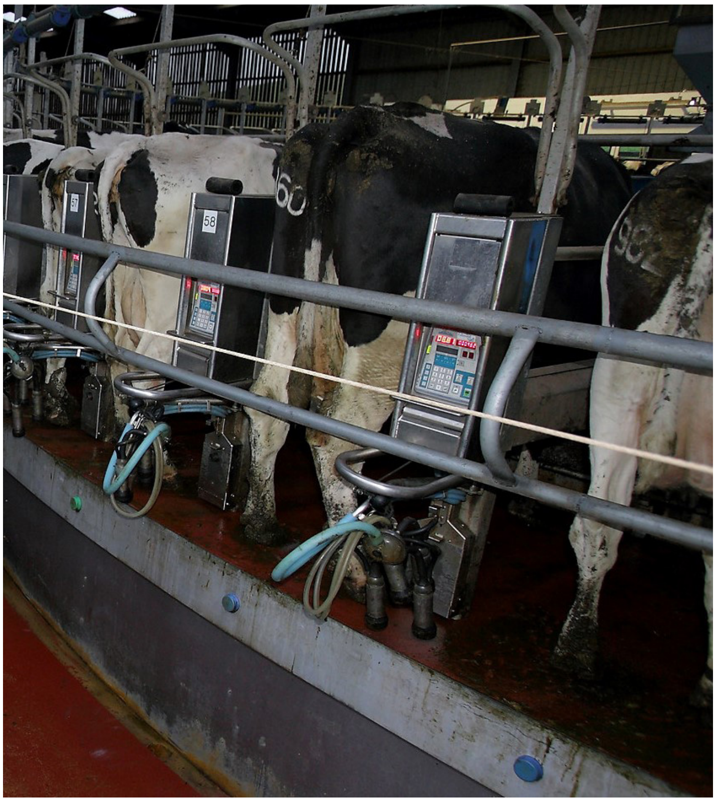
iTEMiD



Case Study:Analysing Renewable Energy Generation Dairy Farming and Identifying Opportunities for on-Farm Utilisation

Research Team

Jim Harkin, Malachy McElholm and Ryan Beveridge, Ulster University (Magee campus)

Acknowledgements

iTEMiD was co-funded by Dale Farm and AgriSearch with additional support from UFU and CAFRE

The team at Ulster would like to thank Jason Rankin (AgriSearch) at, Neville Graham, Gary Watson and Andrew Graham (Dale Farm), James McGreer (McGreer Consulting), Martin Mulholland and Stephen Gilkinson (CAFRE, Greenmount Campus), and Christopher Osborne (Ulster Farmers Union) for their support during the project.

Contents

Intoduction

In partnership with AgriSearch, Dale Farm and McGreer Consulting, Ulster University undertook a pilot study in Intelligent Total Energy Management in Dairying (iTEMiD). Staff from the School of Computing, Engineering and Intelligent Systems (Jim Harkin, Malachy McElholm and Ryan Beveridge) on the Magee Campus of Ulster, commenced the 16-month pilot study in Dec 2020 across six farms consisting of traditional and robotic milking processes.

Phase 1

The first phase explored methods for automatic measuring, recording and visualising of precise energy usage across the Significant Energy Users (SEU) in the milking process which are vacuum pumping, milking cooling and water heating processes.

This phase also explored the development of software to allow the visualisation of energy consumption per stages and the aggregation of data on the energy cost per litre of milk. The data gathered facilitated the analysis of energy usage of the SEU's and comparison across each of the farm sites. With different farm sizes and parlour types, the comparison has been assisted by defining Key Performance Indicators (KPI) including the Total Energy used per 100 litres of milk. Figure 1 a) presents the measurement hardware deployed on site including Data loggers and GSM unts to allow for data transfer to cloud storage. Figure 1 b) represents the overall hardware & Software system architecture utilising 4G GSM units to transfer periodic energy data from dairy farm to Cloud server for analysis and visualisation via the custom dashboard interface.

Phase 2

The second phase reflects the need to focus on energy optimisation for sustainability in the growing milk production sector. This phase explored the measuring and analysis of on-farm renewable generation and how this can be best exploited within the timeframe of the milking processing. Aligned with the measurement of Renewable generation, the team monitored hot water temperatures, milk tank temperature and also investigated the use of machine learning (ML) to automate the prediction of the cost of milk production (kWh per 100 litres) for various scenarios of vacuum pumps consumption.

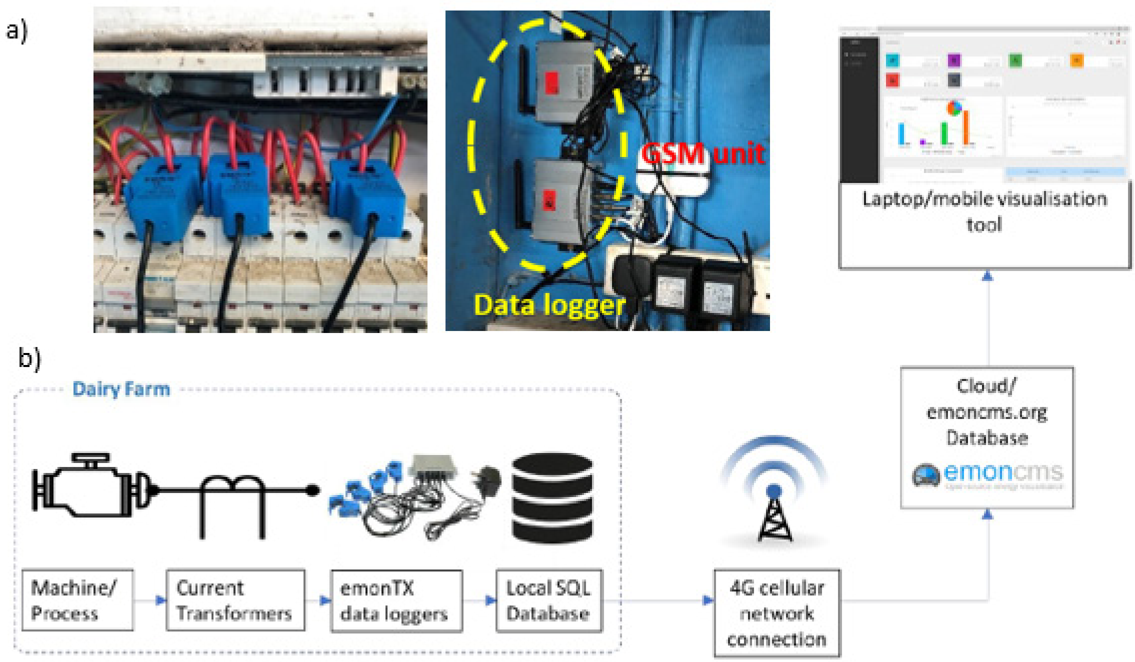


Figure 1-1 iTEMiD Hardware/Software Architecture

Energy Consumption across Key Processes

Table 2.1 Pilot Farm Overview

Farm Name	Farm Type	Herd Qty (approx.)	Notes
Farm 1	Robotic	110	2 x Lely Robots energy use recorded as ‘Vacuum Pump’ (see Figure 2a)
Farm 2	Traditional Parlour	50	Small conventional pump with old Milk Tank coolong system
Farm 3	Traditional Parlour	120	Solar PV on site generation
Farm 4	Traditonal Parlour	250	Milking cessation between Dec and Feb. Solar PV and Wind renewables on site
Farm 5	Traditional Parlour	70	
Farm 6	Traditional Parlour	250	Solar PV on site generation. Variable Speed Drive (VSD) controlled vaccum pun

