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EVALUATING APPLIANCE PERFORMANCE IN THE FIELD

RESULTS FROM MILKING MACHINE TESTING

MARCH 2023

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ACKNOWLEDGEMENTS

This report shares learnings from a field test carried out on 25 single cluster milking machines deployed in Karnataka State, India. This publication is relevant for researchers, manufacturers and distributors within the energy and agriculture spaces working to improve the efficiency of agricultural processes for smallholder farmers often found in off-and weak-grid areas.

This report was developed by CLASP, Efficiency for Access co-secretariat, in partnership with the SELCO Foundation and EED Advisory, on behalf of the Low Energy Inclusive Appliances (LEIA) programme, a flagship initiative of the Efficiency for Access Coalition.

Efficiency for Access is a global coalition promoting energy efficiency as a potent catalyst in clean energy access efforts. Since its founding in 2015, Efficiency for Access has grown from a year-long call to action and collaborative effort by Global LEAP and Sustainable Energy for All to a coalition of 20 donor organisations. Coalition programmes aim to scale up markets and reduce prices for super-efficient, off- and weak-grid appropriate products, support technological innovation, and improve sector coordination. Current Efficiency for Access Coalition members lead programmes and initiatives spanning three continents, 62 countries, and 34 key technologies.

CLASP is a non-profit organisation that works on climate mitigation and expanding clean energy access through efficient appliances. CLASP achieves this mission through a variety of instruments such as policy, research, awards and building tools such as the VeraSol database, MEPSY and the CPRC.

EED Advisory is a multidisciplinary pan-African consulting firm offering technical, analytical and advisory services in energy, water and climate change. Their main service offerings include research and data analytics, projects and program design, policy and strategy, and fund management.

SELCO Foundation is a purpose driven social venture that caters to the needs of the people in rural areas through technology driven energy solutions. SELCO Foundation recognizes that sustainable energy-based solutions can be key to addressing the challenge of poverty and therefore focuses on provision of renewable energy products that are relevant to the needs of the target community. The objective of these solutions is to improve the quality of life and socio-economic development of the poor.

This report would not have been possible without the collective input from many individuals and organisations. Efficiency for Access would like to acknowledge and thank the following for their guidance and help: Makena Ireri, Elisa Lai, Anna Wright, Mike Maina, Martha Wakoli and Lisa Kahuthu (CLASP), Martin Kitetu, Alois Mbutura (EED Advisory LTD), Jakub Vrba (Energy Saving Trust), Rachita Misra and Anil Lobo (SELCO Foundation).

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1. Introduction

1.1 Background

Dairy farming in India is the single largest agricultural activity, contributing to 5% of the national economy and employing more than 80 million farmers directly.[1] Globally, India ranks 1st in milk production and contributes 23% of global milk production. In the last three decades, India's milk production has tripled, from 17 MT in 1950-51 to 209.96 MT in 2020-21.[2] Primarily, the milk is domestically consumed while a small fraction is exported.

Given the significant dependence of farmers on dairy as a source of income, it is crucial to provide solutions that enable productivity and increase income generation. A primary challenge farmers face in caring for the cows and milking is a lack of lighting and erratic power supply, which restricts them from using any technology that would reduce their physical burden and improve productivity.

Through their micro-finance initiatives, the SELCO Foundation previously collaborated with Shri Kshetra Dharmasthala Rural Development Project (SKDRDP) to disseminate information on solar-powered livelihood appliances in Karnataka. Recognising the gap in dairy farming, SELCO Foundation, in partnership with a manufacturer, Ksheera Enterprises, introduced Solar-powered Milking Machines (SpMM) to local farmers. These machines are designed to make the milking process more efficient and provide battery power backup for milking during power cuts, thereby reducing the efforts and time taken in the milking process. SELCO Foundation partnered with CLASP and EED Advisory to understand how these milking machines performed in the field and quantify their impact on end-users' livelihoods.

1.2 SpMM Field Testing

Little is known about how individual milking machines perform in real-life environments and how users interact with and perceive these appliances. Field testing involves measuring, collecting and analysing data about a product used by end users in a real-world setting, often over an extended period. In contrast, laboratory testing provides insights into appliance performance in a controlled environment. However, this delivers a limited representation of how products perform under the rigours of actual use. SpMMs have yet to undergo previous laboratory testing; thus, this field-testing exercise provides baseline data on their overall performance. Field testing[3] is particularly advantageous in nascent appliance markets with a potentially limited history of appliance usage in specific applications.

"Real use" poses challenges for the testing process and the appliance. The planned SpMM testing was going to be conducted in remote off-grid or weak-grid situations, over an extended time and with people using appliances in their daily lives, possibly for the first time. Additionally, the complexity related to the limited movement of people and equipment due to the COVID-19 pandemic required creative solutions to deploy the monitoring instruments.

Successful field testing provides information about product performance and user experience, why products perform the way they do, and their impacts on the end-user's life or livelihood. The data and intelligence gathered from field testing help inform decisions about product design, financing, business models, and more.

1.2.1 Objectives of SpMM Field Testing

This field-testing exercise sought to understand the technical performance of the KSheera Enterprises, Solar Powered, Single Cluster Milking Machines and their impact on dairy farmers and dairy farming practices. The specific objectives of the study were:

- To assess the impact of the SpMM on the socio-economic profiles of the farmer
- To assess the impact of the SpMM on the productivity, time taken, drudgery and health of the farmers
- To assess the technical performance, such as energy consumption against service delivery/milk output of the SpMM

1.3 Technology Scope

The SpMM is intended to provide a reliable power supply and power backup. The solar power supply would help reduce dairy farmers' operating costs by eliminating labour, diesel, or electricity expenses. The SpMM contains a solar module, including solar panels and batteries, that power a DC motor linked to a gearbox that activates a suction pump. The machine exerts the required amount of pressure on each cow's udder so that the cow does not experience any pain on the udder when milking. The battery can also power LED lights, facilitating early morning milking. The machine is mounted on a stainless-steel trolley having polymer wheels which can be dragged easily through a cow shed.

25 models of the single cluster milking machine were field tested from November 2021 to May 2022. The complete semi-automatic single cluster milking machine suitable for milking one animal consists of:

- The machine, including two reciprocating vacuum pumps, linked to a gearbox driven by 120 watts 12V DC motor and mounted on stainless steel trolley with polymer wheels
- Handle for manual operation
- Control block with vacuum gauge
- One 20-litre Milking can of SS304 grade stainless steel
- Cluster assembly with four teat shells and silicon rubber teat liners
- Transparent food-grade milk tube and standard vacuum tube
- 50-gram vacuum grease, two spare O rings and one spare teat liner
- A demonstration CD and instruction leaflets

1. https://www.indiabudget.gov.in/economicsurvey/ebook_es2022/files/basic-html/page277.html#:~:text=India%20is%20ranked%201st%20in,%2D15%20(Figure%2021)
2. https://timesofindia.indiatimes.com/business/india-business/azadi-ka-amrit-mahotsav-india-ranks-1st-in-global-milk-production/articleshow/93567294.cms
3. We have published field testing resources for solar water pumps and refrigerators.

Figure 1: Single Cluster DC-powered milking machine

This machine can also be operated manually through a hand lever during power failure. It consumes very low power and can run on an inverter of 800 VA capacity.

The manufacturer specifications for the 12V DC motor milking machine[4] include:

- Motor Power: 120 Watt
- Dry weight of machine: 35 kg
- Time for milking: 4 to 8 min/cow
- Vacuum level: 350mm Hg max (where 1mmHg = 133.32 Pascals)
- Pulsing pattern: Alternating (two teats/stroke) Pulse rate: 72±4/ min
- Cleaning method: Pumping boiling water and alkaline cleaning agents
- Adaptability: One animal at a time

2. Methodology

2.1 Preparations Phase

2.1.1 User Surveys

The 25 study respondents were selected from a pool of farmers who received milking machines from SELCO between 2017 and 2021 and all had exotic and cross breed cows. Based on the installation dates of the SpMM, the dairy farmers were split into two groups, i.e., Phase I, whose machinery was installed by January 2020 and Phase II, which had their installation between February 2020 and November 2021. A majority of the respondents, 72% (18 farmers), installed their machinery in Phase-I, and the remaining 28% (7 farmers) installed it in Phase II.

