandra site is the 2nd largest overhead (after labour) and is €3.99M annually (2019). Thermal (HFO) and electricity spend is €1.74M and €1.94M respectively. LPG (gas) for casein drier is a further €180k. With the site being "off-grid" thermal heating load (steam) is fuelled from "tankered in" Heavy fuel oil (HFO), HFO availability will become a major issue in 2024. For the site to remain competitive a new fuel source needs to be sought whilst overall energy spend needs to be reduced by at least 30%, i.e. electricity and thermal loads need to be reduced.</p>	<p>Goal/Objective: Identify a replacement fuel source for HFO and optimise the electrical and thermal loads onsite to reduce overall energy spend by 30% by the end of 2022. Full implementation and accreditation of ISO 50001 (2018) standard for Killeshandra Energy Management System, EMS by March 2021</p>
<p>Business Case: Any reduction in energy use air use will go straight to the bottom line in terms of reduced energy bills. A reduction of 30% will give a saving of €1.2M. An alternative fuel source to HFO will enhance business continuity Optimisation of energy use and increase in energy efficiency will allow a more sustainable and marketable business, e.g., use of the ISO 50001 logo on company literature</p>	<p>Scope & Risks: Total Energy Use, Electricity, HFO and LPG (Casein Gas) for Killeshandra Site & Waste Water Treatment Plant. The full ISO 50001 standard COVID-19, Substantial variances against budget volumes in 2020. Availability of resources also negatively effected in 2020. Project implementation may be at risk BREXIT - Volume mix may change which will in turn effect energy profile for site. Capital expense required not available or actions implemented to meet project milestones COMAH - Any change in Fuel or storage thereof may bring the Killeshandra into "The Control of Major Accident Hazards (COMAH) Regulations" and safety management systems will need to be reviewed and updated.</p>
<p>Team: Sponsor: Derek O'Connor, Site Manager Owner/Champion: Seamus McGovern, Engineering Manager Team Members: A cross functional team whom are involved in the process. Conor Downey (Process Engineer), Martin Reilly (Automation Engineer), Kevin Gallagher (Apprentice Mechanical Technician)</p>	
<p>Project Timeline: ISO 50001 (2018) Accreditation - Q1 2021 Identify Replacement Fuel and supplier for HFO - Q1 2021 Identify and quantify options for thermal/electrical reconfiguration - Q1 2021 Board Approval for capital spend - Q2 2021 Detailed Design - Q2 2021 Planning permission for site works (if applicable) - Q2 2021 Project Plan (suppliers, schedule etc.,) - Q2 2021 Project Implementation - Q4 2021 M&V analysis to confirm savings Q1, Q2 2022</p>	



Figure 2: Project Team Charter.

3.4 Measure Current Performance.

In the *Measure* phase, the team collect available data by observing and recording the selected processes. The data collection plan was subsequently developed that identifies how the data would be collected and analysed. As data is collected, it allows the team to develop descriptive statistics of the actual performance in the area. First, the energy metering strategy was refined so that a Pareto analysis of energy could be performed to allow the Significant Energy Users (SEUs) to be

identified and analysed. In the present case study, SEU was categorised into groups such as (1) Steam Boilers; (2) Compressed air; (3) Refrigeration; (4) Separation and Evaporator; (5) UHT; (6) Casein; (7) Lactose; and (8) WWTP. During the Measure phase, JMP software (version 16.0, JMP Germany) allowed the energy management team to put quantifiable data to back up their hypotheses of SEU definitions. The measure phase has also highlighted other lesser considered areas in the past to identify a saving potential with the energy-efficient use at the dairy plant. Regression analysis was performed to give specific energy performance for the distinct business units and typically measured kWh/unit of production.

3.5 Analyse and Determine Root Cause of Defects

Implementing a LSS approach, as done in this case study, allows an organisation to focus on both Lean and Six Sigma simultaneously, providing the best results for improved quality and process efficiency (Plenert and Cluley 2012). The analyse phase consisted of both Lean and Six Sigma tools.

Once the project team identified the appropriate data sets, a detailed analysis of the data was performed. For the majority of SEUs, this typically involved further regression analysis to determine if there was any relationship and, if so, the derivation of a prediction equation and key performance indicators (KPIs) for each SEU. In addition, other Six Sigma tools were used during the measure phase, such as Cause-Effect and C_{pk} studies, to identify factors that may have a significant effect on energy consumption. Following statistical analysis and brainstorming through the fishbone exercise, the team then evaluated each primal under the following conditions to identify the waste generated by categorising the value-added and non-value added activities.

3.6 Improve the Process

Brainstorming exercises with a broad workforce sample were carried out to identify energy-saving projects that were added to an energy 'opportunities register', essentially a large list of possible projects that, if implemented, might reduce either the electrical or thermal load on-site. Capital expenditure and resultant savings were estimated to give an initial idea of project payback. This process was carried out with specialist external energy consultants and met an 'External Energy Audit' requirement, a distinct clause of the ISO 50001 standard. Tools such as a prioritisation matrix were incorporated into the opportunities register to help identify those projects that should be progressed. The dairy management and consultancy defined the weightings in the prioritisation matrix. The most significant features from the opportunities register were further screened in the prioritisation matrix using "easy wins", "high potential", "low priority", and "long game" solutions in relation to the energy upgrade at the dairy plant.

3.7 Control Future Process Performance

Monitoring, measurement, and continual analysis is a key requirement of ISO 50001. Prediction expressions were used to compare actual energy consumption versus target, and control charts were used to satisfy the energy team that a particular process is in control and at target. The pre-thermal transformation process is relatively simple by representing steam boilers as suppliers of a few heat sinks which contain a minimal number of outliers. From June 2022 onwards, it will be a much more complex system after fully implementing the LNG thermal transformation project. JMP software will be a key tool to ascertain relationships between variables (factors), e.g., heat

recovery average temperature or run time on a UHT steriliser and affects such as the LNG usage by the three new LPHW boilers and CHP engine. The prediction profiler function may be used to optimise process settings, and the prediction equation used to set targets and annual energy budgets.

4.0 Results

4.1 Define Phase

During the *Define phase* of the project, an energy management team was first formed. This core team, selected by the author and the sponsor, took part in a one-day workshop event to define the expectations of the project with a view to the development of a project charter and an energy policy, a key requirement and initial deliverable for ISO 50001 accreditation. The site manager signed the energy policy and was the project's sponsor. The energy policy fed into the project charter, which defined the business case, problem statement, scope, milestones, deliverables, and overall DMAIC timeline.

As part of the one-day workshop, a SIPOC was created to define the project scope and help the energy management team clarify the inputs and outputs for the remainder of the DMAIC project, as illustrated in Figure 2. The outputs defined in the SIPOC ensure that the objectives and targets for the project were relevant and appropriate.

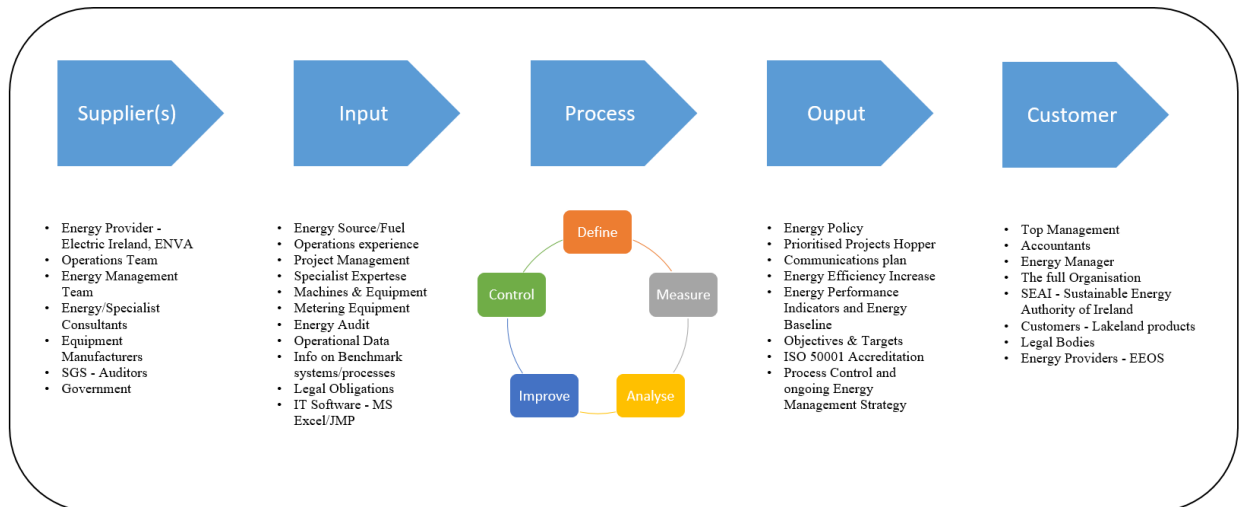


Figure 2: SIPOC diagram.