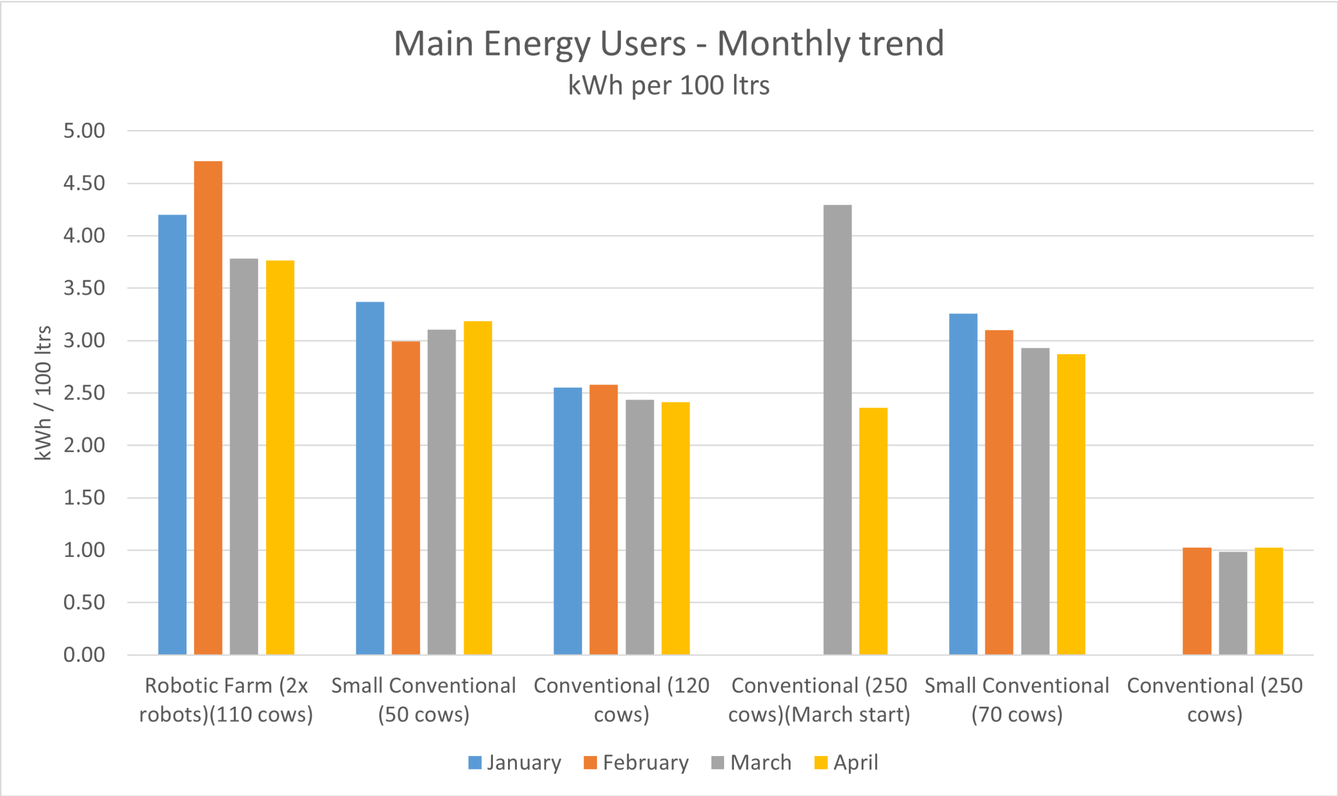
To facilitate the measurement and analysis of electrical energy use on dairy farms, 6 pilot farms of varying size and type with a diverse equipment range were identified and equipped with the necessary measurement hardware and software. Table 2.1 presents an overview of the farm types.

A comparative study was undertaken comprising the 3 largest energy consuming processes on a typical Dairy Farm: Vacuum Pumping, Milk Cooling and Water Heating. To facilitate the comparison of electrical energy consumption for individual processes and cumulative energy usage across the different farm sizes, a Key Performance Indicator (KPI) was established to provide a standardised evaluation across the pilot farms.

The Energy KPI is a measure of the total electrical energy used for every 100 litres of milk produced.

$$Energy\ KPI = \frac{Total\ KWh\ used}{100\ Ltrs\ produced}$$

Figure 2.1 illustrates the cumulative (all 3 processes) energy used per 100 ltrs of Milk for the 6 pilot farms from January 1st 2021 to April 30th 2021. There was no comparative data for farm 4 between January and February as milking only commenced again in early March 2021. Similarly, monitoring on Farm 6 only commenced in February 2021; therefore no energy data was available for January 2021.



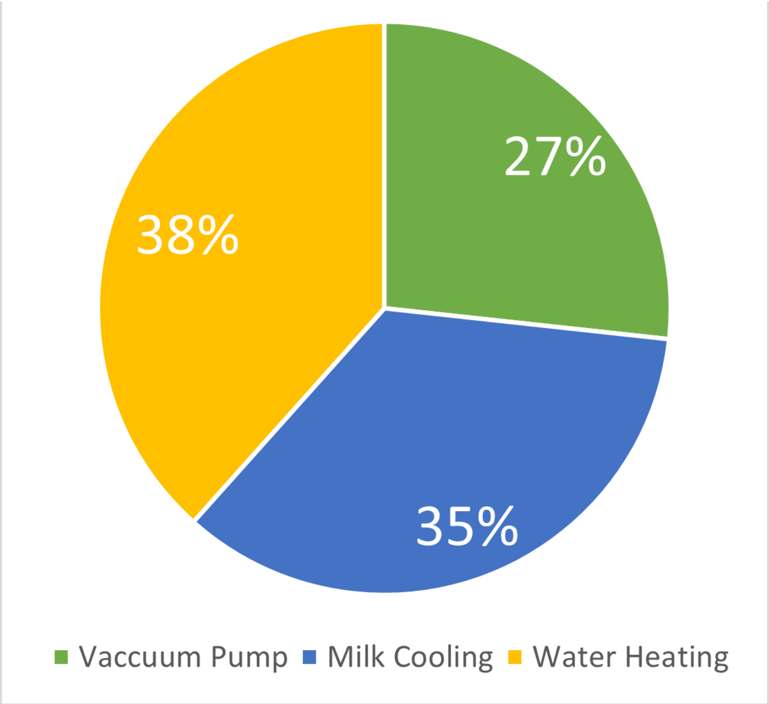
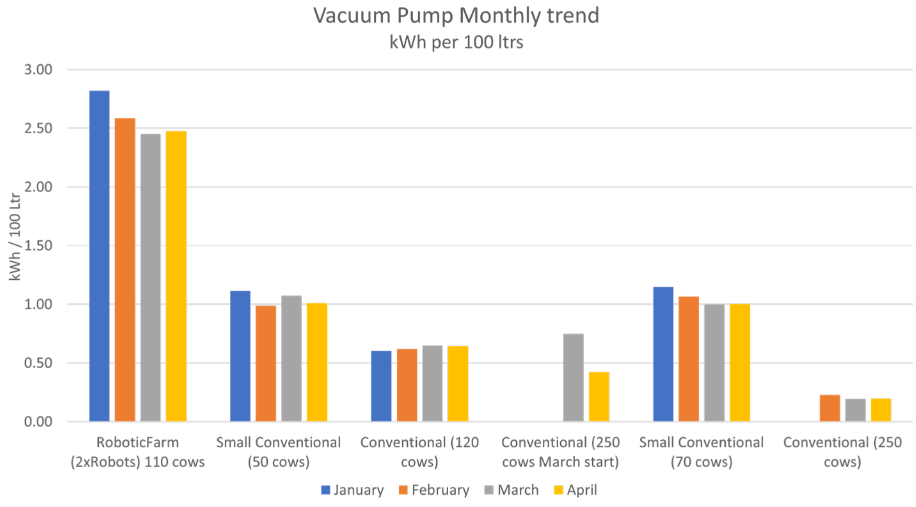
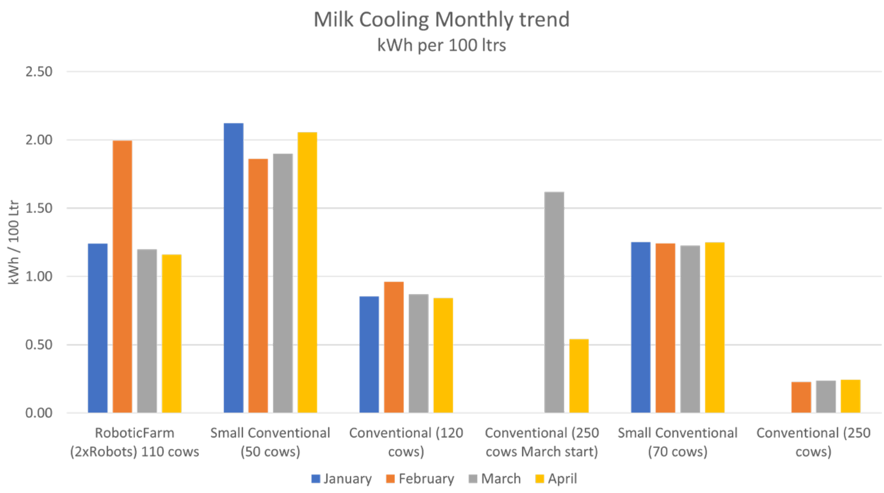