Table 1: Years when the selected candidates received their SpMM

Year	2017	2018	2019	2020	2021	Total
Total	1	1	6	10	7	25

The 25 dairy farmers who agreed to participate in the whole study activity were selected through purposive sampling and satisfied the following criteria:

- They agreed to install the Remote Monitoring Sensor (RMS) device and share milk yield data via SMS.
- They resided within the study radius, which was limited to 4 districts in Karnataka: Ramangara, Manday, Udupi and Dakisha Kanada.
- They were using the SpMM single cluster machine. The double cluster machines were not available within the study radius.
- They had functional dairy farms, which ensured continuous data capture of RMS data and allowed for comparison of the before and after scenarios.

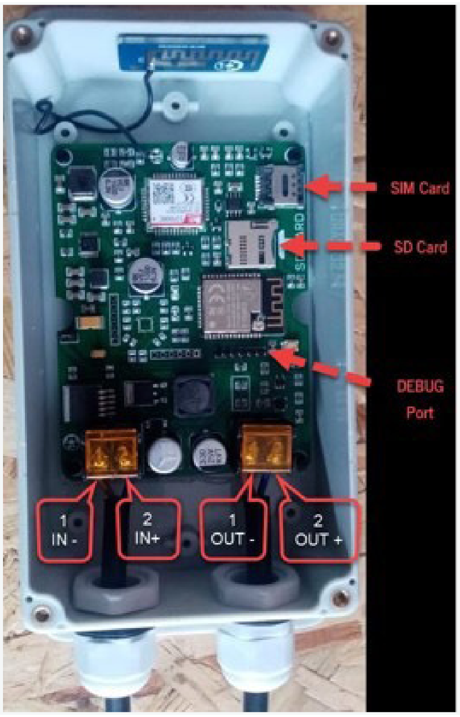
2.1.2 RMM Development

The milking machine RMS devices design incorporated a voltage measurement range of 0-72 Volts and a current measurement range of 0-8 Amperes. Each monitor included an SD card and SIM card for data transmission and storage. The communication antenna was positioned within the monitor enclosure to keep the monitor waterproof and prevent damage from liquids such as milk and water. Each monitor was programmed to record data at a 5-minute sampling interval and store this data together with a time stamp of when the measurement was recorded.

Figure 2: Top view of the monitoring module

4. The SpMM model introduced by the SELCO Foundation is only suitable for milking exotic and crossbreed cows. This is because the udder and teats in indigenous cows and buffaloes are different compared to exotic and crossbreed cows.

Figure 3: Internal terminations of the milking machine monitor



For the yield data, the most accurate and scientific method to collect milk yield from the milking machine would be using a flowmeter. However, COVID-19-related supply-chain bottlenecks created a challenge in acquiring a food-grade flowmeter for the study. Consequently, the initial design was modified to use a GSM-enabled text-based system allowing farmers to self-report their daily milk yield during the study period.

2.2 Monitoring Phase

2.2.1 Qualitative Data Collection

The enumerators participated in a two-day training session at the SELCO Foundation office in Bangalore. The training schedule included a first day devoted to classroom training, providing a conceptual understanding of the SpMM and study tool. The second day was dedicated to mock practice and role-plays. After the comprehensive training sessions, the trained enumerators conducted face-to-face interviews by travelling to the participating farms in the four districts of Karnataka. Before the data collection began, SELCO Foundation helped develop a list of district point of contact persons (PoCs) whom the enumerators could contact. The district PoCs were part of SELCO India's executive team responsible for SpMM installation in the state. Enumerators would contact SELCO Foundation PoCs in each district before contacting the end-users and administering the interviews.

The socio-economic study data collection took place between January to March 2022. A semi-structured questionnaire comprising two main components, i.e., socio-economic profile and drudgery scale, was administered to the farm owners and the other family members and employees involved in the farm's milking activities. The structured questionnaire was pilot tested at three SpMM sites in the Tumkur district, which is not covered in the scope of this study, but due to COVID-19 movement restrictions, the team could not travel too far. The testing was to help design a final questionnaire. The finalised study tool included inputs and feeback from the pilot exercise. Field investigators also received instructions on correctly administering specific questions from the pilot test learnings. The final study tool was translated into Kannada, the regional language, and then cross-checked with the English tools for accuracy and validity. This step ensured that the vocabulary used was understandable by the data collectors and end-users.

SELCO Foundation's research manager reviewed the completed questionnaires. All data collected was confidential during each stage of the research process, including data collection, data capture and management and reporting outputs. Every end-user under the study received a unique UID (serial number). All data and pre-analysis forms were stored electronically on password-protected computers. Hand notes and answer sheets were stored in a secure cabinet.

Key challenges during the data collection included:

- With the end-users located across four districts, in some cases, the contact number provided was either old or unreachable. The SELCO Foundation executive supported enumerators to reach the end-user's location wherever possible.
- Although appointments were scheduled before the visit date, some end-users (about three to four) were not present on the visit date due to arising commitments. To address this challenge, the researcher provided an alternate date after consultation with the SELCO Foundation executive and the end-user.

2.2.2 Quantitative Data Collection

Through our technology partner, EED advisory, an installation team based in India, was trained on the installation procedure for the RMS. They then installed the RMS on the 25 single cluster machines between November 2021 and May 2022 to monitor the power consumption of the milking machines and capture the data. The remote monitors were installed between the battery and the milking machine, as shown in Figure 4.

The monitor was installed before the machine's electrical on/off power switch to facilitate round-the-clock monitoring of the battery and the machine. It also enabled battery measurements while the milking machine was off. For stability, the monitor was tied to the machine's frame to prevent movement caused by vibration during machine use.

At the end of the monitoring period, each remote monitor was retrieved, and the SD card data was extracted and sent to the data analysis team. To mitigate human error during submission, each device codes a unique number to the data to link the device to the data submitted. Through this data collection process, 1.07 million unique data points were collected on the milking machine use, which were processed and eventually saved in a spreadsheet for further analysis.

For the yield data, the planned GSM-enabled text-based system that would allow farmers to self-report their daily milk yield was not deployed successfully. As an alternative, respondents were called once a week between 13th March 2022 and 22nd May 2022 (11 weeks) during the monitoring period to estimate their weekly milk yield. This data was considered together with the self-reported daily milk yield recorded while SELCO Foundation carried out the socio-economic study.

Figure 4: Installation of the monitor relative to the milking machine

2.3 Synthesis Phase

2.3.1 Qualitative Analysis

The study used a retrospective pre- and post-study design with a quantitative approach. For the evaluation study, a structured interview schedule was administered. Since the baseline data were not available to compare with the end line, the evaluation study used the recall method and created the baseline data, which was used to make before-after comparisons of the impact of the SpMM intervention. The basic structure of the study tool was to collect information on:considered together with the self-reported daily milk yield recorded while SELCO Foundation carried out the socio-economic study.

a) Socio-demographic profile of the dairy famer

b) Dairy farm practices before installation of SpMM

c) SpMM installation process

d) Current practices at the dairy farm

e) Changes reported by dairy farmers once they started using the SpMM

f) Drudgery scale

Recall Bias – Eight out of 25 study respondents adopted SpMM more than three years before the study period, which meant that recalling the events before the intervention was highly challenging. Consequently, the questionnaire design started with the end-user's profile, followed by their dairy farm practices before installation, the installation process, the present situation and finally, impacts to minimise the recall bias. The end-users could remember the information more easily due to the questionnaire flow. Enumerators asked for the before and after information separately to minimise confusion.