The ISO 50001 framework stipulates that Significant Energy Users (SEUs) must be defined for the site, and it was these that were brought forward through the DMAIC project steps. To ascertain the SEUs, the site metering strategy for both electricity and steam was optimised, and data was used to generate a Pareto analysis, as shown in Figure 3.

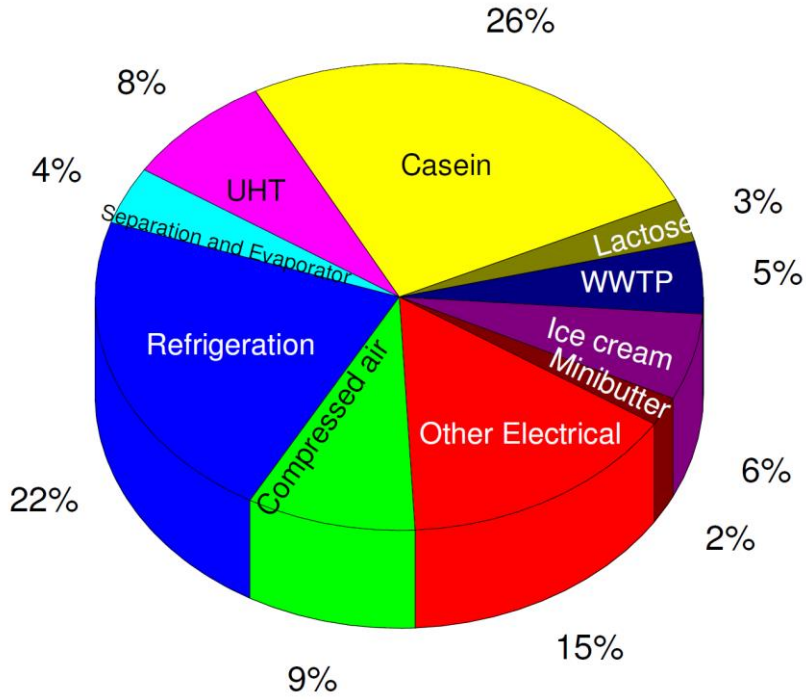


Figure 3(a): Electrical energy consumption.

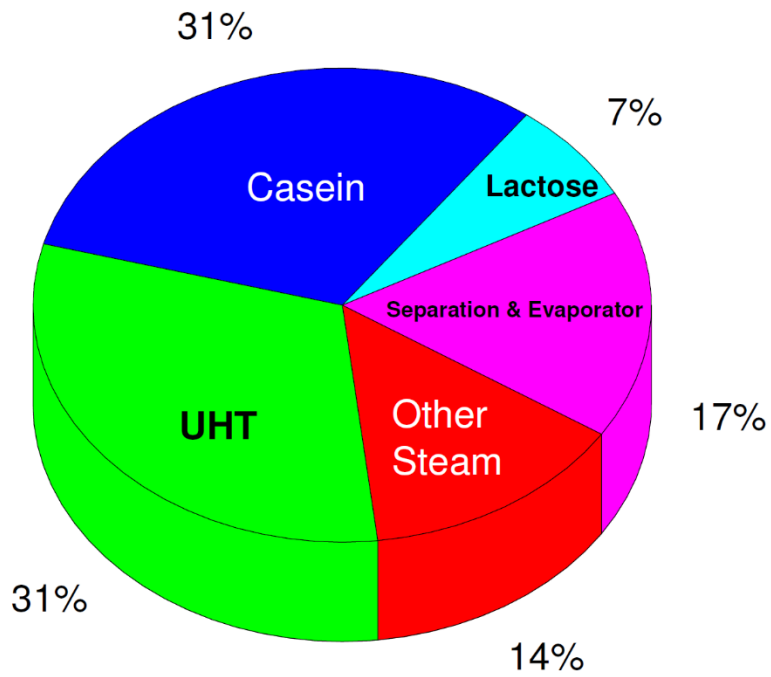


Figure 3(b): Steam breakdown.

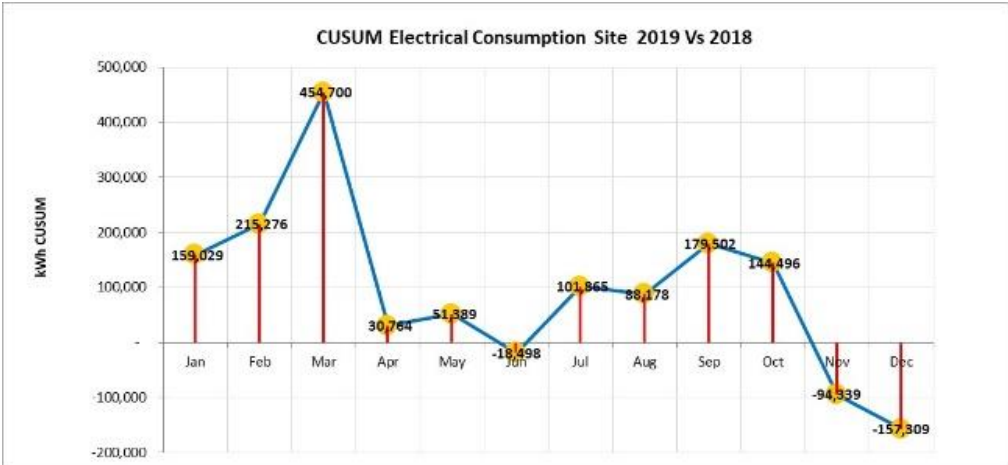
Figure 3: Energy Use Pareto Analysis for the electrical and thermal energy consumption.

The define step was deemed essential by the energy management team as it helped them develop a common understanding of the problem and the objectives necessary to implement a benchmark energy management system. It was agreed that failure to define the scope properly and the vision for the project increased the risk of scope creep later in the project. By identifying the critical few SEUs, the team could ensure that they worked on the right projects.

4.2 Measure Phase

During the measure phase of the project, the team aligned on the key objectives, gathered the data and quantified energy performance using various statistical and six sigma tools for the site and its significant energy users, SEUs. This part of the project again went hand in hand with the ISO 50001 implementation in that, as part of the ISO standard, an annual energy review, which analyses each of the SEUs, is required.

Current results show a steady increase in energy consumption from 14,205 MWh in 2013 to 21,123 MWh in 2019. This increase can be attributed to an increase in volume rather than a decline in energy efficiency, and a CUSUM analysis reinforces this hypothesis. CUSUM analysis compares two separated periods of data to each other, in this case, to assess electrical performance in 2019



Vs 2018. Figure 4 illustrates the results of the CUSUM analysis of entire site electrical consumption for 2019 vs 2018.

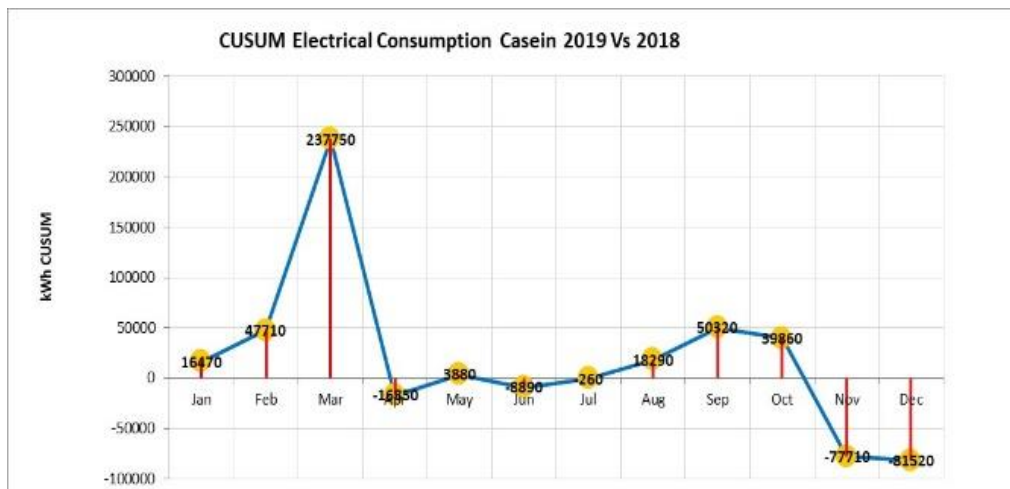


Figure 4: CUSUM analysis of the total site and casein electrical consumption.