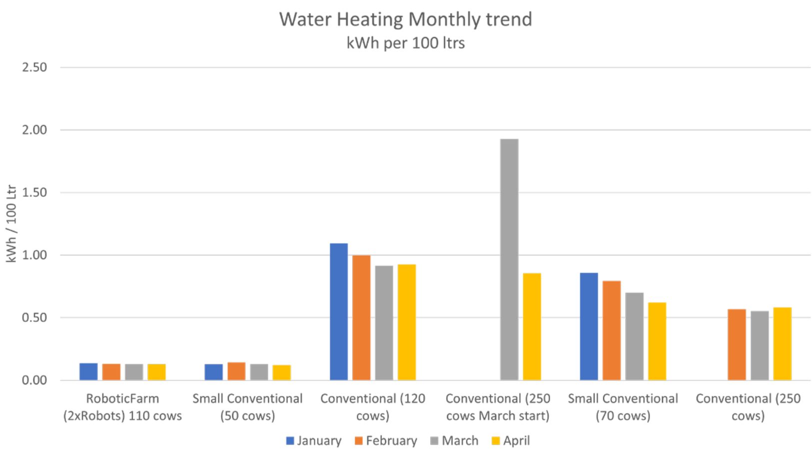
Figure 2.1 Cumulative total of Dairy Farm main energy users - Total Electrical Energy per 100 ltrs of milk



a)



b)



c)

Figure 2.2 Individual Process Energy use per 100 ltrs produced (a) Vacuum Pump(s) (b) Milk Cooling (c) Water heating

Figure 2.2 presents a breakdown of the 3 main on farm Energy using processes (Vacuum Pumping, Milk Cooling & Water heating) with the same KPI applied, Energy used per 100 ltr of milk produced.

The accumulated data presented in Figure 2.1 is the summation of the granular data shown in these three charts. Data is again presented across 4 months, Jan–Apr 21.

Due to the consistent operation of the Robotic system, the Vacuum pump operation is consistently higher for Farm 1 in comparison to the other pilot farms. It should be noted that to maintain consistency with traditional farms in dashboard reporting, the total Electrical energy used to operate the Robotic system is aligned with the Vacuum Pump process. Farm 6 is the only traditional farm to deploy Variable Speed Drive (VSD) control of the vacuum pumping. This, aligned with the larger milk yield/herd size (250 approx.) results in a much smaller KPI value and therefore more efficient process than the other traditional parlour farms as shown in Figure 2.2 a)

Farm 6 also performs very well in the Milk cooling process (Figure 2.2 b) in comparison to other farms. As expected, the farms with higher milk yield results in a reduced KPI value (energy used per 100 litres produced). The 2 farms without pre-cooling (Farm 2 and Farm 5) require more electrical energy in the milk cooling process and thus have a larger KPI value, which represents poorer energy use performance. Figure 2 b) demonstrates a level of consistency month on month across the farms with the exception being Farm 4 (slowly increasing yield from early March) and the February KPI value for the robotic farm 1. Further analysis determined a condenser issue in late February resulting in an increase in energy usage over a 10-day period. This energy profile is not consistent with condenser energy use over the remaining pilot study period, as illustrated in Figure 2.3.

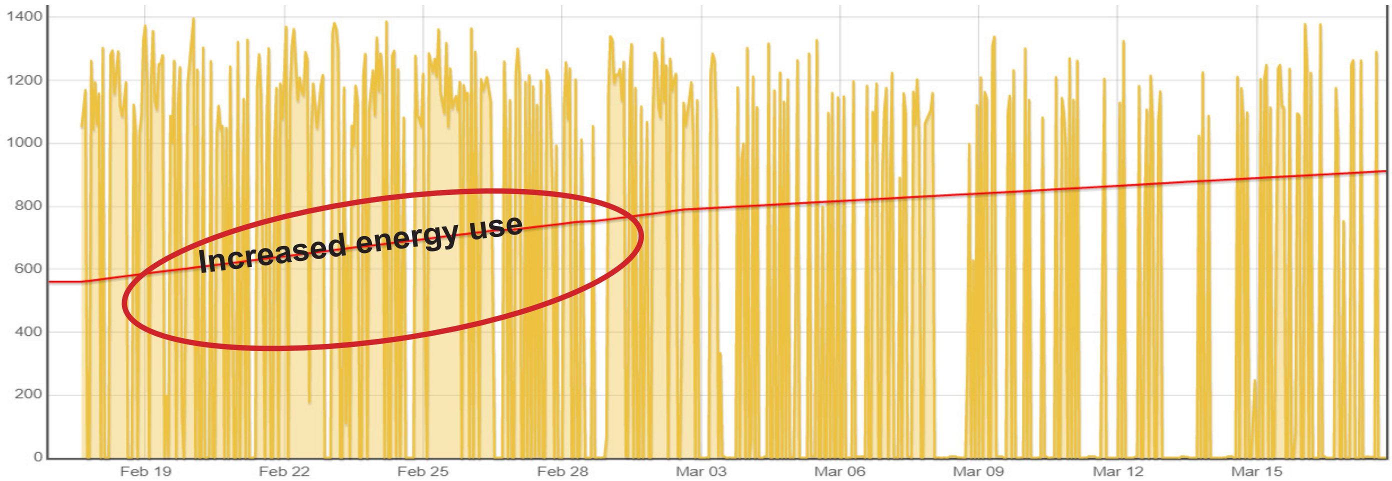
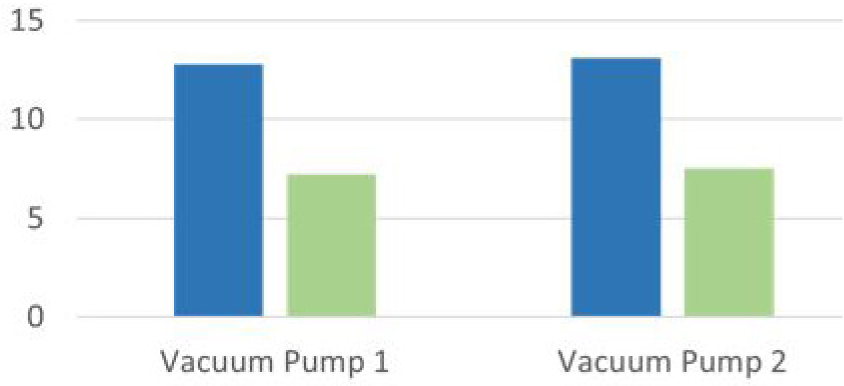


Figure 2.3 Condenser issue - exceeding energy profile

The energy alert system integrated with the dashboard visualisation (see section 6) is designed to identify these issues by using a threshold system based on previous performance averages. If the energy use exceeds (or goes below) a threshold band the system will display an alert message related to the process equipment.Figure 2.2 c) illustrates the energy KPI for Water heating across the 6 pilot sites. The best performing sites for water heating are the robotic Farm, Farm 1 and traditional parlour farm 2. The total robot energy use is assigned to the Vacuum Pump although this will also include the water heating needed for periodic robot cleaning. Therefore, the Water heating KPI only takes into consideration the hot water requirement for tank wash every 2 days. Farm 2 performance can be explained by the fact that on this small traditional farm a hot wash is only performed weekly, therefore the water is only heated once per week as opposed to every day on all other farms in this study. Farm 5 has shown considerable performance improvement month on month. This is as a result of initial data analysis that identified the water heating process was starting earlier that needed to be, resulting in a period of cyclical heating & cooling to maintain hot water temperature. Minor timeclock adjustments resulted in reduced water heating duration and significant energy improvements for this process.