2.3.2 Quantitative Analysis

The RMS data were extracted in May 2022 for the 25 farmers who participated in the 6-month study period. Daily time and energy readings were logged in 5-minute intervals for most devices. From the data collected, readings from 13 devices were excluded from further analysis due to the following reasons:

- F102 did not record readings between December and April, possibly because the appliance may have been affected by voltage rises from usage during strong solar irradiation due to the lack of a solar voltage limiter/regulator or because the battery was behaving irregularly.
- F106 only had data for installation from November until the end of December. However, no yield data for the period was recorded; therefore, a correlation could not be achieved.
- F10D had significant measurement outliers (outside of milking time), making it difficult to isolate milking time.
- F10E only recorded from December 1st to December 29th. However, no yield data for the period was recorded; therefore, a correlation could not be achieved.
- F110 only recorded at the start of the study with sparing use throughout. The erratic use did not align with any day when we had yield information; thus, a correlation was not established.
- F118 did not record any data at all. The RMS may have been damaged because the report from the enumerator stated that all appliances were working. It could also be the connection between the RMS and the appliance was broken.
- F114 only recorded data between December and February. However, no yield data for the period was recorded. Therefore, a correlation could not be achieved.
- F104, F10F, and F115 had current readings that were below 1 Ampere for the duration of the study and had significant data gaps during the recording period, which could imply that the users had difficulty milking with the appliance and therefore did not use them or that the RMS connection was faulty.
- F117 only recorded on November 3rd, 2021, during the installation, while F111 only recorded data for the 1st two days after installation. In this case, it is most likely that the RMS installation was faulty, and the devices stopped recording.
- F113 had a very noisy signal throughout the study period. A potential explanation could be the motor was occasionally overloaded; thus, it overheats and stalls/trips a circuit breaker. For this reason, there was no consistent way to isolate milking time.

Despite the limitations of the data collected by the RMS, we introduced a second layer of assessment to extract data from the devices that met the qualifications to be analysed.

As daily yield data was not available for the study duration, we matched the self-reported yield data by the farmers to the daily milking machine readings for that day. An upper timing limit informed by manufacturer specifications of milking time per cow was introduced, and the analysis eliminated all the devices where milking time was greater than 9 minutes per cow per milking event. With that benchmark introduced, only eight devices had RMS readings that met the below thresholds:

- The device had RMS data collected on the same day as the self-reported milk data
- The device had RMS current readings that were greater than 1 Ampere
- The device showed a milking event where the time taken was less or equal to 9 minutes per cow

Finally, the milking machine could only be used on exotic and crossbreed cows. However, some of the milk yield data reported by the farmers included other cow breeds like indigenous and buffaloes. To avoid misreporting and distorting the analysis, only the farmers who had exclusively exotic and crossbreed cows were studied. This further eliminated three devices, leaving the five devices that were studied as:

- F10C
- F101
- F105
- F107
- F116

2.4 Study Limitations

As with most studies, this study presents certain limitations, which include:

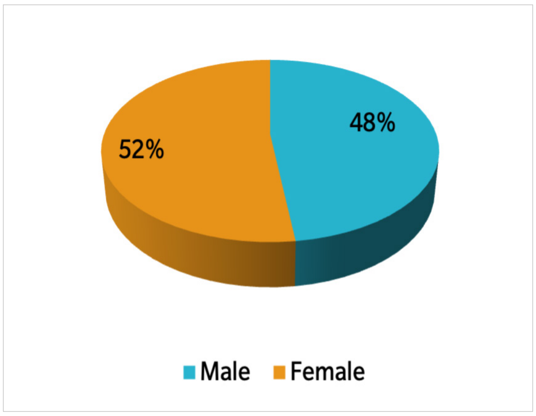
- Given the small sample size, the results and their interpretations may not be statistically significant. Therefore, drawing conclusions for the entire population is not possible. This is particularly key in interpreting observations on the technical performance of the appliance.
- The sample is not broad enough to provide robust estimates at the district or intervention phase levels.
- Since the SpMM was given to the farmers at different points, i.e., some received the machinery over two years ago while others received it as recently as three months ago, the interpretations may not be generalised.
- Due to the absence of baseline data, the baseline has been established regarding the pre-intervention condition retrospectively based on recall by the farmers. Therefore, the data is subject to recall biases.
- The milk yield data was not captured with the power consumption data. The device's performance would require a correlation of these two variables; thus, the technical performance assessment was included as Annex 1[5] with the limited data available.

3. Dairy Farming: Before SpMM Intervention

3.1 Dairy Farmer Profile

All the households covered were rural, and most had previous electricity connections for lighting and cooling purposes. Prior to the intervention, most of the dairy farmers used grid electricity supply (96%, n=24) for their lighting needs. More than half of these households (52%) were situated in hilly areas, and the rest were in plains. Only 4% of them were based in a forest area. Female respondents accounted for 52% of the total sample covered.

Figure 5: Gender profile of respondents (n = 25)



In terms of educational background, almost all the respondents had attended either school/college except 4% who did not have any formal education. 80% of the respondents 80% attended primary school, 12% attended college, and 4% were diploma holders in dairy science.

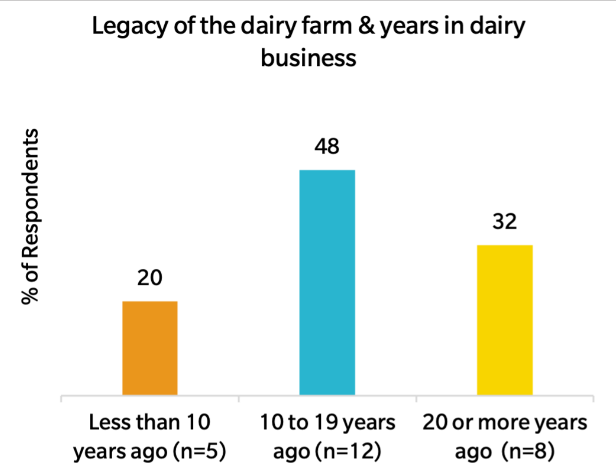
These rural households mainly depend on agricultural activities and dairy farming for their livelihood. They also experience vulnerable social conditions such as women being the head of the family (12%), too many dependents (52%), health issues and disability (36%).

3.2 Dairy Farm Characterisation

We found that most dairy farmers inherited the dairy farm from their families and have more than 10 years of involvement (80%), with 14 years as the average duration of involvement in the dairy business.

5. Included at the end of the report.

Figure 6: Dairy farmer experience



Excluding one dairy farm, all cowsheds of the farmers studied were attached to the farmer's residence. The common electricity line that provided lighting for the home also supplied the cowsheds. The average size of the cowshed was 534 square feet; the largest was 1,800 square feet, and the smallest was 120 square feet.

The SpMM was deployed to dairy farmers who owned exotic or crossbred (Holstein Cow or Holstein Friesian (HF) cows and Jersey cows. Some of the farmers also owned indigenous cows and buffalos. On average, each farmer owned five exotic/crossbreed cows, and four were lactating during the data collection. Out of 25, only 19 farmers exclusively owned exotic or crossbreed cows, while the rest had indigenous cattle or buffalos along with exotic or crossbreed cows. The farmers surveyed had three main breeds of cow:

- Two farmers had all three types of cows (F100, F10A)
- F108, F102 and F112 had indigenous and crossbreed cows
- F10B had crossbreed cows and buffalos
- The remaining 19 dairy farmers had only exotic or crossbred cows

Most dairy farmers (17) had five to ten lactating cows before the intervention, while the average number of lactating cows for these dairy farmers was five. During the intervention, most dairy farmers (16) had four or fewer lactating cows, while the average number of lactating cows for these dairy farmers was four. As a result of the pandemic-induced economic contraction, most of the farmers had fewer lactating cows.

3.3 Milking Practices & Challenges Faced

Hand milking was the most common method for smallholder dairy farmers in Karnataka. From the study, before receiving the SpMM, 24 dairy farmers were practising the hand milking method. Only one farmer was using an electric milking machine.

Figure 7: Hand milking

Major challenges related to hand-milking practice highlighted by dairy farmers practising manual milking were a high level of drudgery (100%), too much time taken for other milking activities (100%), restrictions on travel or mobility (96%) and health issues (75%). Farmers also highlighted challenges related to the milk quality and cow's health. This includes wastage (reported by 100% of dairy farmers), contamination of milk (83%), inability to milk the cows (71%), and adverse effect on the cow's health due to the fisting practice (??%).

Those who practised manual milking and depended on grid electricity for various uses in their dairy farming activities highlighted frequent power outages (83%), high electricity charges (54%), and voltage fluctuation (50%) as major challenges.