It can be seen that the site CUSUM follows the same pattern as the CUSUM for the casein plant, i.e., the site electricity will go up and down with the casein production profile. Regression analysis on both overall site electricity and casein electricity is performed later. The variation of production volumes through each food ingredient and food service business meant that an overall KPI for site electricity consumption was initially difficult to define. Therefore, JMP software was used to carry out a multi-variant regression analysis to ascertain the resultant energy consumption with changes

in site product mix. The two key effects identified were skim processed through the casein plant and the UHT plant production output. Figure 5 shows the response, including the prediction equation, generated by JMP software.

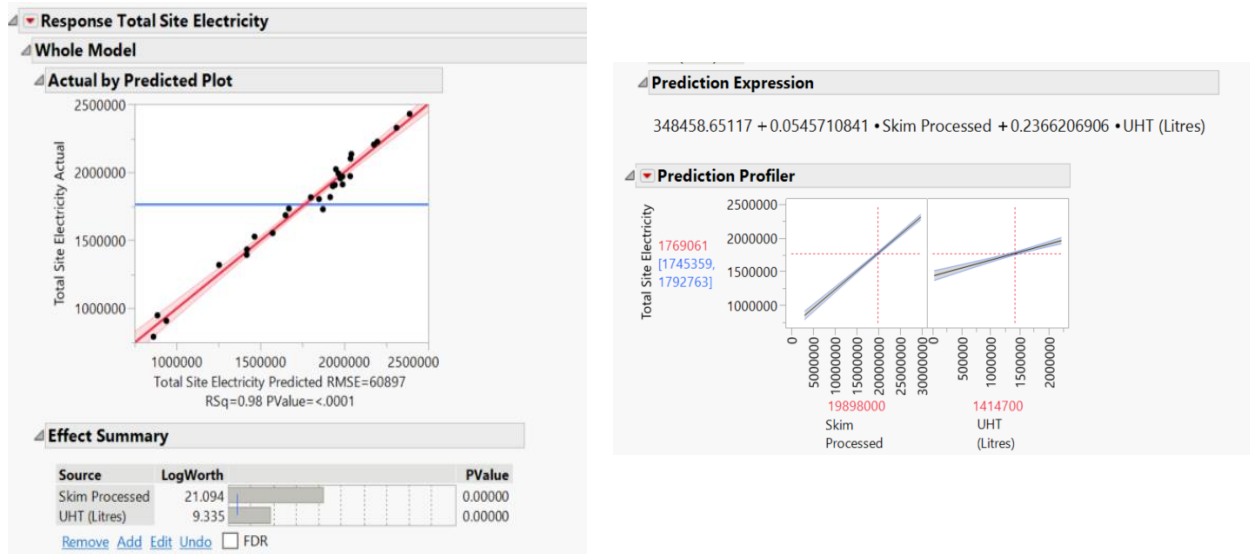


Figure 5: Response and Total Site Electricity.

The response variability was determined with an R2 value of 0.98, and a p-value of less than 0.0001 for both skim throughput in the casein plant. The UHT plant volume was characterised as significant, demonstrating a linear relationship. The total site electricity in KWh was calculated to be $348,459 + (0.055 \times \text{litres of skim throughput in casein}) + (0.237 \times \text{litres produced in the UHT plant})$. To satisfy the ISO 50001 standard, a similar regression analysis was carried out for each of the SEUs, where the prediction equation could then be used to set a monthly target KPI and consequently predict monthly manufacturing volumes. These equations will be further used to quantify the baseline performance for each SEUs and make suggestions for improvement in the project.

Both the electricity and thermal load are significant in dairy processing facilities. Steam use (tonnes) and electricity demand were converted to kWh, and using JMP software, a model for the total site steam consumption and electricity demand was established, as shown in Figure 5. Whole milk intake (litres), skimmed milk processed (litres), casein (tonnes), UHT production (litres), ice cream production (aerated litres) and lactose (tonnes) volumes were initially selected as possible model effects. Effects with a p-value greater than 0.03 were removed, leaving the model in a form as shown in Figure 6.

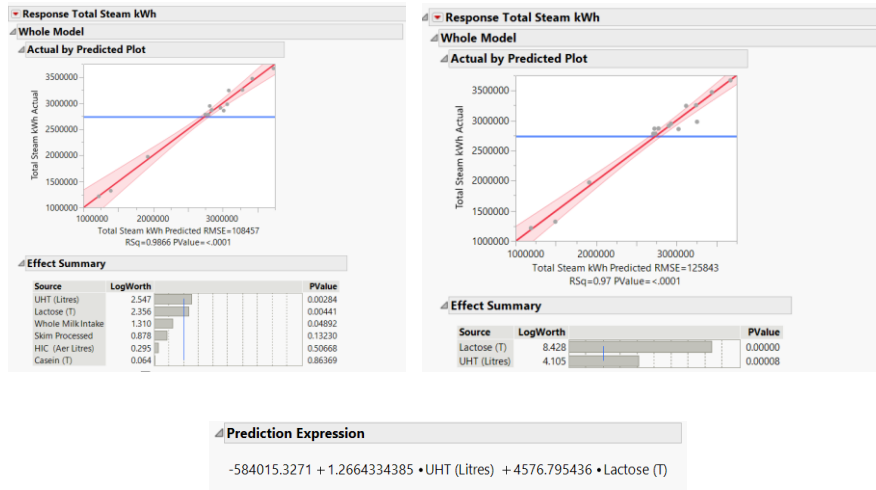


Figure 6: Response total steam with prediction expression.

The R^2 value is 0.97, indicating a very good linear relationship and the low p-values for UHT (litres) and lactose (tonnes) show that these two factors are significant. Predicted steam consumption in kWh is therefore $-584015 + (1.267 \times \text{UHT production, litres}) + (4576.80 \times \text{Lactose production tonnes})$. It should be noted that, unlike a typical spray dryer that uses steam, the casein dryers are attrition type that burns liquefied natural gas (LPG) to create a stream of hot air. Thus, the model presented in Figure 6 includes the dryers' thermal load.

In Lakeland Dairies Killeshandra, 8 bar (g) compressed air is generated using 160kW and 200kW fixed drive machines and a 250kW variable speed drive compressor. When reviewing compressed air system performance, there are two main KPIs to be measured, total electricity used to generate compressed air (a direct measure of the quantity of compressed air used) and the specific energy consumption of the air compressors, i.e., the quantity of compressed air (output) for every kWh of electricity (input) to the three air compressors. Electrical consumption used to make compressed air can be $12,208 - (0.084 \times \text{aerated litres of ice cream}) + (0.124 \times \text{UHT litres}) - (0.010 \times \text{whole milk intake}) + (434 \times \text{casein tonnes})$. The corresponding R^2 is 95% which emphasises the high quality of the established JMP model. Using regression analysis, the actual efficiency of the air compressors is calculated as 6.23 m³/kWh, i.e., for every kWh of electricity input, we obtain 6.23 m³ of compressed air. With the R^2 of 0.96, the model indicates that the specific energy consumption does not change with a corresponding volume change. The high thermal loads could cause high cooling loads, which are generated by the chilled water at 2°C from an ammonia refrigeration plant. This can be calculated as equivalent kWh of chilled water divided by the kWh of electricity used to chill that water. Only the skim processed through the casein plant was significant in terms of variation, and there is a baseload of 118,209 kWh/month through the UHT and ice cream departments when casein production is zero. Steam boiler efficiency is essentially a measure of the energy out (heat in the form of steam) divided by the total available kWh in the fuel. The average monthly efficiency of the steam and oil flow meters was calculated at just 53%. In practice, the steam system efficiency is less than 50% as steam is used for hot well heating (boiler feed water) and heating required to maintain the HFO at a temperature where it will flow from HFO tanks to the boiler burners.