Impact of Variable Speed Drives (VSD)

Only one of the 5 conventional parlour farms adopt a VSD controlled Vacuum pump system. To analyse the performance of this system against the non-controlled Vacuum Pump, a comparison across farms with similar milk yields was undertaken. Figure 2.4 demonstrates the comparison between Farm 6 (VSD system) and Farm 4 (non-VSD) for dates with similar milk yields (7099 and 7096 litres respectively). This limited comparison shows a significant variation in Daily kWh requirement for a parlour with 2 vacuum pumps in operation. Figure 2.4 also presents an extrapolated energy saving in both Electricity usage and Monetary saving based on a fixed electricity cost of 15p per KWh. Although this Energy savings is inferred from a daily comparison, it is indicative of the potential savings, monthly and annually, of installing a Variable Speed Drive system. This information should provide some clarity for farmers in terms of return on investment for the capital expenditure needed for a VSD system.



VSD on Vacuum Pump

Variation	kWh	Cost @ 15p / kWh
Daily	11.2	£1.68
Monthly	336	£50.40
Annual	4088	£613.20

Figure 2.4 Vacuum Pump comparison across farms with similar Milk yield

KPI variance based on milk yield

With varying herd size/types with different lactation periods, further analysis was undertaken to determine the KPI variance between the dates within the pilot period that produced the lowest and highest milk yield. Figure 2.5 illustrates the KPI variance per farm with the High and Low milk yield totals presented along the X-axis. These results indicate that for farms with a lower average milk yield, a smaller variance in milk produced has a more significant impact on the Energy KPI performance. This is evident in both Farm 2 and Farm 4 results shown in Figure 2.5. The large variance in milk yield and Energy KPI on the Farm 5 is again due to milking gradually resuming on the farm in late February early March, with a much lower return in the early weeks. Figure 2.5 again highlights the good performance from Farm 6 in relation to the other dairy farms in the study.

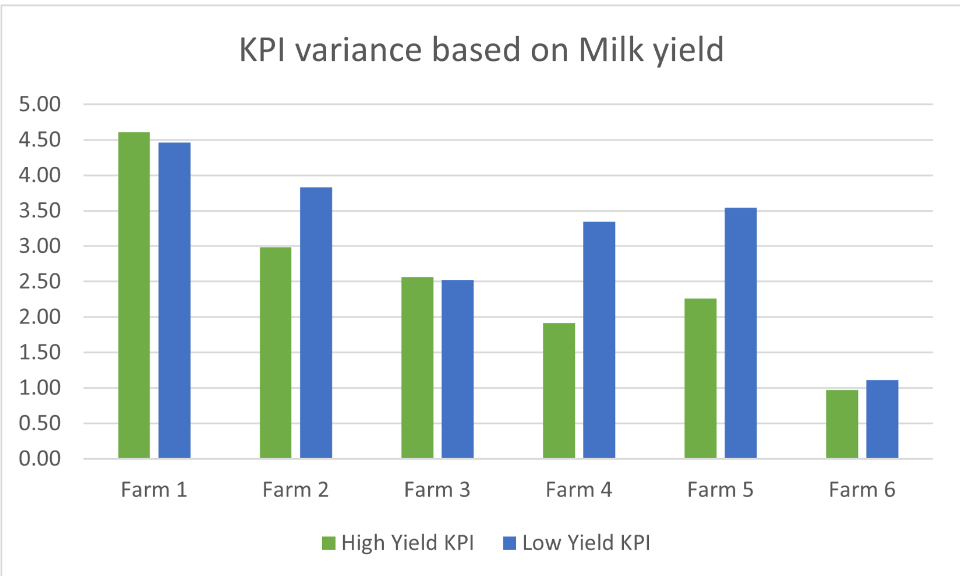


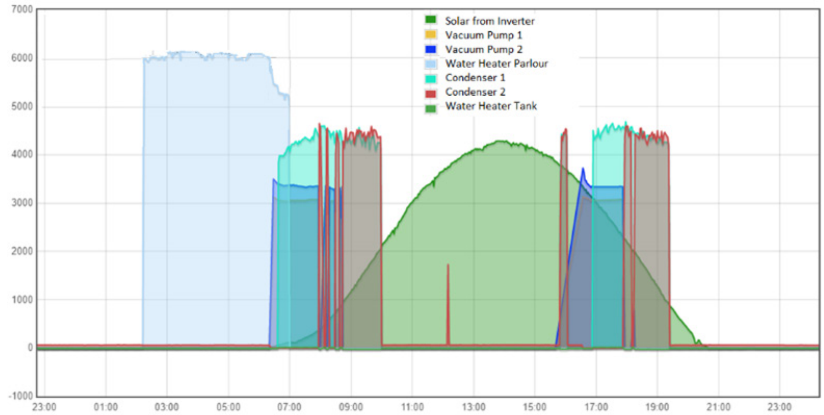
Figure 2.5 Farm by farm KPI comparison based on Milk yield variance

On-Farm Solar & Wind Renewable Generation

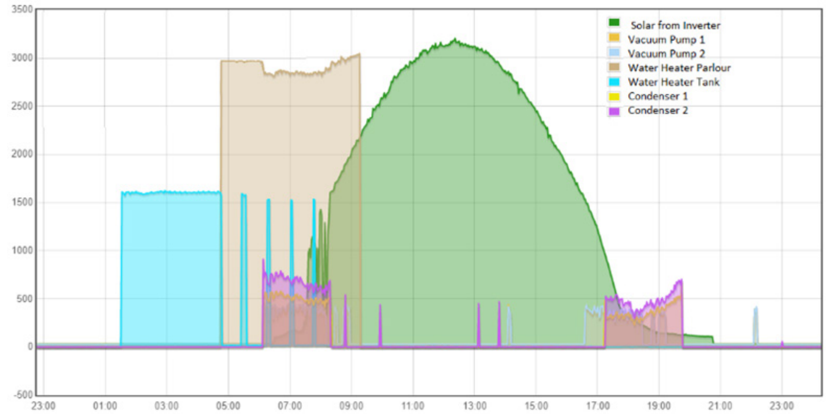
The main focus of Phase 2 of the iTEMiD research pilot study was to quantify the onsite renewable generation on our pilot farms and analyse the potential benefits and opportunities for real time local usage of the renewable energy generated. Three of the 6 pilot dairy farms had on site renewables, as detailed in Table 2.1.

Figure 3.1 provides an energy profile of all processes measured (Vacuum, Milk Cooling & Water Heating) and the energy generated from the 5kW Solar PV installation on 2 farm sites.

The green area on both images is the kWh produced by the Solar PV over a 24hr period. As expected on a day with consistent sunny periods, the profile is of 'bell curve' type with maximum generation occurring between 1 and 3pm.



a)



b)

Figure 3.1 Solar PV Energy profile a) Farm 3 b) Farm 6

What is also evident from Figure 3.1 is that the main energy generated by the Solar PV system occurs in between the 2 main energy intensive event on the dairy farm, morning and evening milking events. This profile provides stimulus for investigation and analysis into opportunities for the best on site use of this generated energy. Opportunities include water heating, ice building & battery storage for later use, and will be discussed further in section 4.

Figure 3.2 illustrates the Solar PV energy generated over a 2-month period (March and April) for both Solar PV farms. The results demonstrate the unpredictability and intermittency of Solar energy, but does show a general upward trend for average energy produced as the year progresses. The average energy generated at the end of April is considerably greater than average energy generated in early March. This seasonal response from Solar PV generation should be considered when determining best use for on-site renewables.

A similar approach was taken to measurement and monitoring of energy generated from a 5kW wind turbine on Farm 4. Figure 3.3 demonstrates the wind energy profile over 24 hours and again demonstrate the intermittency of this natural resource. There are significant differences in energy generated each month, with 660kWh generated in March and only 350 kWh generated in April.