Common lighting-related issues highlighted by farmers were power outages in the morning (92%), poor visibility due to poor lighting (24%), poor safety of cows and milk (8%) and encounters with reptiles (4%).

All farmers reported that they switched to the SpMM to mitigate these electrical and lighting challenges.

Table 3: Cow breeds

Breed	Indigenous Breed (n=5)		Exotic or Cross breed (n=25)		Buffalos (n=3)		Total (n=25)	
	Herd Size	Lactating cows	Herd Size	Lactating cows	Herd Size	Lactating cows	Herd Size	Lactating cows
Total	7	4	128	104	3	3	138	111

Figure 8: Electricity-related challenges faced by farmers practicing manual milking (n=24)

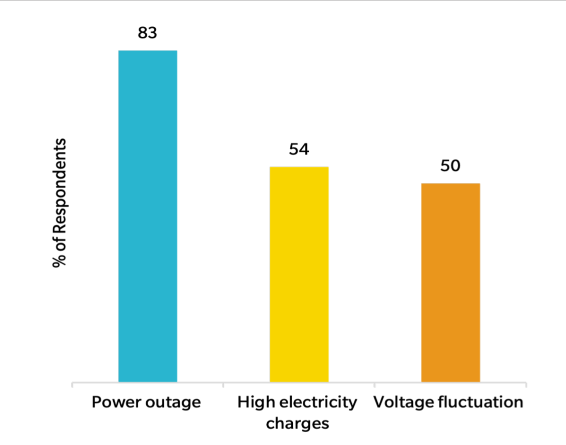
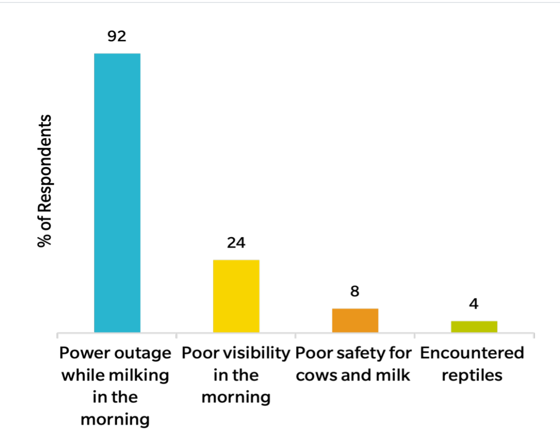


Figure 9: Lighting-related challenges faced by farmers practicing manual milking (n=25)



4. SpMM Installation

4.1 SpMM Configuration

The study's scope covered dairy farmers with the Single Cluster Machine (120 W, 12 Vdc) with the lighting option. However, within that scope, the farmers had different capacities of panels and batteries. Table 4 shows the various configurations the dairy farmers used during their SpMM installation.

More than half of the respondents (52% of them) opted for the SpMM with a panel capacity of 120 Watt-peak (Wp) and a battery capacity of between 80-120 Ampere-hours (Ah). The remaining dairy farmers opted for the SpMM with a panel capacity of 75 Wp and 80 Ah batteries.

Table 4: Panel sizing for SpMM

Panel Capacity (Wp)	Battery capacity (Ah)	% of SpMM
120	100	4%
120	120	44%
120	80	4%
75	80	48%

4.2 SpMM Installation and Function

All dairy farmers stated that during installation, the SELCO technician had provided onsite training on various aspects of operating the machine, such as pressure setting, greasing, machine cleaning and solar panel maintenance. 96% of the respondents were satisfied with the installation service only contained small-sized units.

The study also probed the current use of the SpMM. 80% of the respondents said that the appliance was in running condition. 16% said that though the machine was in good condition, they were currently not using it (F110, F108, F102, F10F). Only one farmer said the machine was not running efficiently (F100).

The 16% were asked why they were not using the machine, and most said it was because their cows were not lactating or pregnant. The respondent who had issues with the SpMM reported experiencing a pressure-setting issue in the device. The RMS attached to these machines corroborated these reports as it did not have readings for analysis (F100).

Though the majority (56%) of the farmers had not faced issues with machinery since the installation, 40% reported a breakdown of the SpMM once or twice during use. The most common problems outlined by the farmers were machine problems, non-availability of sunshine, charger controller issue, battery breakdown and panel issues shown in Table 5.

Figure 10: Current status of SpMM unit

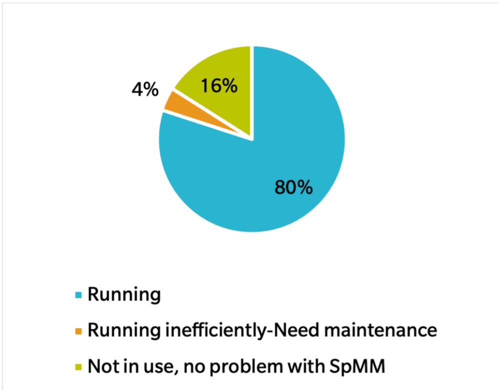


Table 5: Issues reported with SpMM

Problem Type	Number of dairy farmers	Device IDs
Machine Problem	11	F10C, F105, F104, F110, F100, F10A, F10D, F102, F10F, F10E, F111
Non-availability of Sunshine	4	F101, F104, F118, F10E
Charger Controller Breakdown	2	F107, F114
Battery Breakdown	2	F106, F113
Panel Issues	2	F113, F103

4.3 Ease of Use and Maintenance

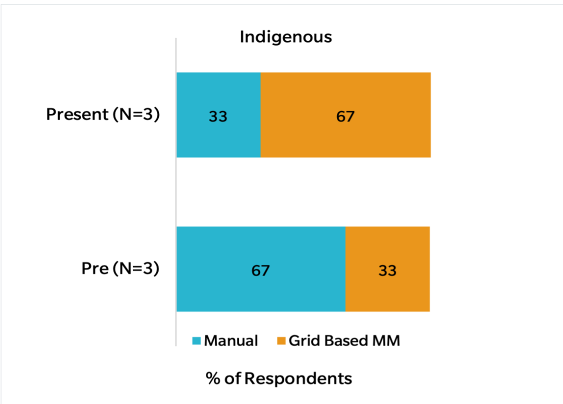
In terms of the user experience, the users were asked about the ease of operation and maintenance. 96% of the respondents said that the SpMM was easy to operate and maintain. Only one (F10D) of the respondents said they found operating and maintaining the machine difficult but did not elaborate on what kind of difficulty they experienced.

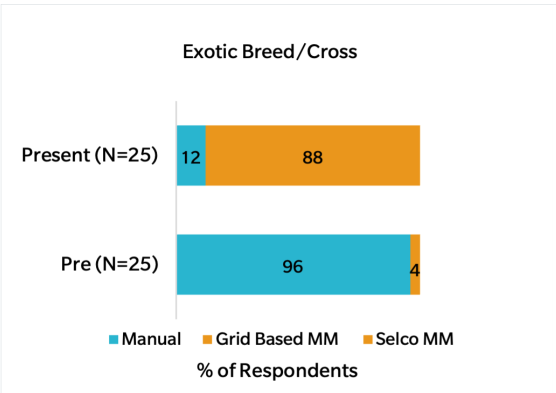
5. Dairy Farming: After SpMM Intervention

5.1 SpMM Use

The SpMM machine was mainly used on exotic and crossbreed cows. As illustrated below, most of the farmers who had exotic and crossbreed cows shifted to SpMM-based milking, with 88% of the respondents reporting the same. 12% (n=3) of the farmers said they had switched back to the hand-milking method as their number of lactating cows had reduced.

Figure 11: SpMM use on different cow breeds





Note: Pre (N) shows the number of dairy cows being milked before the intervention and Present (N) shows the current number of milks milked since adopting the SpMM.

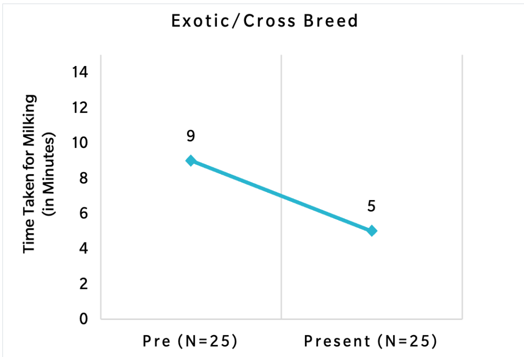
The increased usage of the milking machine led to increased involvement of both male and female members of the household in the milking activities.