When 'whole' milk is first delivered to the site, it is sent through a separation process to give cream and skim milk. These two product streams are then pasteurised before the skim is sent to other production departments for processing. The cream is cooled to 6°C and sent to other sites in the group to be processed, e.g., for the churning of butter. Whey streams from the casein are sent through a series of membrane plants to give whey protein concentrate (WPC), and lactose-containing permeate is put through an evaporator, increasing solid content before sending it to crystallisation tanks at the lactose plant. Milk separators, pasteurisers and the steam evaporator are identified as one SEU, including electrical and thermal use in the area. Steam use is predominantly affected by the lactose production volume. In addition, the evaporator is part of the lactose manufacturing process, which is known as a very energy-intensive process. The model showed the R^2 of 0.97, which indicates a good fit for the predicted steam usage described by the equation of $126,224 + (2921 \times \text{lactose tonnes})$ in kWh. The regression analysis for electricity gave an R^2 value of 0.95 when kWh of electricity is plotted against skim processed using the equation of $12,856 + (0.0030 \times \text{skim throughput litres})$ in kWh. The electrical consumption at the evaporator was shown to be less than that in the separation area using the equation of $3096 + (97 \times \text{Lactose tonnes})$ in kWh.

The SEU defined by the energy team for the UHT department includes all the electrical equipment and process steam used in the production of both UHT products and ice cream. There are two different types of sterilising plant used, infusion plant versus tubular, but it was observed from the JMP modelling that sterilising plant is not significant in this case study. The number of CIPs (Clean in Process) carried out at the dairy plants was significant, approximating 1.2 tonnes of steam for each CIP performed. The level of the variation in ice cream volume observed by the team is not significant for the steam used during operation. This is because there is a constant steam baseload

in ice cream manufacturing. Product mix and changes in volume output for each of the main product families (production lines) were considered when the initial model for UHT/HIC electricity was established. The high p-values did not highlight any significant effects. Thus, simple regression analysis for electricity was predicted to be $60,886 + (0.0665 \times \text{UHT litres})$ in kWh.

The casein plant is the largest energy user on-site, including a series of pasteurisers, coagulation plants (with hydraulic acid), membrane plants and dryers. The regression analysis for electricity and steam determined the R^2 values of 0.91 and 0.98 for steam and electricity, respectively, indicating that the regression model fits the data. Steam usage is estimated to be $135,012 + (2.12 \times \text{casein tonnes})$ kWh and electricity consumption is $55,967 + (909 \times \text{casein tonnes})$ kWh. Chilled water energy use is not included in this electricity number. LPG (propane) is the fuel used in the two casein burners that feed hot air to each casein dryer. The regression analysis indicates that this energy use can be quantified as $71,644 + (633 \times \text{Casein tonnes})$ kWh. Steam consumption for the lactose plant can be approximated as $14,614 + (668 \times \text{lactose tonnes})$ in kWh, whereas electricity can be approximated as $8,172 + (192 \times \text{lactose tonnes})$ in kWh.

4.3 Analyse

Once the measure phase was completed, the energy management team could evaluate a baseline performance and potential improvements with the quantified project savings. After several brainstorming exercises, and with the help of an external energy consultant, a register of opportunities register was created by the energy management team, as shown in Table 1. The Lakeland Dairies site in Killeshandra is off-grid in terms of thermal energy supply. Thus, other energy demands associated with HFO, such as preheating of oil, tank heating and technical

inability to use flue gas economisers on HFO boilers (due to generation of sulphuric acid during condensing), indicated that HFO steam boilers might not be the optimum technology for optimal generation of the site's thermal needs. The purchasing department informed the energy team that HFO will be phased out from 2024. A reduction in supply may result in a higher fuel cost. Excess hot water and steam are pumped to the WWTP. Typically, this is perfectly clean, warm water, but because there were no heat sinks for the heat to be used, the water is pumped to the WWTP and thus, increasing costs.

As expected, the energy management team was faced with a challenge in prioritising projects. In addition, it was recognised that not every energy reduction project would be viable for inclusion within the broader continuous improvement program due to several factors, including staffing availability, time to execute projects, rate of return and other budgetary constraints. Therefore, a method of project analysis and prioritisation decision making was required. The project hopper (opportunities register) was updated to include an 'Opportunity Prioritisation' matrix that gave an 'Overall Weighted Priority Ranking' score, out of one hundred, for each project. Once the opportunities register was finalised, it was clear that a number of projects could be grouped, as shown in the supplemental material (Figure 7). The weighting percentage for each business criteria was defined with a higher value allocated to criteria with greater strategic importance. In the next step, a prioritisation matrix was developed to map the ideas emerging from the categorisation of projects and further determine their potential for implementation immediately or in the future, as shown in Figure 7.

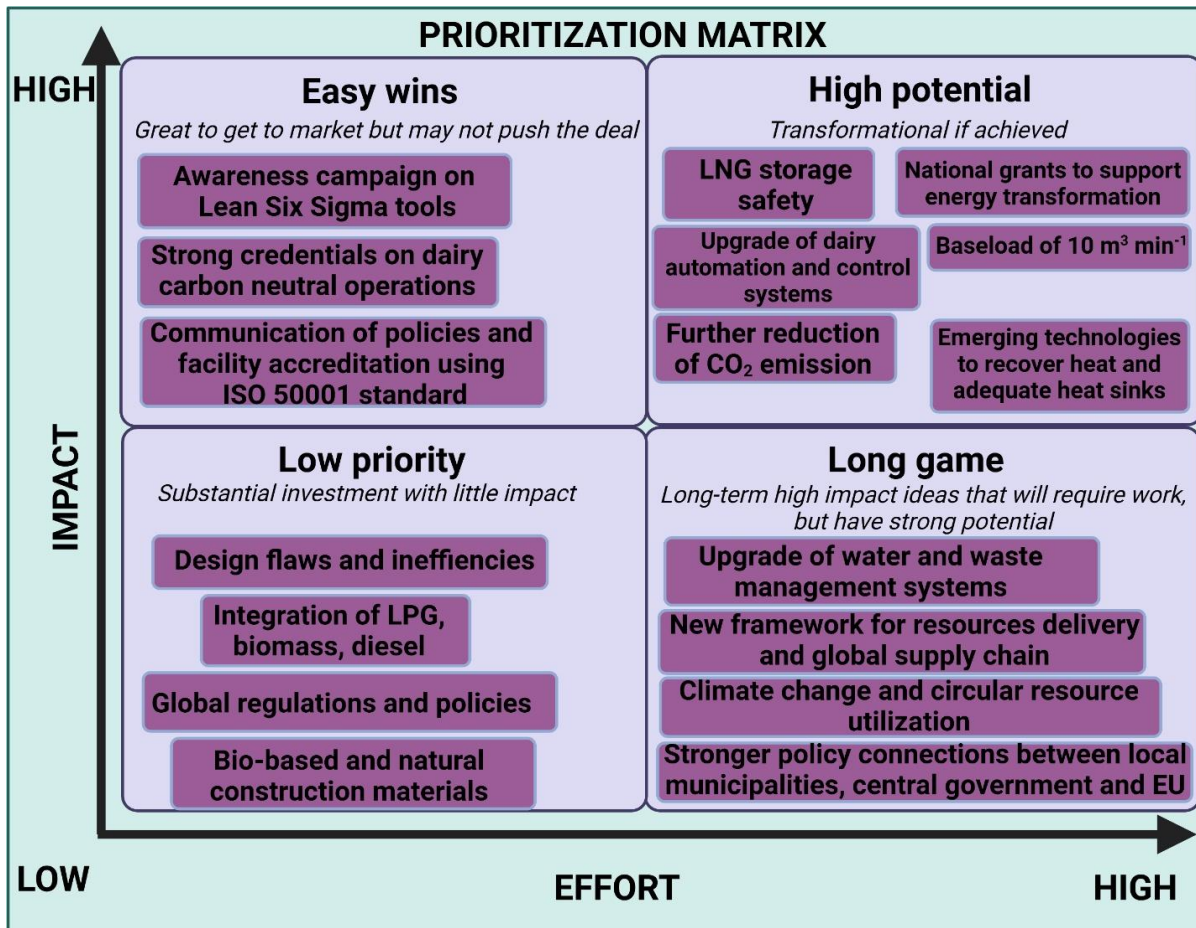


Figure 7: Opportunities Register and Prioritisation Matrix.