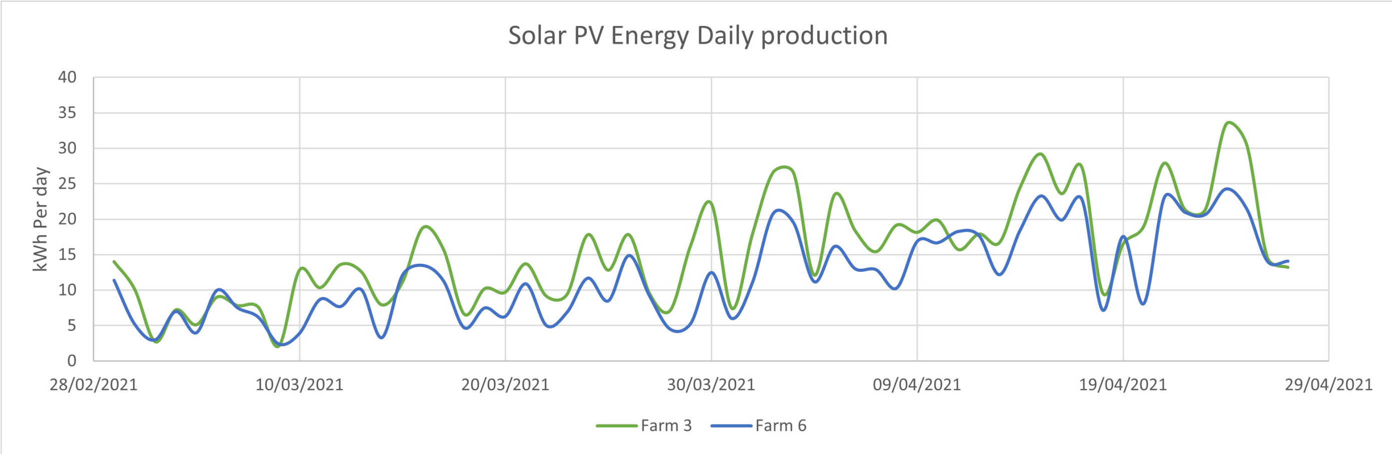


Figure 3.2 Solar PV Generation: March - April

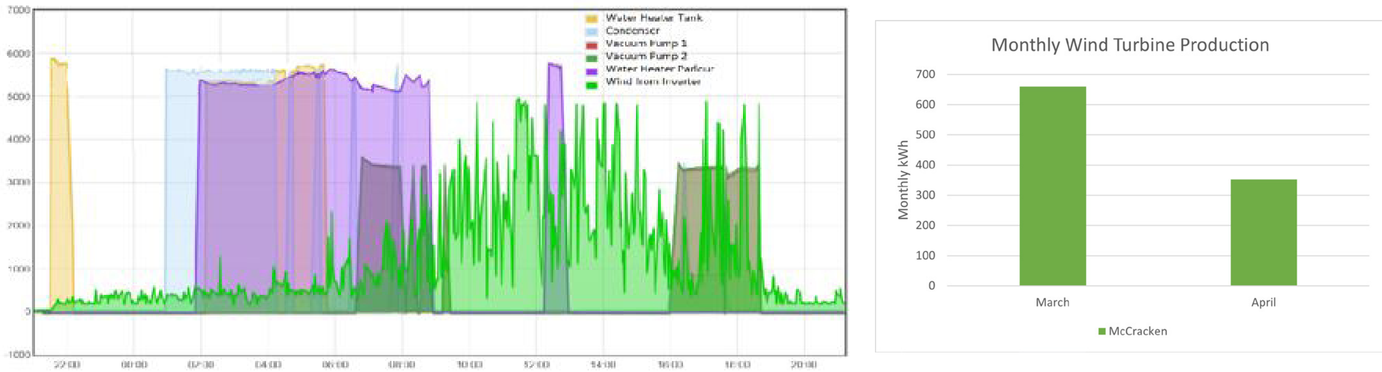


Figure 3.3 Wind generation Energy Profile - Daily view

A more granular look at the daily energy generated is shown in figure 3.4, with obvious windy periods around 10th-12th and 25-29th of March accounting for a lot of the generated total. Once again, there is opportunity to utilise more efficiently the energy generated on site, rather than return to the grid at a much cheaper rate than farmers have to pay for grid electricity when required. This will be discussed further in section 4.

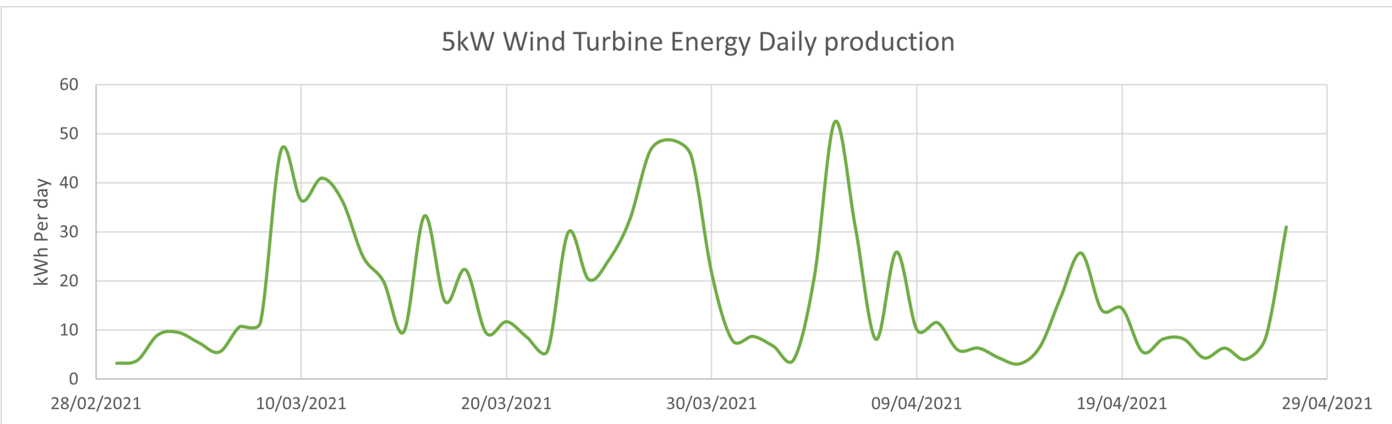


Figure 3.4 5kW Wind Generation: March-April

Opportunities for On-Farm Utilisation

This section analyses the water temperature profile of an example water heater tank for an average day and assesses the energy (kWh) required to bring the temperature to a known target value. Analysis of the timing of on-farm energy consumption for the water heater and renewable generation of solar is also provided with a proposed closed-loop system to maximise the use of solar energy.

Water temperature analysis

Fig.4.1 shows the temperature change within one-full day for an example 6kW Cotswold water heater (450L) (parlour wash). The figure also shows the tank wash temperature profile. The water tank is current activated during the night on an economy tariff and reaches 84°C for the 450L within ~5-hours. After the morning parlour wash the tank is half empty (~225L) and temperature starts to reduced steadily and show in the figure. The tank refill is activated at ~10pm in the night time. The interesting point to note is that the water temperature drops during the day by ~30°C, leaving the evening wash with a much lower water temperature. Considering on-farm renewables are generating kWh electricity during the day, in particular solar, this leads to opportunities in utilising the energy to heat the water to the target temperature.