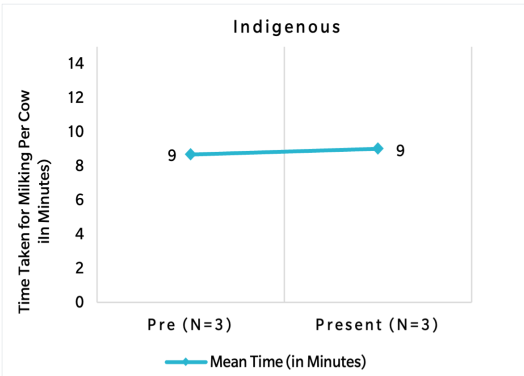
5.2 Milking Time

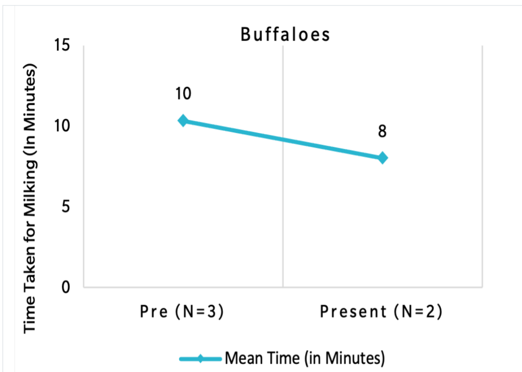
It was reported that with the use of the SpMM, the average milking time for exotic and crossbreed cows reduced by 4 minutes. A statistical test used to compare the means of two groups, often in hypothesis testing to determine whether a process or change actually influences the population of interest, was conducted. When reporting t test results, the p value communicates whether the difference between the two groups is statistically significant, meaning it is unlikely to have happened by chance.[6] A t-test conducted on the reported time for exotic and crossbreed cows showed a significant difference ($P<0.05$) in the time taken for milking after the introduction of the SpMM.

Conversely, the milking time for indigenous breeds remained the same over time. The milking time for buffaloes only decreased by two minutes. Both breeds remained hand-milked during the study. This difference in time taken was not found to be significant ($P>0.05$).

Figure 12: Average milking time across different cow breeds



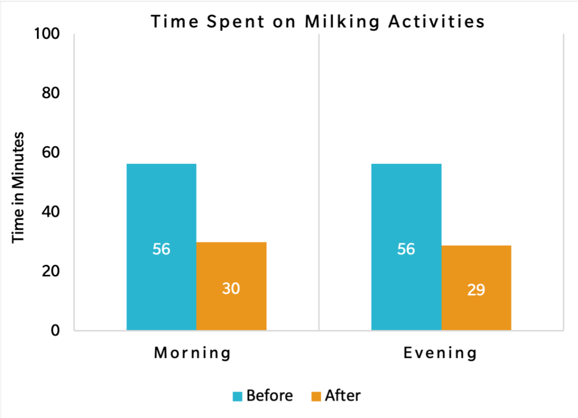




6. Bevans, R. (2022, December 19). An Introduction to t Tests | Definitions, Formula and Examples. Scribbr. https://www.scribbr.com/statistics/t-test/

The SpMM intervention's impact was evident when farmers reported spending on dairy farm activities, including cleaning the shed and feeding and milking the cows. The reported reduction in time was 56 minutes spent each morning and evening to 30 minutes and 29 minutes after the intervention. A t-test of the time spent milking during morning and evening shows a significant difference ($P<0.05$) in the time spent on milking-related tasks.

Figure 13: Total time spent on milking activities



5.3 Drudgery Reduction

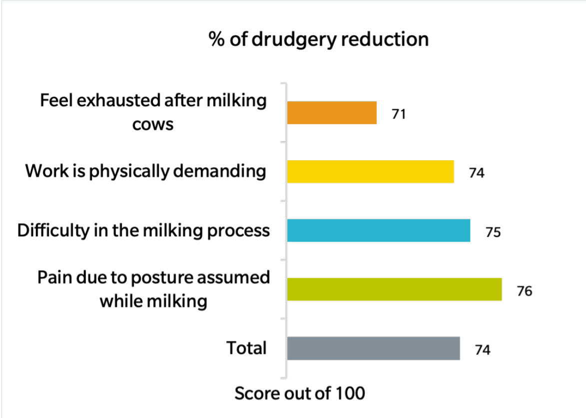
To measure the SpMM's impact on drudgery, a specific tool was administered to the family members involved in the milking activities. The drudgery scales captured data on a 1 to 5 scale, with one referring to the lowest intensity and five referring to the highest intensity of parameters such as:

- Work is physically demanding
- Feel exhausted after milking cows
- Pain due to posture assumed while milking
- Difficulty involved in the milking process

Each parameter produced a score, and a total score was arrived at using a combination of these parameters. The score was calculated by measuring the percentage change before and after the intervention. The maximum score in each parameter was 100, indicating that the higher the score, the better.

68% of the respondents were dairy farm owners, 28% were spouses of the dairy farm owners, and 4% were parents of the dairy farm owners. In most cases (80%), women were mostly involved in milking activities before the installation of the milking machine; therefore, the drudgery scale was administered to them. The minimum years of involvement in miking activities were 4 years, while the minimum involvement of the respondent in the intervened dairy farm was 1.5 years.

Figure 14: Indicators of reduction in drudgery



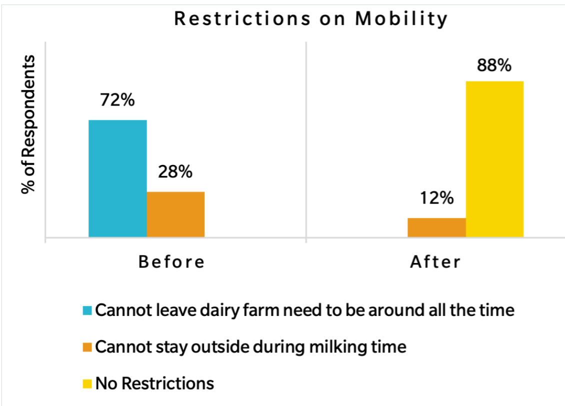
We observed that across all four parameters, the score was above 70, indicating that the SpMM has been able to reduce the physical exertion, exhaustion, pain and difficulty involved in milking activities to a great extent.

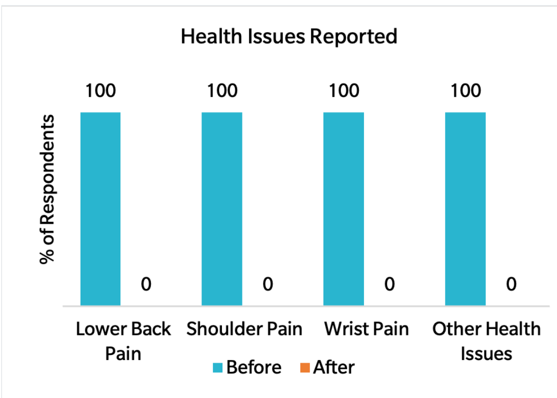
5.4 Health Benefits

In terms of health issues, prior to the intervention, all the respondents reported health issues such as lower back pain, shoulder pain, wrist pain, and other health issues. 46% (n=12) had consulted a doctor for health issues prior to the intervention.

However, after the intervention, none of these issues was highlighted by the respondents, and none of the respondents consulted a doctor.

Figure 15: Health benefits of SpMM





5.5 Mobility

The SpMM intervention has to a great extent, impacted the mobility of the family members. Before the intervention, 72% of the respondents said their mobility was highly restricted. However, 88% of the respondents said their mobility was not restricted after the intervention. See Figure 16. Previously, if the milking men/women took leave before the milking was incomplete or other family members had to take over and milk the cows manually. However, due to the installation of SpMM, other family members can use it for milking in the absence of the milking men/women, as reported by all respondents.