The *easy wins* related to awareness of LSS integration, strong credentials on carbon neutral operation of the dairy plant, and communication of policies which could facilitate the accreditation of dairy plant according to pre-requisites of ISO 50001 standard. Options for an alternative fuel source were reviewed. These included LPG, biomass, and diesel. As stated earlier in this paper, LNG offers a viable alternative to HFO and would lend itself to other projects identified in the opportunities register, namely heat recovery, low-pressure hot water for heating and a combine heat and power plant (CHP). Therefore, LNG and optimisation of heat recovery and CHP installation were ranked as solutions for *easy wins*. Sources of heat recovery included evaporator

condensate (water evaporated from the permeate), coolers on an installed CHP plant(s), hot gas at the condensing towers of the refrigeration plant and cooling water from the sterilisers in the UHT process. If steam boilers will be installed, these could be fitted with the economisers and the most modern emerging technologies for control and water treatment. For those sites, the thermal loads require hot water of 90°C, which was recognised as the most efficient heat source with a thermal efficiency of 95%. The previous studies indicated that the efficiency of the most steam efficient boilers is below 78% (Pelka et al., 2021). All thermal loads at the dairy plant were therefore analysed by the energy team to determine their suitability for deferral to hot water. The identified loads included lactose dryer preheating, casein coagulation tubes heating, thermisers (pasteurisers) in casein, and pasteurisers in the separation department. All remaining thermal loads which could not be technically operated with the hot water have continued to utilise steam facilities. The installation of a LPHW network and associated gas supply would enable CHP to be designed on-site to generate LPHW and electricity. The CHPs should be a gas engine to ensure a high heat recovery from the flue gases (economiser) and cooling jacket.

A balance between LNG safe storage requirements, further reduction of CO₂ emissions, application for the national funding, baseload of 10 m³ min⁻¹, emerging technologies to recover heat, and upgrade of automation and control systems at the dairy plant were ranked as solutions of *high potential*. On the other hand, the design of future dairy plant using bio-based and natural construction materials were identified as *low impact*, as previously discussed (Trubetskaya et al., 2022). In addition, the global supply chain management and policies were emphasised as an important solution, but due to the high investment and long-term implementation, this solution was ranked as **a low priority**. Stronger policy connections between different governmental policy levels, new frameworks developed to foster the adoption of raw materials and circular resource

utilisation, upgrade of water and waste management systems which would include both technological and behavioural change of staff and senior management at the dairy plant, were categorised as *long game solutions*.

4.3.1 Justification & Energy Savings Calculations

Figure 8 illustrates a future state thermal flow chart that visualises all the heat sources and sinks identified by the project team. In addition, it shows the energy flow from LNG tanks to the various outputs, including electrical energy from the CHP plant.

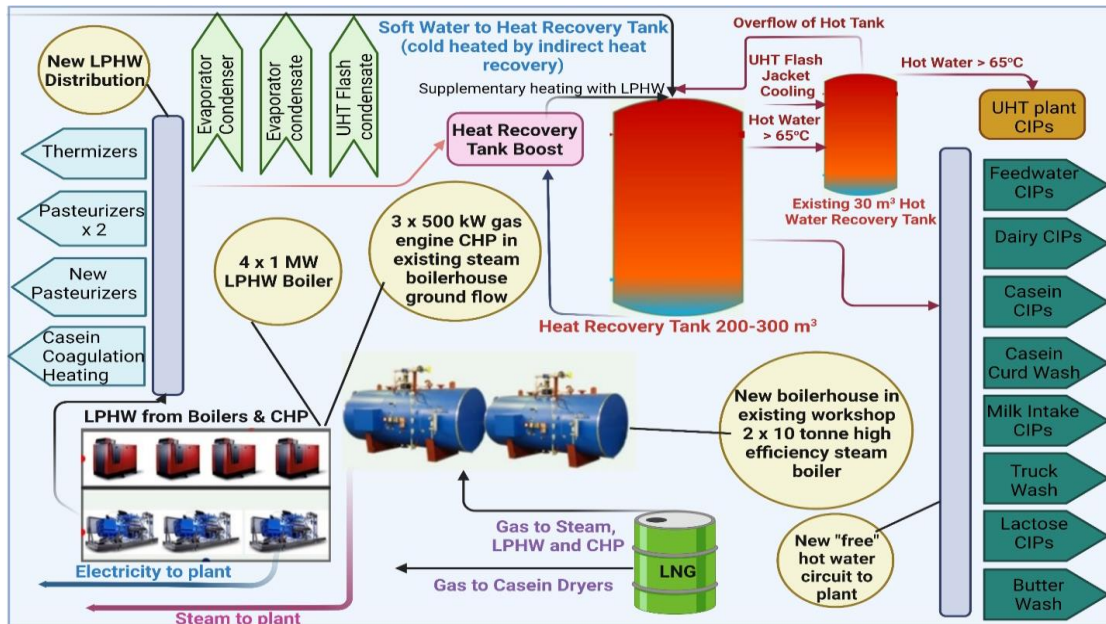


Figure 8: Thermal Flow Diagram Lakeland Thermal Reconfiguration Project.

Current and future state thermal models were used to calculate energy savings; the future state thermal model assumed full implementation of the thermal reconfiguration project, i.e., the use of hot water in all possible casein manufacturing processes and a full heat recovery system. It was also assumed that the newly installed LNG steam boilers would have an efficiency of 78%. The

thermal efficiency of a CHP engine was estimated to be 46%, whereas the electrical efficiency of the dairy plant will range up to 41%, giving a total plant efficiency of 87%. The resultant energy savings associated with the thermal transformation are shown in Table 1.

Table 1: Project Savings.

Area	Description	Savings / MWh		CO ₂ Savings / tonnes
		Electricity	Fuel	
Steam	Convert HFO Steam Boilers to LNG (Steam Loads may have increased since original calculations - based efficiency used)	0	13815	5864
Casein / Whey	Casein / Whey thermal Reconfiguration - LPHW and Regeneration	814	10463	2537
Dairy	Pasteurization to LPHW	0	1230	251
Heat Recovery	Centralized Heat Recovery Tank from Refrigeration, Evaporator Condensate & UHT for Washdown / CIPs	0	5376	1097
CHP	Gas Engine LNG CHP 1 MW	6716	-8799	1523
Total:		7530	22272	11309

Based on the current energy use profile, this project has the potential to save 22.272 MWh in fuel input and a further 7.530 MWh in imported electricity due to the installation of a CHP. Calculated at 2019 energy prices, the project will reduce the total annual energy bill by 35% with a payback of fewer than 2 years.

4.4 Improve

Following the detailed design and definition of savings in the analyse phase of the project, the Killeshandra thermal reconfiguration project was initially approved by the Lakeland Dairies Board in March 2021 and further commenced in June 2021. Therefore, the energy management team proceeded to the project's improvement phase. As described previously, this 'thermal reconfiguration' project consists of several small projects such as the integration of the heat recovery instead of the previously used waste heat systems, the use of LPHW instead of steam in all viable processes and the improvement of the total dairy plant efficiency concerning the combined use of steam and hot water systems, as shown in Figure 9.

Three 1000 kW Hot Water Boilers will supply LPHW, and a LPHW distribution network will be installed on-site. The heat load for each user was calculated so that the hot water boilers could be sized accordingly. Two new 10 tonne/hour LNG steam boilers will be installed in the current steam boiler house and sized according to the case scenario that if LPHW is not available, the manufacturing departments can revert to steam, thus offering full duty standby and business continuity. On the advice of the external consultants, a new 'deaerator' will be installed to treat boiler feed water. The deaerator is essentially a large kettle that is designed to remove corrosive gases, dissolved oxygen, and carbon dioxide to a level where corrosion is minimised. In addition, the storage capacity for recovered heat will be increased with a new 300 m³ heat recovery tank which will be a source of heat from the evaporator condensate, the CHP intercooler, oil cooler and UHT cooling water (Brush et al., 2011). This tank will then supply domestic hot water (DHW) to all CIP centres and wash water stations on site. It is envisaged that a CHP unit will generate 1,000 kW of electricity and 1,078 kW of thermal energy (to heat water for the LPHW system) with an electrical efficiency of 40.9% and a thermal efficiency of 46.4% by giving an overall system efficiency of 97.3%.