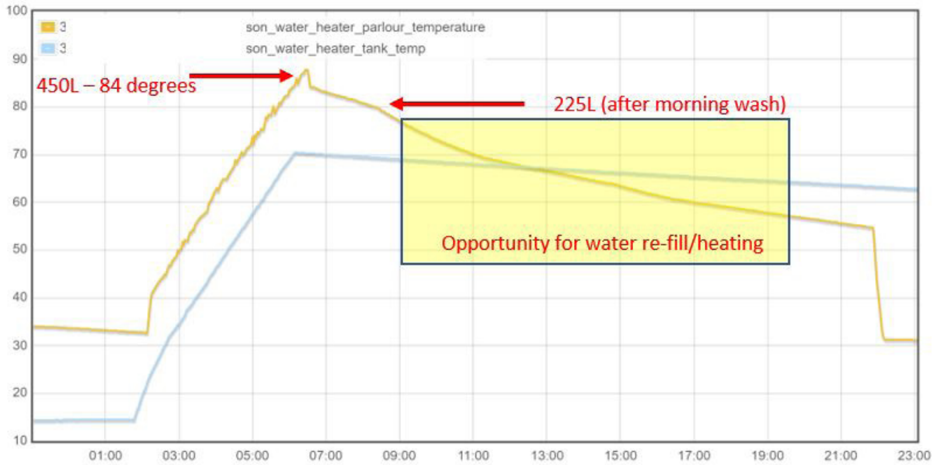


Figure 4.1 Hot Water Temperature: Parlour & Tank

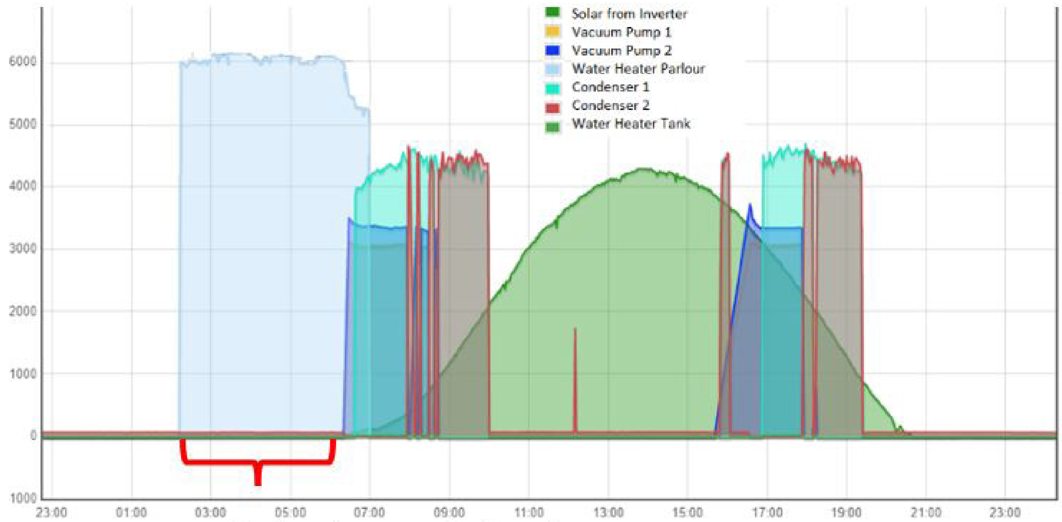


Figure 4.2 Timing of energy consumption against energy generation

Analysis of Renewables Energy Generation

The key challenge in maximising the use of renewable generation on the farm is aligning the timing of generation versus consumption. Fig. 4.2 illustrates the timing of water heating (during the night) and the time when energy (kWh) is generated from the solar renewable; these readings are taken during a day in the month of May. The Y-axis defines the watts used/generated and the x-axis the time. The solar renewable generates electricity gradually from the morning ~7.00am through to the evening ~7.00pm. The parlour water tank is used in the morning and the remaining half-tank is used in the evening. There is clearly an opportunity to gradually re-fill the 450L water tank with fresh water and use the solar generated electricity to heat the water tanks. Fig 4.3 extracts the solar energy generation profile and illustrates the proposal whereby as more electricity is generated (more kWh to heat the water), more water can be re-filled into the tank to ensure it remains at its target temperature.

Clearly as the solar energy generated varies so too should the level of water re-filling. This approach enables the on-farm solar to be re-used rather than sold back to the grid. The key advantage is additional water can be heated to the max temperature. This results in a higher starting temperature and larger volume of the water for the night-economy electricity usage. Ultimately, making effective use of the renewable energy for energy consumption during the day-time.

Fig. 4.4 shows a proposed closed-loop system that could implement the optimising of the water tank heating using solar. Wind energy is also applicable however it is noted that it is less consistent in its pattern of energy generation. The figure shows a single water inlet and outlet, an electronically controlled in-let valve, temperature and water level sensors, and a controller. The key component is the controller which reasons with the electricity levels generated by the renewables and the level and temperature of the water in the tank. As more electricity is generated the controller measures the temperature and water level and activates the water in-let for a period of time. The period of time is commensurate with the energy been generated and energy required to heat the new litres of water. It is estimated that the development cost for the closed-loop system would be in the range of £150-£200 when in volume production.

Table 4.1 shows an analysis of the Cotswold water heating energy-saving based on the heating profile shown in Fig. 4.5. Fig. 4.5 shows the measured starting and target temperatures at 25.8°C and 88.5°C, respectively. Based on the measured temperature, an analysis of the Cotswold 450L water heater shows that each 2.1°C increase in temperature requires 1 kWh of electricity.

Table 4.1 allows a further analysis of the maximum change in temperature of the water tank based on the timing of the generated solar energy (solar profiled shown in Fig 4.2). The analysis shows that at an average peak during mid-day between (11am – 5pm), 3.5 kW per hour is generated with a total of 21kWh for that period. This mid-day period alone provides a 450L tank with capacity to increase its water temperature by 44.3°C.

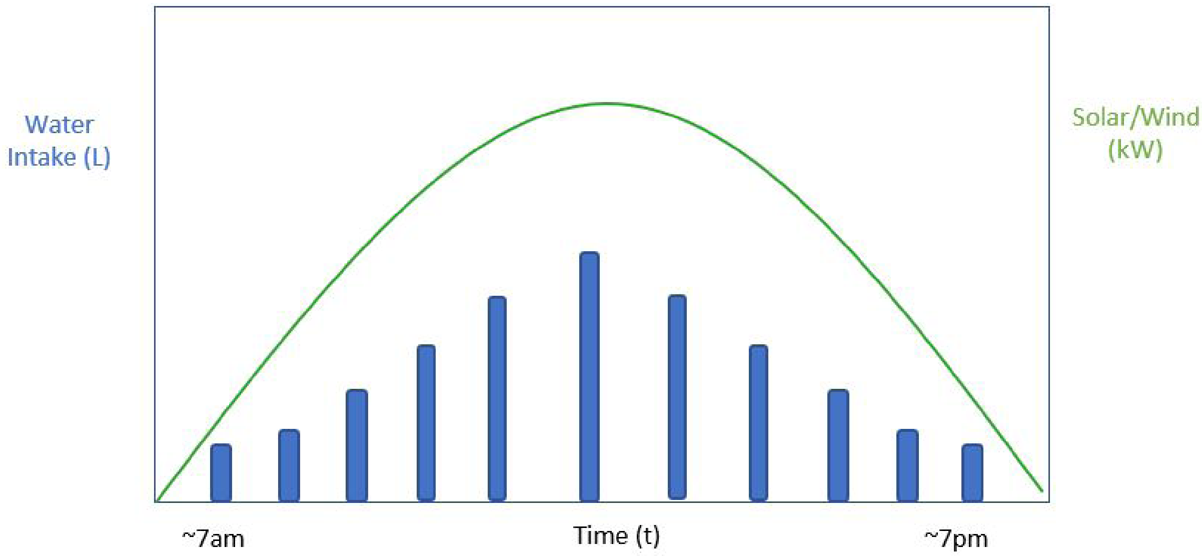


Figure 4.3 Example profile of solar energy generation and water heater re-filling

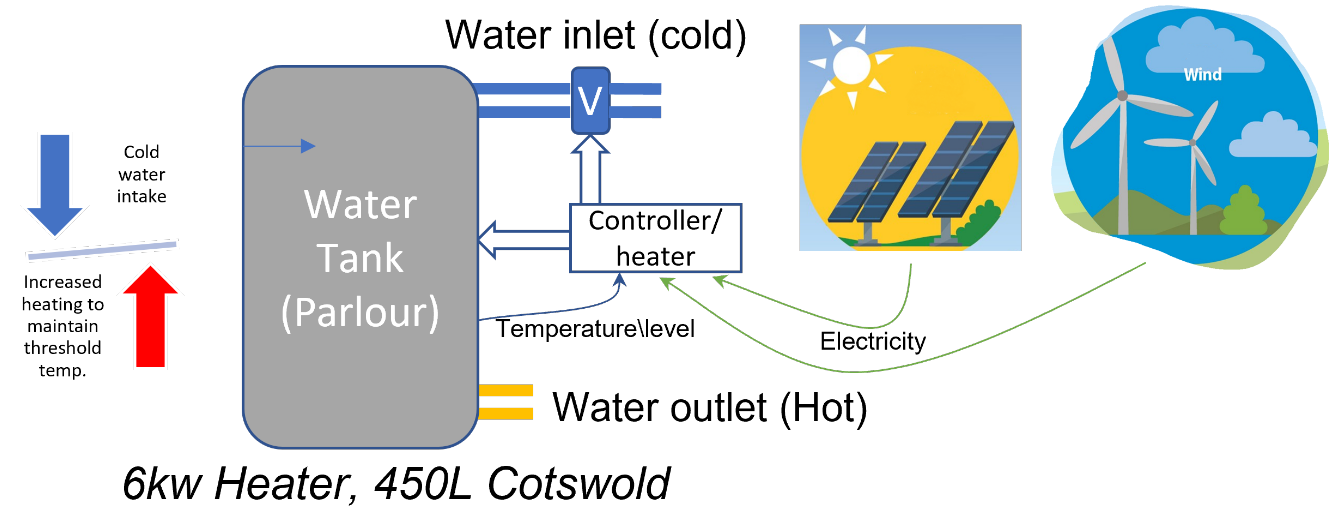


Figure 4.4 Optimising Water Heating Energy with Renewables

Based on an electricity tariff of £0.15 per kWh, the total saving in using the renewable energy to heat the water is £3.15. This is based on one single day of washing for the parlour. Additional water heaters could be used as the number of solar panels increases. In addition, while outside the scope of this study, the ice maker is another target energy user that can benefit from using the generated renewable energy. Across a 48-day period, the cost of the proposed closed loop system at £150 could be amortised, or paid off during this period. This analysis provides an early indication of the cost benefits in using on-farm renewable sources in the dairying process.