5.6 Attitude Towards New Technology

To evaluate the reception towards new technologies, the medium used by the farmers for learning about new technology was assessed. 92% of the respondents reported learning about new technology from SELCO executives. Other significant sources of information were newsletters/IEC initiatives of the agriculture Department (24%), fellow dairy farmers (24%), panchayat meetings (12%), and TV/Radio (12%), among others. [7]

The adoption pattern for the various technologies available to aid dairy activities was assessed. The farmers were asked about their likely adoption behaviour for various equipment that is available in the market. A chaff cutter was one piece of equipment that 40% of the farmers wanted to adopt, followed by a water heater (36%), and a pressure washer (24%).

Figure 16: Fewer restrictions on mobility

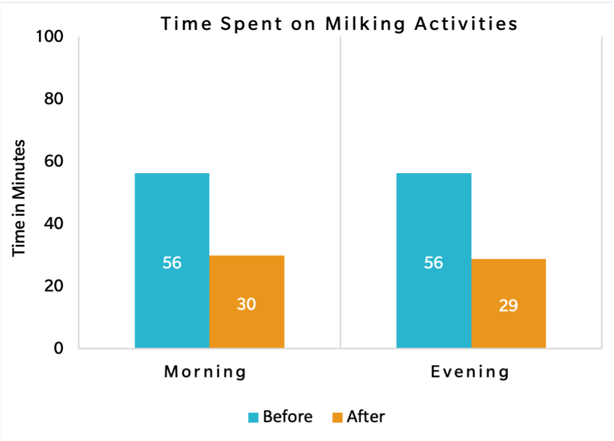


Figure 17: How users learn about new technology

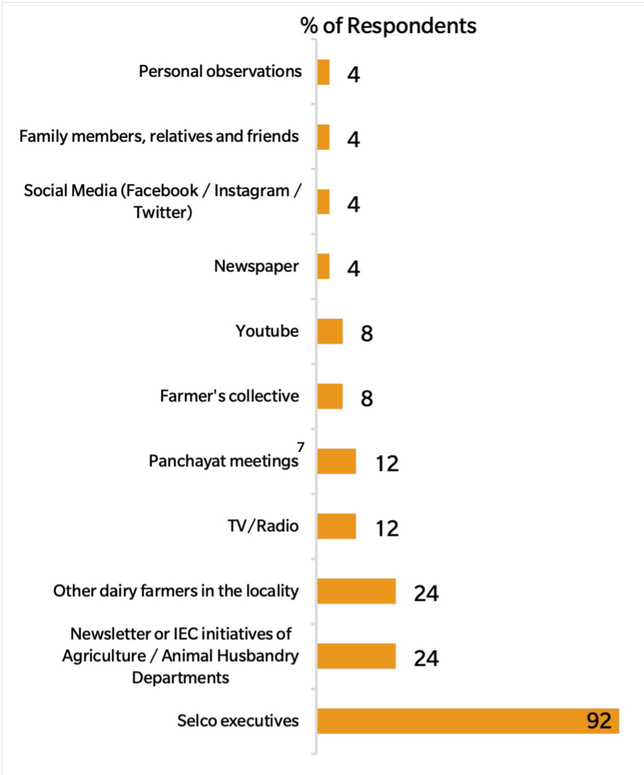
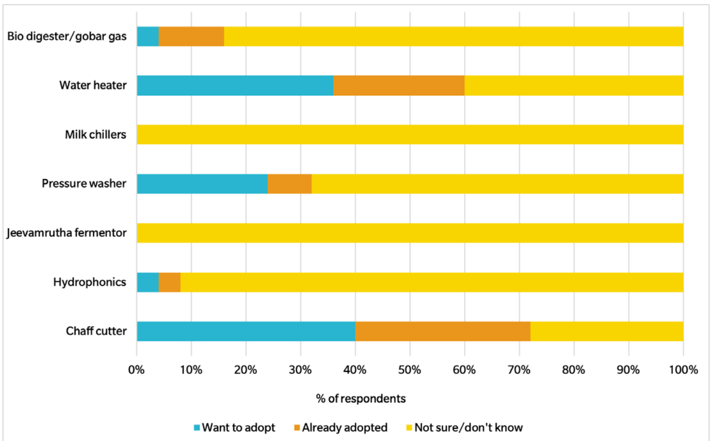


Figure 18: Willingness to adopt dairy technology available in the market



7. A panchayat is a basic village-governing institute in Indian villages. It is a democratic structure at the grass-roots level in India.

6. Learnings & Recommendations

Introducing the SpMM to farmers who previously relied on manual milking methods resulted in several observed and reported positive impacts:

- The appliance reduced the milking time by at least 4 minutes for all respondents with exotic and crossbreed cows.
- The appliance reduced drudgery by a minimum of 70% for all respondents.
- The overall time used for milking and other related activities was reduced.
- There was a reported health benefit with fewer complaints of wrist aches, shoulder, and back pain.
- There was an increased willingness to adopt other technology that could further support dairy farming activities.

The installation and maintenance process was reported to be simple and reliable. Providing training to the installers prior to the deployment of the appliances helps to improve the quality of the installation, therefore, reducing instances of failure.

For the testing methodology, several lessons were learnt to inform future field-testing activities:

- For the preparation phase, candidate selection for the study could include more criteria beyond the geographical radius. To further enhance the study, respondents using the double cluster machine could be compared with those using the single cluster machine. Additionally, milking machines from different manufacturers could be compared against each other and testing the performance of the appliances in users in both off and weak-grid areas.
- The beta testing of the RMS device should include testing the data collection in different states of the milking machine, such as when the machine is left running while no pumping is happening and when boiling water is being pumped for cleaning purposes. Additionally, the changeover should be calibrated from milking one cow to the next. Being able to distinguish between milking events and other reasons why the milking machine may be running would allow for more accurate data interpretation during the synthesis phase.
- To better understand the impact of the SpMM on milk output/yield, measurements should be taken during every milking event, both morning and evening. This would generate multiple data points to facilitate trend observations, anomaly elimination and improve the accuracy of the analysis.
- To improve understanding, gathering information on the baseline of the breed of lactating cows (not the entire herd) and their actual stage of lactation before and during the study would help understand the impact on the milking time.
- During the monitoring phase, the data collected and survey responses should be analysed for correctness, veracity and consistency every month to allow for early troubleshooting and adjustments to be made to the study to enhance the analysis of the information collected afterwards.

The field-testing exercise has contributed to a greater understanding of the usage of the SpMM and its service delivery across four districts within Karnataka in India. From an appliance performance perspective, the following considerations would improve the understanding of efficiency:

- standardising the breed of cow
- understanding the lactation stage of the cows
- considering the years of experience a farmer has had with the SpMM

These would contribute towards eliminating other external factors that may influence the appliance's performance.

Annex 1: Technical Analysis

The data collected from the RMS was analysed for five devices that met the criteria described in Chapter 1 above and are presented in the subsections below. Common observations were made on three key indicators:

- Milking patterns: A consistent pattern of 2 milking events occurred in the morning and evening. We also observed a consistent use of the appliance throughout the month reported.
- Milking time: The measured milking time was lower than the reported pre-intervention.
- Energy consumption:

Milking Patterns

To understand the milking patterns of the five devices that fell within the analysis thresholds, a graph of the daily current drawn by the machine was extracted for the five devices for a single day when the yield was reported as well as for the month to check whether there was consistent use of the appliance. It is worth stating, however, that the current draws could not be isolated to distinguish activities such as when the milking machine was on but pumping was not happening or when the cleaning with boiling water is happening or when there was a change over from one cow to the next. The graphs below illustrate the various devices milking patterns obtained from the RMS on the dates corresponding to when the yield data was reported.