Other benefits of the thermal reconfiguration project have emerged, including the overall energy use minimisation at the dairy plant. The total volume of flue gases will be improved by reducing the gross CO₂ emissions of the facility by 9,531 tonnes (46%). The change of fuel from HFO to

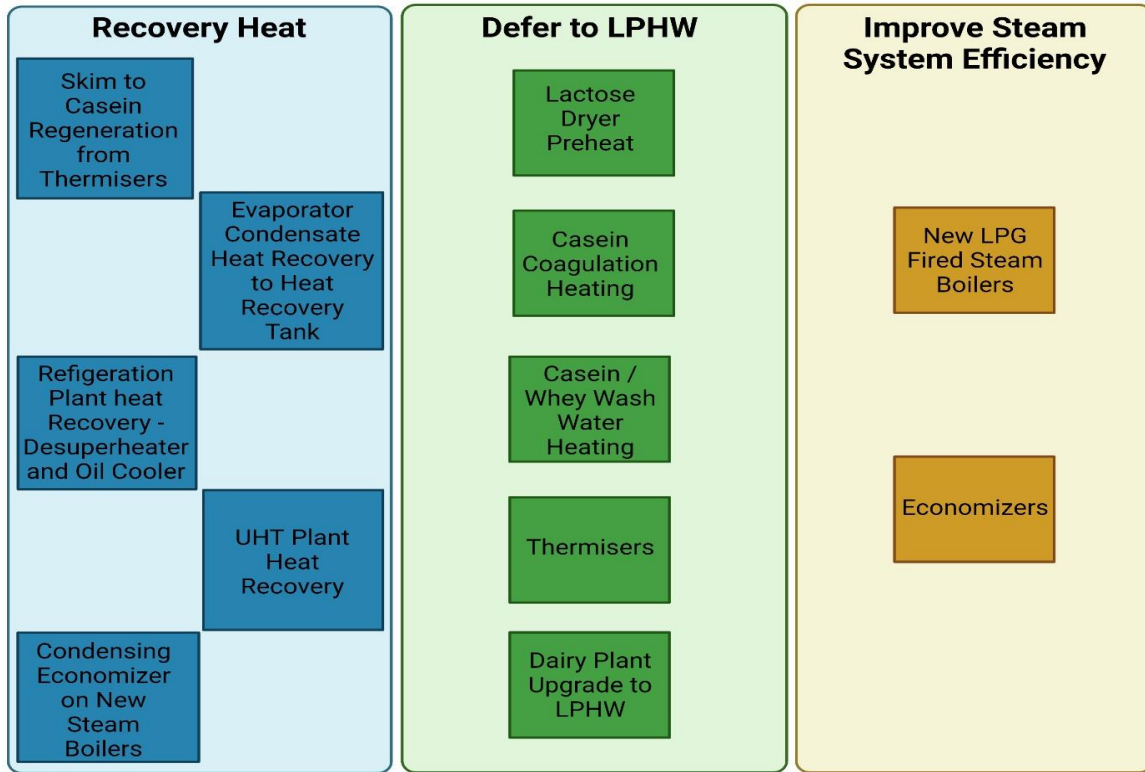


Figure 9: Overview of Killeshandra thermal reconfiguration project.

LNG will reduce the harmful emissions associated with the burning of high sulphur HFO. NO_x will be reduced by 75%, whereas SO_x emissions will be eliminated. Business continuity will be enhanced due to the installation of new steam boilers, which will have full N + 1 redundancy, which are currently not available at the peak loads. The high quantity of LNG that is defined as a hazardous substance must be safely stored on-site at the dairy plant with the preliminary safety assessment according to COMAH regulations (Controls of Major Accident Hazards). To the

authors' best knowledge, the Lakeland Diaries facility in Killeshandra will become the first site in Ireland to meet the national LNG storage regulations.

In the next steps of the *Improve* phase, Gantt charts will be actively used to define the roadmap for the thermal transformation program. Inputs for the roadmap will be sourced from the stakeholder analysis, managers and supervisors, including capacity planning, timing, and individual measures of success. In the form of design reviews and construction reviews facilitated by the project team, workshops took place to understand the most optimal sequencing of project actions. Risk assessment exercises were undertaken as part of these reviews to identify and manage potential risks during the *Improve* phase of the project. In addition, change and communication plans will be completed and verified with the project team, contractors, and sponsor prior to implementing the *Improve* phase.

4.5 Control

After installing equipment and processes in the *Improve* phase, all new energy systems will be commissioned using a structured process following commissioning protocols. The control phase of the project is important for the project certification according to ISO 50001 standard. Statistical analysis using X bar and R charts and control charts are used to control how the developed model will be continuously followed to meet the requirements of ISO 50001 standards. The thermal process became more complex with the introduction of heat recovery and CHP to provide hot water at the dairy plant. Therefore, the variant analysis should be performed to optimise process settings, e.g., water temperatures or flows, to obtain an optimum energy performance. A full MV (measurement and verification) report will be written to confirm all savings identified in the

Improve phase. This MV report will be approved by an independent external consultant to maintain impartiality and give confidence to the actual savings declared by the energy management team. The team will essentially repeat the measure phase, using JMP variant analysis (ANOVA), multi-variant regression analysis and other tools to compare baseline usage for the savings quantification. Process control charts are used to review weekly energy consumption by each SEU with action limits set at $\pm 10\%$ from the target. The site metering strategy is integrated into the control chart to track each energy meter and will be further updated when a new meter is added to the dairy plant facility. The data from the meters on the consumption of electricity, steam, compressed air, and chilled water is given in a kWh/unit for each SEU. ISO 50001 requires a defined internal auditing process whereby each SEU is reviewed annually by a trained auditor, and non-conformances are captured in a non-conformance register. When a KPI is outside target limits for more than 3 consecutive weeks, a non-conformance is also raised and added to the register. This will lead to a change in a statistical model, including the eight tests as special causes.

5.0 Discussion

In this case study, a selected DMAIC approach facilitated an understanding of energy use in the dairy manufacturing facility (RQ1). The Six Sigma tools identified the significant factors affecting energy use and allowed the quantification of these effects. This proved important in developing a full understanding of the underlining process and enabled project identification to reduce the overall energy consumption. The energy management team found that the DMAIC approach and ISO 50001 go very hand in hand, and if the DMAIC approach is followed for energy reduction, the energy management system (EMS) will be successful in an ISO 50001 audit. As a part of the

ISO 50001 standard, the EMS is essential for energy efficiency optimisation through a structured summary of activities that an enterprise should take to save energy and costs (Lee et al., 2014).

This project presents a new approach for the dairy manufacturing facilities, which are off-grid to meet their thermal energy requirements. This study details how a full thermal transformation for a dairy manufacturing site can be realised and savings performed (Ramirez et al., 2004). The most visible energy savings require minimal capital investments (Lee et al., 2014). However, for a dairy off-grid plant to change its primary fuel source to LNG, significant capital investment can be required to construct a LNG storage facility and associated gasification plant, gas distribution network, and boiler/gas burner replacements. The integration of LNG in the dairy plant infrastructure will open several opportunities to install CHP on-site that enable steam displacement with hot water. Figure 10 illustrates the optimised thermal load at the dairy plant, whereas 42 % of heat is generated by the newly installed CHP infrastructure with the recently integrated heat recovery facility that supplies 30 % of heat on-site. In the current project, the steam load was reduced to 15 % by installing a new low-pressure hot water system to satisfy the thermal needs of dairy plant areas that require 90°C or less, e.g., pasteurisation, CIP centres, casein coagulation etc. Moreover, this project demonstrates an increase in energy efficiency due to installing new LNG steam boilers, as reported previously (Singh and Bakshi, 2018)(RQ2). The installation of new steam boilers, in turn, allows for the capture of what was previously waste heat and water to be reused in the dairy manufacturing units. Although capital investment is required, there is an associated cost-benefit and an acceptable rate of return. Thus, the present thermal reconfiguration project is a business case that will back up the dairy plant's environmental and business continuity benefits.

The overall energy usage in the Irish dairy processing industry was set to be 474 kWh m⁻³ of milk processed (Finnegan et al., 2013). This comprises 114 kWh m⁻³ milk processed in electrical energy and 360 kWh m⁻³ milk processed in thermal energy. Before the thermal transformation was implemented as part of this project, energy use was 95 kWh m⁻³ and 208 kWh m⁻³ in electrical and thermal energy, respectively. Direct comparison or benchmarking of this performance data is difficult as each dairy plant differs from another in terms of processes used and products produced. In addition, there may be multiple intermediary milk derivatives coming to and leaving a site for processing elsewhere. For example, whey protein concentrate (WPC), lactose powder and cream are transferred to other sites within the Lakeland Dairies group for further processing, whilst skimmed milk, cream and bulk butter produced in sister plants are brought to the plant and used to produce various food service products. However, it may be assumed that the plant in Killeshandra demonstrates similar performance to others. Direct comparison by product type is not possible as much of the data is not available, and for that data that is available, the assumptions used quantitatively are unclear. The project team estimated that the total energy consumption for the food ingredients business, casein, and lactose, is 4.27 MJ kg⁻¹ and 17.01 MJ kg⁻¹ for electricity and thermal loads, respectively. Compared to previous results, the electricity and thermal energy consumptions were significantly lower (0.92 MJ kg⁻¹ and 4.12 MJ kg⁻¹) than in the present study (Ladha-Sabur et al., 2019). The difference could come from the representation of a full manufacturing process in the Killeshandra plant case study, whereas the past studies might include only several process segments, excluding drying processes and auxiliary services, which have a significant impact on the overall steam boiler efficiency.