Table 4.1 Cotswold Water Heating Energy with Renewables

	Time	Duration (Hrs)	Average generated per hour (kWh)	Generated (kWh)	Temperature change (C)
Solar Morning	9.00am- 11.00 am	2	1.5	3	6.34
Solar Mid-day	11.00am - 5.00pm	6	3.5	21	44.43
Solar Afternoon	5.00pm - 7.00pm	2	1.5	3	6.34
Total		10		27	

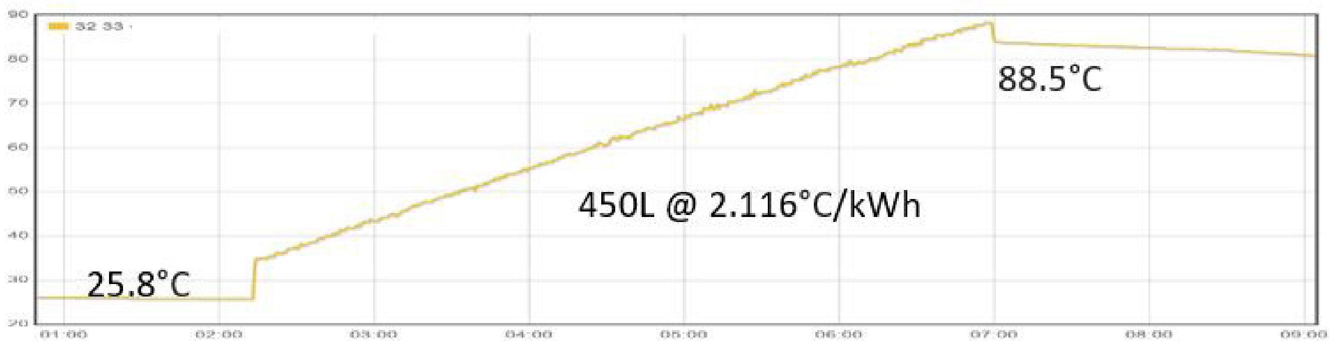


Figure 4.5 Optimising Water Heating Energy with Renewables

Milk Tank Temperature

Milk quality has a close correlation with milk temperature in on farm milk tanks, and the current milk temperature is monitored prior to collection. What is not analysed is the milk temperature profile in the tank over the period between collection, which is normally a 2-day cycle. In Phase 2 of the pilot the milk tank temperature was monitored on one farm, to provide a better understanding of the temperature profile over the 48-hour window between collections. Figure 5.1 illustrates the changes in temperature during this cycle.

The morning milk prior to collection is added to an already cooled volume of milk (3 previous milking events) and therefore has a minimal effect on milk temperature (rising to approx. 8 degrees before cooling again). After Milk collection the hot water tank wash cycle begins, causing the tank temperature to rise significantly as expected. With no Milk in the tank and therefore no cooling, the tank temperature remains high until evening milking event and the cooling process begins, reducing the volume temperature from 22 degrees to 4 degrees over a 2-hour period. The next morning milking event, which would approximately double the milk volume in the tank causes milk temperature to rise to approximately 12 degrees, before cooling process reduces the temperature to the desired range in just over 1 hr. As the next evening milk event is increasing the volume by approx. one third (2 thirds cool milk and 1 third fresh milk) the temperature increases and thus the cooling period is again reduced.

The key outcome from this study is to understand the temperature profile between milk collection periods and ensure the milk temperature does not stay above the desired temperature for too long during any of the milking events. Pre-cooling milk (Plate Heat exchanger etc) has a significant impact on the milk temperature entering the tank, and subsequently decreases both the time milk spends at a higher temperature and the cost of cooling the milk.

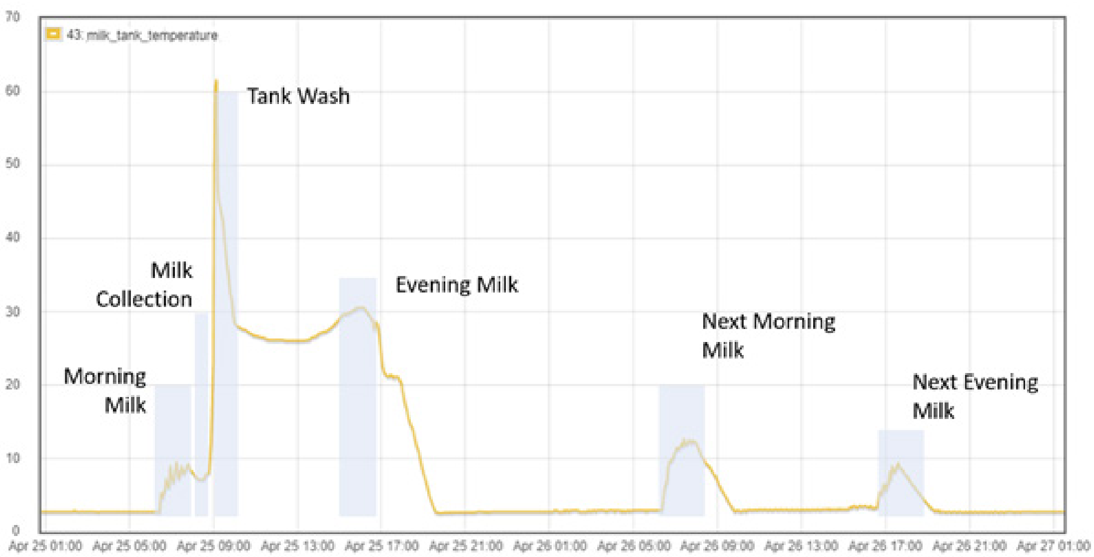


Figure 5.1 Milk Tank Temperature Profile - 48 hr duration

iTEMiD Dashboard Interface

The user application interface Farm Level view for a typical day is shown in figure 6.1. The main features and information available through the application prototype include:

1. Header cards that provide a snapshot of daily energy usage for each dairy farm process.

2. Buttons to select daily, weekly or monthly view of energy use for the 3 main energy using processes on the farm.

3. Daily process energy comparison graph. The green bars represents the energy usage on a daily level for the farm and includes the three (or more) individual processes. A pie chart in the top right hand corner represents the overall Energy shared across the 3 processes. The adjacent grey bars show the average energy use for that process over the preceeding seven days.

4. Bulk tank milk temperature chart. This presents the milk temperature in the tank over the previous 48-hours, tracking milk temperature providing insight into the length of time Milk spends above the required temperature.

5. Generation and consumption chart. This chart presents the daily renewable energy yield and also includes the Utility / Grid energy usage for that day. A pie chart presents the share of renewable against Utility energy for visual reference.

6. Parlour and tank wash hot water temperature chart. This presents the parlour wash and tank wash water temperature over a 24 hr period.

The dashboard home view provides a process level comparison of the Energy KPI performance of all farms in the pilot, with Daily, weekly and Monthly comparison available to the user. Although the comparison includes all pilot farms, with a more extensive farm uptake this could in future be filtered to compare farms by type, size, equipment (pre-cooling, ice-bank etc), locality or dairy processor.