Figure 19: Daily Milking Events for device F10C

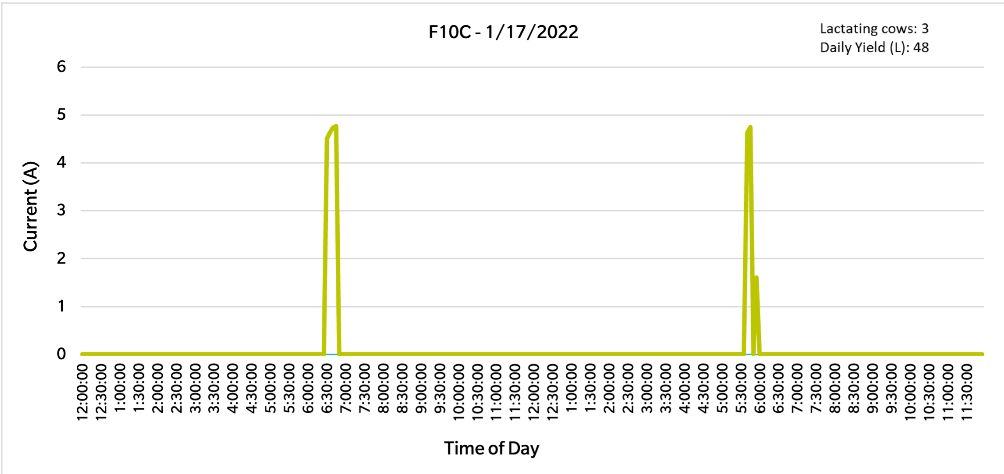
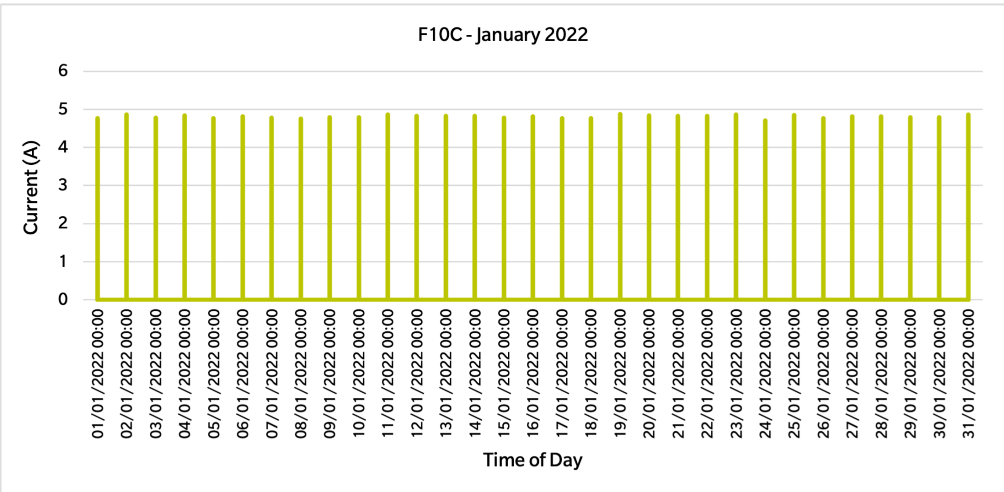


Figure 20: Monthly Milking Events for device F10C



For device F10C, the farmer had three lactating cows at the time of the study. The farmer only kept exotic or cross-breed cows, so it was assumed that they all responded the same way to the milking machine. Two distinct milking events are observed in the morning and evening. The evening signal is much noisier than the morning, which could be potentially caused by poor voltage regulation or the pumping motor overheating, therefore tripping the milking machine. The changeover from one cow to the next is also not evident on this graph, so the analysis assumed that for both milking events, all three cows were milked in the period the milking machine was drawing current.

Figure 21: Daily milking events for device F101

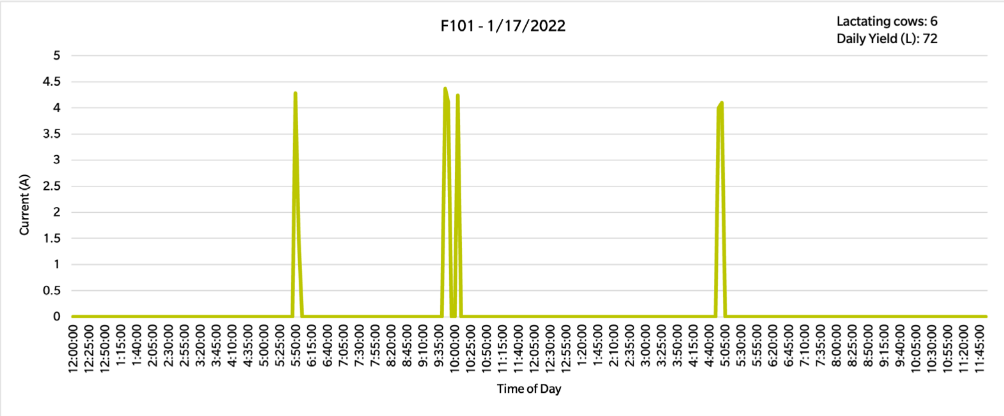
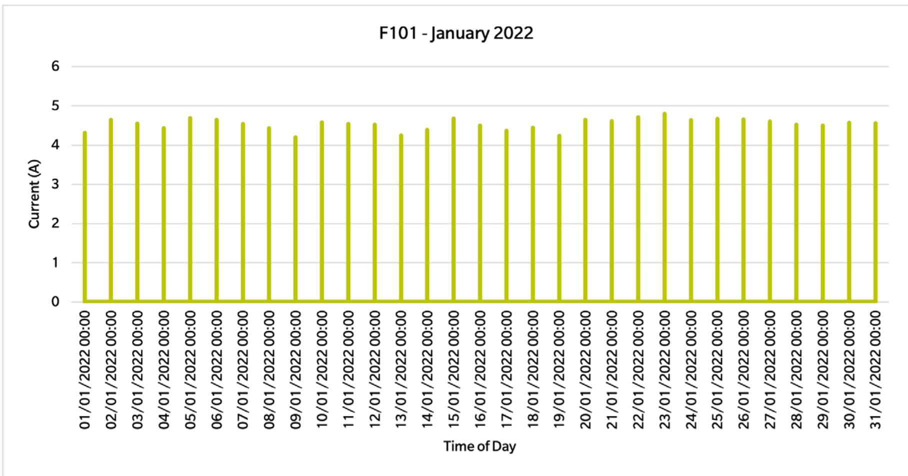


Figure 22: Monthly milking events for device F101



For device F105, the farmer had three lactating cows at the time of the study, and they were all exotic or crossbreed cows; thus, it was assumed that they all responded the same way to the milking machine. In this case, 2 distinct incidences of current draw were observed indicating 2 milking events in the morning and evening. The morning milking signal has much more noise which may be as a result of voltage fluctuations. However, the changeover from one cow to the next is not readable from the graph thus it is assumed that for both milking events, all 3 cows were milked in the period the milking machine was drawing current.

For device F107, the farmer had 4 lactating cows at the time of the study and they were all exotic or cross breed cows thus it was assumed that they all responded the same way to the milking machine. The signal from the RMS was very noisy so only the 2 current draws with the highest peaks were considered as milking events. The current draws after 6.55p.m were considered an anomaly. The changeover from one cow to the next is not evident on the graph thus it is assumed that for both milking events, all 4 cows were milked in the period the milking machine was drawing current. We observe the same noisy signal persisting for most of the days of the month which might imply that the RMS was incorrectly installed or experiencing a lot of vibration.