The CO₂ emissions associated with the thermal transformation were reduced by 46%, as shown in Figure 10. Future optimisation of the thermal model could incorporate other 'hotspot locations'

concentrating on steam usage and heat recovery at the large refrigeration plant (O Reilly (2017)). Despite the fact that the CO₂ emissions were planned to be reduced by 49% in the *Define* stage, the target was not completely reached due to the additional fuel burned with the installation of a CHP plant. The reduction of emissions overall occurred because the amount of imported electricity was minimised with the CHP plant installation.

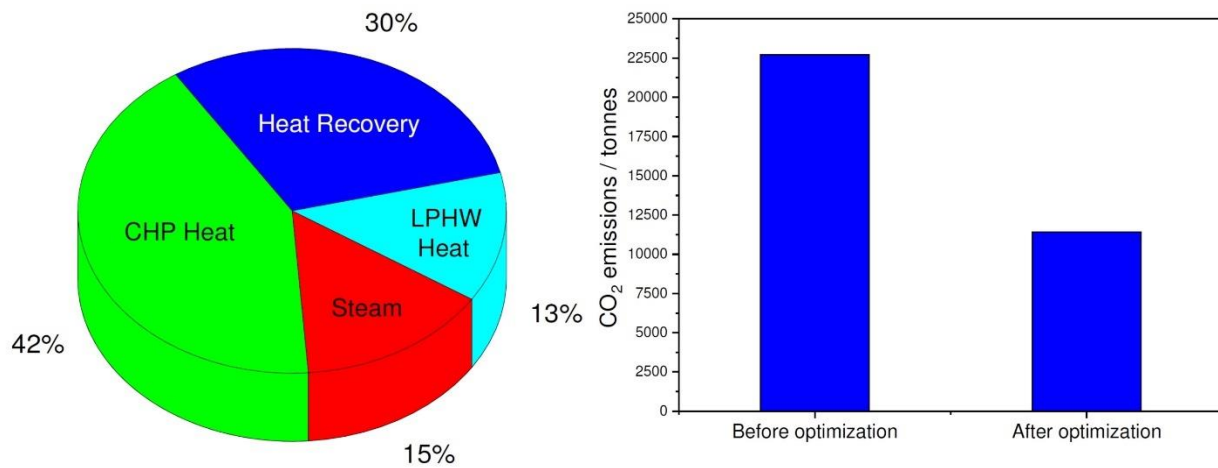


Figure 10: Optimised thermal load and carbon emission reduction.

The project's recommendation is to apply a DMAIC methodology in any organisation that hopes to realise the full potential of their EMS and further project accreditation according to ISO 50001 standard. Lean and Six Sigma tools were invaluable in supporting the energy management team in describing SEUs and key drivers in energy consumption at the dairy plant. A full suite of data is paramount, but quick; efficient multivariate analysis is possible once the data is gathered, allowing energy reduction projects to be identified. One area in which the presented results may be further improved is the use of weekly control charts during the final control phase; results are currently manually downloaded from the site SCADA system and entered in a spreadsheet linked to JMP

software. It is envisaged that the SCADA reporting screens be updated so that control charts are automatically updated daily and the eight tests for special causes performed. Therefore, further extending the SCADA database and potentially establishing a new database will significantly benefit enterprises interested in accrediting their manufacturing facilities according to ISO energy standards.

An important point to consider by an energy management team is the available public funding that will offset any capital investment required and improve the rate of return. An Enterprise Ireland grant was successfully attained for the thermal reconfiguration project, along with a considerable EEOS (Energy Efficiency Obligation Scheme) payment that was also secured. The clear understanding of problems and solutions associated with the use of Six Sigma tools makes the application process and corresponding MV reporting relatively easy. These grants should be included in the prioritisation matrix to identify viable projects properly. Companies genuinely interested in improving energy efficiency and reducing their carbon footprint should actively seek to build a relationship with their local government energy authorities, which will keep the company informed of revenue streams and provide expert help for technical projects. In Ireland, the Sustainable Energy Authority of Ireland (SEAI) and the Large Industry Energy Network (LIEN) are those organisations companies should approach.

6.0 Conclusion

This research met the RQs and utilised LSS tools integrated within the ISO 50001 energy management system to reduce energy management consumption and identify an alternative LNG energy source to meet the thermal load of the dairy site.

The main contributions of this work are due to the novelty of the application of LSS in the dairy sector as an enabler of a greater energy-efficient facility, as well as the testing of the DMAIC approach to meet a key objective for ISO 50001 accreditation. The developed statistical model includes a valuable toolset to analyse and control the energy management processes in the dairy and food manufacturing sectors. To the best of the author's knowledge, this proposed model was the first to combine the LSS and ISO 50001 system approaches in the dairy industry and has provided beneficial outcomes resulting in the minimisation of thermal energy use by 36% and CO₂ footprint by 46%. The application also impacted financially by achieving an annual reduction of 35% in energy cost. Furthermore, this work has shown that LNG can offer both an alternative to HFO or fuel oil whilst also providing opportunities for CHP, hot water displacement of steam and heat recovery. The DMAIC model developed in the present work should be further extended and integrated into the food and dairy sectors to continuously identify influencing factors and their tuning towards the energy-efficient operation of plants by eliminating waste. This study can be leveraged by other organisations interested in improving and optimising their energy management systems and wishing to get accredited to ISO 150001. Government energy bodies can leverage the learnings in order to understand how they can further support energy management projects and organisations in energy reduction. Further research could involve a further longitudinal study on the use of LSS integrated with the EMS within the case study organisation and on case studies involving other dairy organisations.

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Bibliography

Alexandratos, N., Bruinsma, J., 2012. World Agriculture towards 2030/2050: the 2012 revision, ESA Working paper No. 12-03. Rome.

Ahmad, A. and Khan, A.A. (2022) The combined implementation of Green, Lean and Six Sigma approaches for achieving environmental sustainability – A Review, IOP Conference Series: Materials Science Engineering, 1224, 012004.

Brahmanand, B. MdIrfan, A. Kumar, S. Anuruddh, K., Sujit, M. (2018) Power consumption and Efficiency during manufacturing of dairy products in a dairy plant, Int J Adv Sci Res Management, 1, 132-133.

Brush, A., Masanet, E., Worrell, E. (2011) Energy Efficiency Improvement and Cost Saving Opportunities for the Dairy Processing Industry: An ENERGY STAR Guide for Energy and Plant Managers, US Environmental Protection Agency Report DE-AC02-05CH11231, 1-135.

Byrne, B., McDermott, O. and Noonan, J. (2021), “Applying Lean Six Sigma Methodology to a Pharmaceutical Manufacturing Facility: A Case Study”, Processes, Vol. 9 No. 3, available at:<https://doi.org/10.3390/pr9030550>.

Carvalho, H., Azevedo, S.G., Machado, V.C. (2010) Supply chain performance management: lean and green paradigms, Int. J. Bus. Perform. Supply Chain Modell, 2(3/4), 304-333.

Carl, K., van der Schoot, E., Pfeiffer, E. (2012) Continuous improvement of energy performance; How policymakers can support ISO 50001 implementation for industry, ECEEE Summer Study on Energy Efficiency in Industry, 715-722.

Chay, T., Xu, Y., Tiwari, A., Chay, F. (2015) Towards lean transformation: the analysis of lean implementation frameworks, *Journal of Manufacturing Technology Management*, 26(7), 1031-1052.

Cherrafi, A, Elfezazi, S, Govindan, K. (2016) “ A framework for the integration of green and lean Six Sigma for superior sustainability performance”, *International Journal of Production Research*, 55, pp. 1–35.

Costa, L.B.M., Godinho Filho, M., Fredendall, L.D. and Gómez Paredes, F.J. (2018), “Lean, six sigma and lean six sigma in the food industry: A systematic literature review”, *Trends in Food Science & Technology*, Vol. 82, pp. 122–133.

Csikai, A., 2010. Introduction of Six Sigma Tools into the Supply Chain Quality Management of Feed Production, s.l.: Institute of Food Processing. Quality Assurance and Microbiology.

De Mast, J. and Lokkerbol, J. (2012) An analysis of the Six Sigma DMAIC method from the perspective of problem solving, *International Journal of Production Economics*, 139(2), 604-614.

Dora, M., Kumar, M., Van Goubergen, D., Molnar, A. Gellynck, X. (2013) Operational performance and critical success factors of lean manufacturing in European food processing SMEs, *Trends Food Sci-Tech*, 31(2), 156-164.