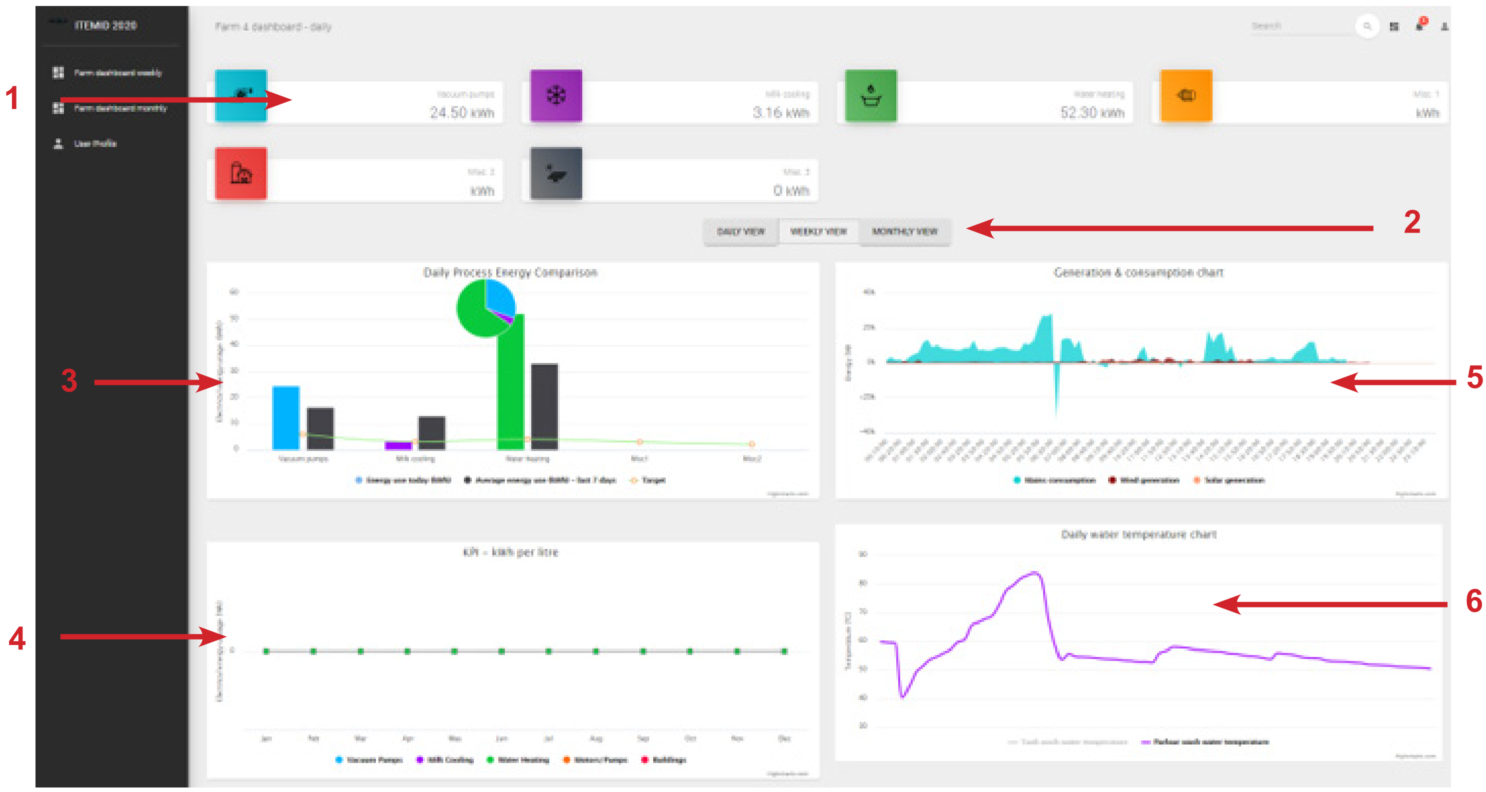


Figure 6.1 Farm-specific daily data as presented in the user application.

Discussion

The key findings and outcomes from the pilot study, considering work undertaken in both Phase 1 and Phase 2 of the project include:

•The equipment monitoring and data collection provides valuable real time insight into electricity consumption for main energy using dairy processes (Vacuum Pumping, Milk Cooling, Hot Water).

•Development of a Web accessible dashboard that visualises energy use and cost, provides alerts for system failures or anomalies and offers comparisons against other machine types (vacuum pump variance etc)

•Accessible data to inform decision making around capital expenditure, given profile and energy performance of comparable process equipment. For example, Section 2.1 compares performance of VSD based Vacuum pumps and energy performance against non VSD systems. This results in an estimated saving of £613 per annum.

•Viable opportunity for on farm renewables (solar PV / Wind) to substantially reduce hot water electricity costs using automated controller

•Based on analysis of the energy data during the project, it was demonstrated that for an electricity tariff of £0.15 per kWh, a total saving in using the solar renewable energy to heat a standard 450L water tank was £3.15. This is based on one single day of washing for the parlour. Across a 48-day period, the cost of the proposed closed loop system identified in the project could be amortised, or paid off during this period.

AgriSearch Booklets

- A Comparison On Four Grassland-Based Systems Of Milk Production For Winter Calving High Genetic Merit Dairy Cows
- Dairy Herd Fertility – Examination Of Effects Of Increasing Genetic Merit And Other Herd Factors On Reproductive Performance
- Developing Improved Heifer Rearing Systems
- Reducing Organic Nitrogen Outputs From Dairy Cows and Beef Cattle in Nitrate VulnerableZones
- The Effect Of The Type Of Dairy Supplement On The Performance Of The Grazing Dairy Cow
- Are International Dairy Sire Genetic Evaluations Relevant To Milk Production Systems In Northern Ireland?
- Effective Footbathing Of Dairy Cows
- Effects Of Feeding Maize And Whole Crop Silages On The Performance Of Dairy Cows Offered Two Qualities of Silage
- The Effect of Reducing the Protein Content of the Diet on the Performance of Dairy Cows
- Comparisons of Dairy Cow Management Strategies Which Differ in Labour Inputs
- Reducing Phosphorus Levels In Dairy Cow Diets
- The Effect Of Applying Slurry During The Grazing Season On Dairy Cow Performance
- A Comparison Of The Performance Of Holstein-Friesian And Norwegian Red Cows On Northern Ireland Dairy Farms
- The Effect Of A Number Of Novel Supplementation Strategies On Milk Production And Fertility Of High Yielding Dairy Cows
- A Comparison Of The Performance Of Holstein-Friesian And Jersey Crossbred Cows Across A Range Of Northern Ireland Production Systems
- The Effect Of Applying Cattle Slurry As The Sole Source Of Nutrients Over A Four Year Period On The Yield And Persistency Of Seven Perennial Forage Crops
- Grassland Performance And Its Relationship With Profitability On 10 Northern Ireland Dairy Farms
- The Effect Of Offering Concentrates During The Dry Period On Dairy Cow Performance
- Prevalence Of BVD In Northern Ireland Dairy And Suckler Herds
- Developing Improved Concentrate Feeding And Grazing Strategies For Dairy Cows
- The Effect Of Early Lactation Concentrate Build-Up Strategies On Dairy Cow Performance
- A Comparison Of Four Intensive Grassland-Based Systems Of Milk Production
- A Comparison Of Strategies To Improve The Body Condition Score Of Thin Cows In Late Lactation, And Their Effects On Performance During The Subsequent Lactation
- Calf Rearing Essentials
- Zero-Grazing: A Best Practice Guide
- Studies on The Use of Locally Grown Field Beans and Red Clover in Dairy Cow Diets

OTHER PUBLICATIONS

- A Comparison Of Confinement And Grazing Systems For Dairy Cows

DISCLAIMER

The Northern Ireland Agricultural Research and Development Council (AgriSearch) has provided funding for the RamCompareNI project but has not conducted the research. AgriSearch shall not in any event be liable for loss, damage or injury suffered directly or indirectly in relation to this report or the research on which it is based.

AgriSearch NI

Driving Excellence & Innovation

Innovation Centre
Large Park
Hillsborough
County Down
Northern Ireland
BT26 6DR
T: 028 9268 1539
E: info@agrisearch.org
www.agrisearch.org