Egas, D., Ponsa, S., Ilenas, L., Colon, J. (2021) Towards energy-efficient small dairy production systems: An environmental and economic assessment, *Sustainable Production and Consumption*, 28, 39-51.

Finnegan, W., Goggins, J., Clifford, E., Zhan, X. (2017) Global warming potential associated with dairy products in the Republic of Ireland, *Journal of Cleaner Production*, 163, 262-273.

Geraphty, R. (2011) Resource Efficiency in Ireland's Dairy Processing Sector, *Enterprise Ireland Report*, 1-46.

Gibbons, P. M. (2006) Improving overall equipment efficiency using a Lean Six Sigma approach, *Int J of Six Sigma Compet Adv*, 2(2), 207-232.

Gonzalez Gutierrez, C., Suarez de la Fuente, S., Bonello, J.M., Bucknall, R. (2021) An empirical analysis on the operational profile of liquified natural gas carriers with steam propulsion plants, *74(2)*, 273-292.

Hakimi, S., Zahraee, S.M., Rohani, JM (2018) Application of Six-Sigma DMAIC methodology in plain yogurt production process, *Int J Lean Six Sigma*, 9(4), 562-578.

International Organization for Standardization, ISO50006 (2014) *Energy Management Systems*, Stockholm: Swedish Standards Institute.

International Organization for Standardization, ISO 50001 (2011) Swedish Standards Institute, Stockholm.

Kane, J. (2019). Using Six Sigma to drive energy efficiency improvements at DuPont. Supply Chain Solutions Center, Discussion Forum, 50-61.

Kanchiralla, F.M., Jalo, N., Thollander, P., Andersson, M., Johnsson, S. (2021) Energy use categorisation with performance indicators for the food industry and a conceptual energy planning framework, *Applied Energy*, 304, 117788.

Kapadia, M.M., Kapadia, K.P., Kulkarni, S., Shetty, K. (2005) Six Sigma's Power to Save: A DMAIC Project Reduces Energy Consumption for Visible Savings, *ASQ Six Sigma Forum*, 1-2.

Kaushik, P. and Khanduja, D. (2009), Application of six sigma DMAIC methodology in thermal power plants: a case study, *Total Quality Management*, 20(2), 197-207.

Kumar, P. (2002) Six Sigma in manufacturing, *Productivity Journal*, 43(2), 196-202.

Łaciak, M., Sztekler, K., Szurlej, A., Włodek, T. (2019) Possibilities of Liquefied Natural Gas (LNG) use for power generation, *IOP Conference Series: Earth and Environmental Science*, 214, 012138.

Ladha-Sabur, A., Bakalis, S., Freyer, P.J., Lopez-Quiroga, E. (2019) Mapping energy consumption in food manufacturing, *Trends in Food Sci-Tech*, 86, 270-280.

Lee, J., Yuvamitra, K., Guiberteau, K. and Kozman, T.A. (2014) Six-Sigma Approach to Energy Management Planning, *Strategic Planning for Energy and the Environment*, 33(3), 23-40.

Lee, T.W. (1999), *Using Qualitative Methods in Organizational Research*, Sage, Thousand Oaks.

Lee, W. and Lucey, J. (2004), Structure and physical properties of yogurt gels: effect of inoculation rate and incubation temperature, *J Dairy Sci*, 87(10), 3153-3164.

Li, N., Laux, C.M. and Antony, J. (2019), "How to use lean Six Sigma methodology to improve service process in higher education: A case study", *International Journal of Lean Six Sigma*, Vol. 10 No. 4, pp. 883-908. <https://doi-org.proxy.lib.ul.ie/10.1108/IJLSS-11-2018-0133>

Lung, R.B., E. Masanet, and A. McKane. (2006) *The Role of Emerging Technologies in Improving Energy Efficiency: Examples from the Food Processing Industry*. Proceedings of the Industrial Energy Technologies Conference, New Orleans, Louisiana.

Makaliunas, S. and Nagevicius, M. (1998) Process Integration and Waste Heat Recovery in Lithuanian and Danish Industry, Case Study: Dairy AB Kupiskio pienas, Danish Ministry of Energy - EFP-95 Programme.

McDermott, O., Antony, J., Sony, M. & Looby, E. (2022), “ A critical evaluation and measurement of organisational readiness and adoption for continuous improvement within a medical device manufacturer”, International Journal of Management Science and Engineering Management, DOI: 10.1080/17509653.2022.2073917

Mkhaimer, L. G., Arafeh, M. and Sakhrieh, A. H. (2017) ‘Effective implementation of ISO 50001 energy management system: Applying Lean Six Sigma approach’, International Journal of Engineering Business Management. doi: 10.1177/1847979017698712.

O’Reilly, A. J. (2017) Dairy processing heat and energy recovery: an analysis of energy usage within the dairy processing sector in Ireland, MSc thesis, University of Limerick.

Pavlenko, N., Comer, B., Zhou, Y., Clark, N., Rutherford, D. (2020) The climate implications of using LNG as a marine fuel, Working paper 2020-02, pp. 1-40.

Pelka, G., Wygoda, M., Lubon, W., Pachytel, P., Jachimowski, A., Paprocki, M., Wyczesany, P., Kotyza, J. (2021) Analysis of the Efficiency of a Batch Boiler and Emissions of Harmful Substances during Combustion of Various Types of Wood, Energies, 14, 6783.

Plenert, G. and Cluley, T. (2012) *Driving Strategy to Execution Using Lean Six Sigma: A Framework for Creating High Performance Organisations*, CRC Press, 247.

Powell, D., Lundebj, S., Chababa, L., Dreyer, H. (2017) Lean Six Sigma and environmental sustainability: the case of a Norwegian dairy producer, *Int J Lean Six Sigma*, 8(1), 53-64.

Ramírez, C.A., Patel, M., Blok, K. (2006) From fluid milk to milk powder: Energy use and energy efficiency in the European dairy industry. *Energy*, Elsevier, 31(12), 1984-2004.

Saunila, M., Ukko, J., Rantala, T. (2018) Sustainability as a driver of green innovation investment and exploitation. *J Clean Prod* 179, 631-641.

Shine P., Upton, J., Sefeedpari, P., Murphy, M.D. (2020) Energy Consumption on Dairy Farm: A Review of Monitoring, Prediction Modeling, and Analyses, *Energies*, 13 (1288), 1-25.

Singh, B.J. and Bakshi, Y. (2018) Six Sigma for Sustainable Energy Management: A Case Study. *Int. J. Sci. Technol. Management*, 2, 60-72.

Sony, M. (2019), "Lean Six Sigma in the power sector: frog into prince", *Benchmarking: An International Journal*, Vol. 26 No. 2, pp. 356-370. <https://doi-org.proxy.lib.ul.ie/10.1108/BIJ-10-2017-0276>

Taghizadegn, S. (2014) *Mastering Lean Six Sigma: Advanced Black Belt Concepts*, Momentum Press, 400.

Trubetskaya, A., Horan, W., Conheady, P., Stockil, K., Moore, S. (2021) A Methodology for Industrial Water Footprint Assessment Using Energy-Water-Carbon Nexus, *Processes*, 9(2), 393.

Trubetskaya, A. and Mullers, H. (2021) Transforming a global human resource service delivery operating model using Lean Six Sigma, *International Journal of Engineering Business Management*, 13, 1-16.

Trubetskaya, A., Scholten P.B., Corredig, M. (2022) Changes towards more sustainable food packaging legislation and practices. A survey of policymakers and stakeholders in Europe, *Food Packaging & Shelf Life*, 32, 100856.

US Energy Information Administration (2021) Natural gas explained Liquefied natural gas. Eia.gov. Available at: <https://www.eia.gov/energyexplained/natural-gas/liquefied-natural-gas.php>. [Accessed: 20th May 2022]

Yin, R.K. (1981), "The case study as a serious research strategy. Knowledge creation. Diffusion, utilisation", available at <http://journals.sagepub.com.proxy.lib.ul.ie/doi/pdf/10.1177/107554708100300106>

Yin, R.K. (2009), *Case Study Research: Design and Methods*, 4th ed., Sage, Thousand Oaks.

Yin, R.K. (2014), *Case study research: Design and methods* (Fifth).

Zahraee, S.M., Khademi, A., Khademi, S., Abdullah, A., Ganjbakhsh, H. (2014) Application of design experiments to evaluate the effectiveness of climate factors on energy saving in green residential buildings, *Jurnal Teknologi (Teknologi)*, 69(5), 107-111.