Figure 23: Monthly milking pattern for device F105

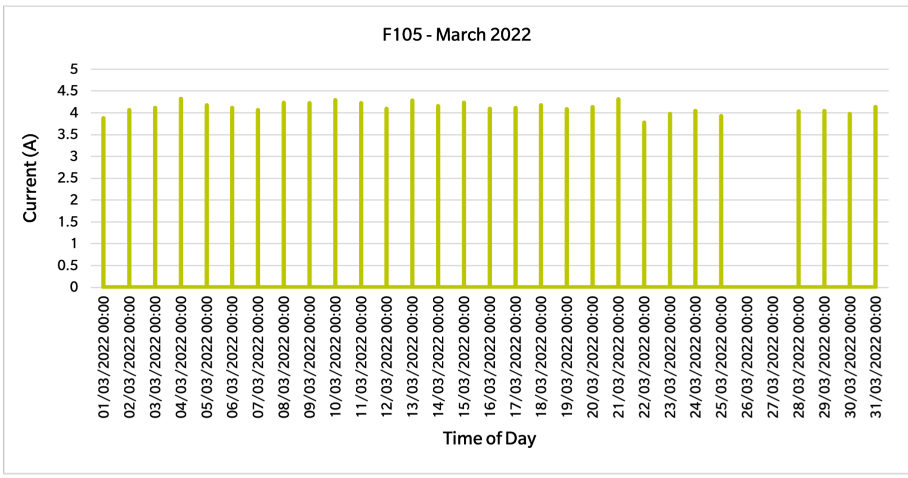


Figure 24: Daily milking pattern for device F105

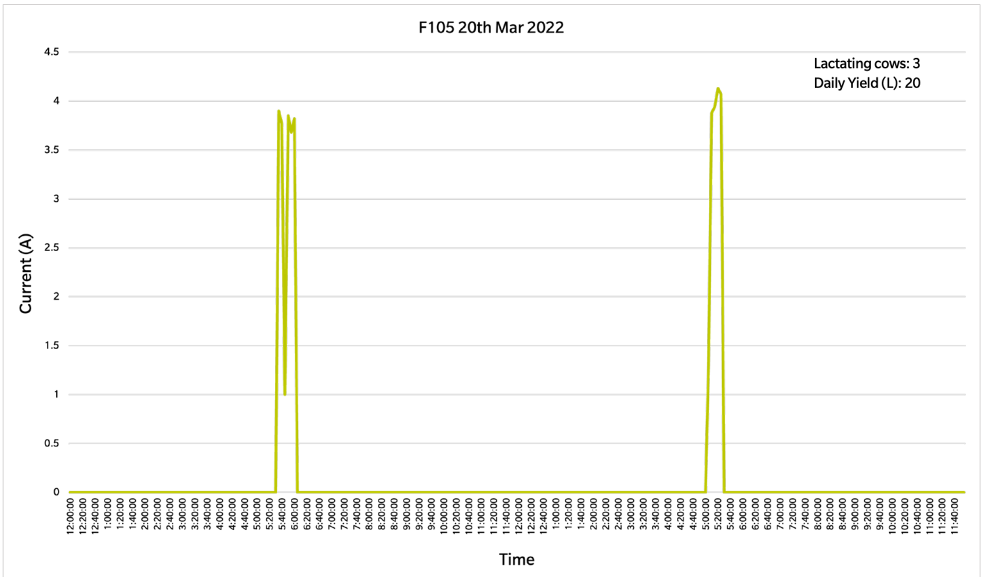


Figure 25: Daily milking pattern for device F107

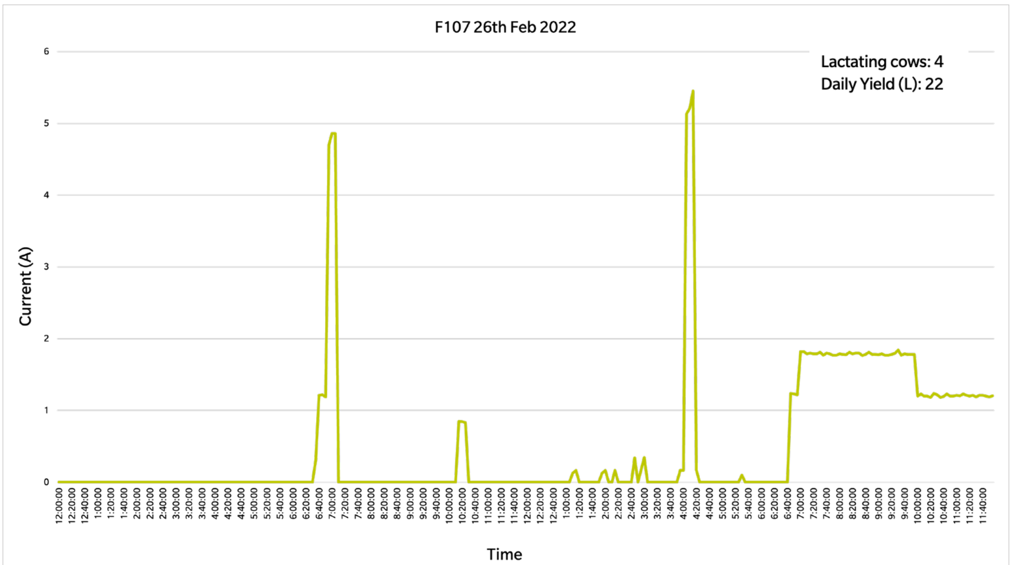
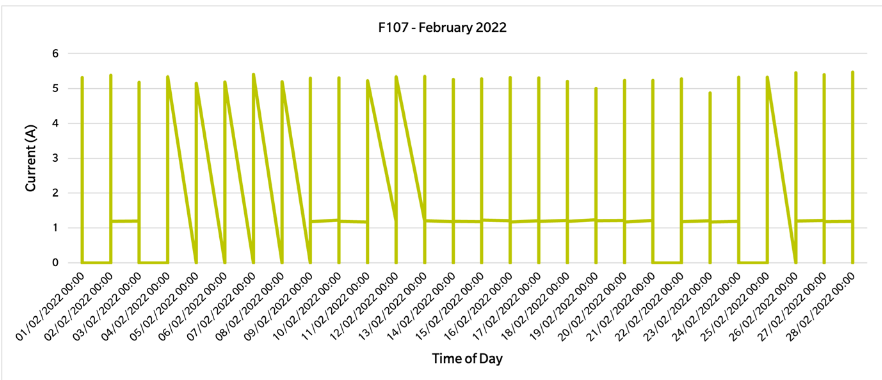


Figure 26: Monthly milking pattern for device F107



For device F116, the farmer had 4 lactating cows at the time of the study, and they were all exotic or cross breed cows thus it was assumed that they all responded the same way to the milking machine. In this case, 2 distinct milking events were observed. The morning signal is much noisier potentially due to voltage fluctuations. The changeover from one cow to the next is not evident on the graph thus it is assumed that for both milking events, all 4 cows were milked in the period the milking machine was drawing current.

Figure 27: Daily milking pattern for device F116

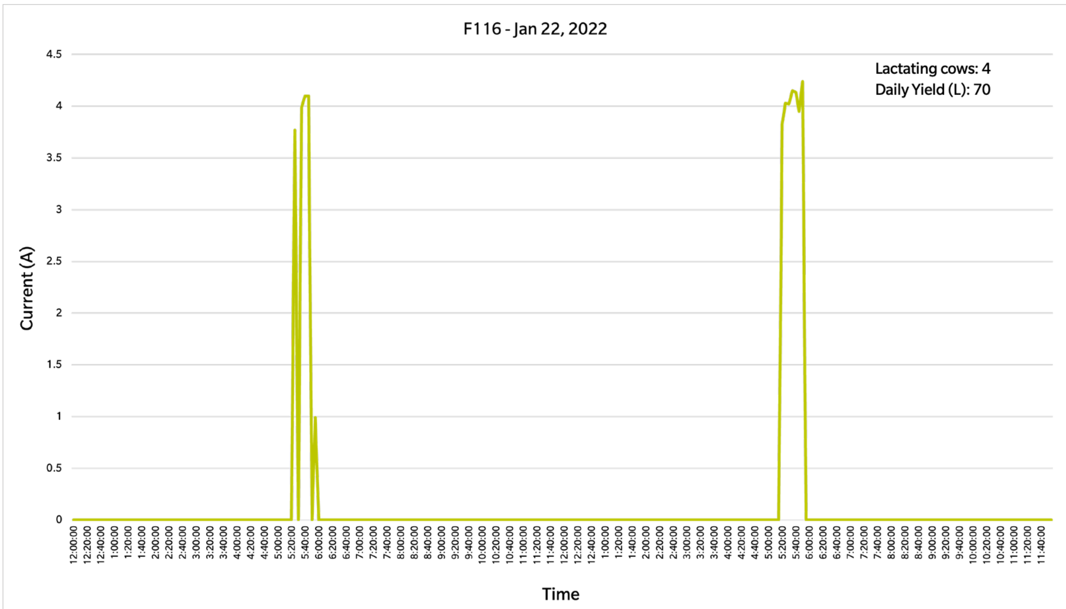
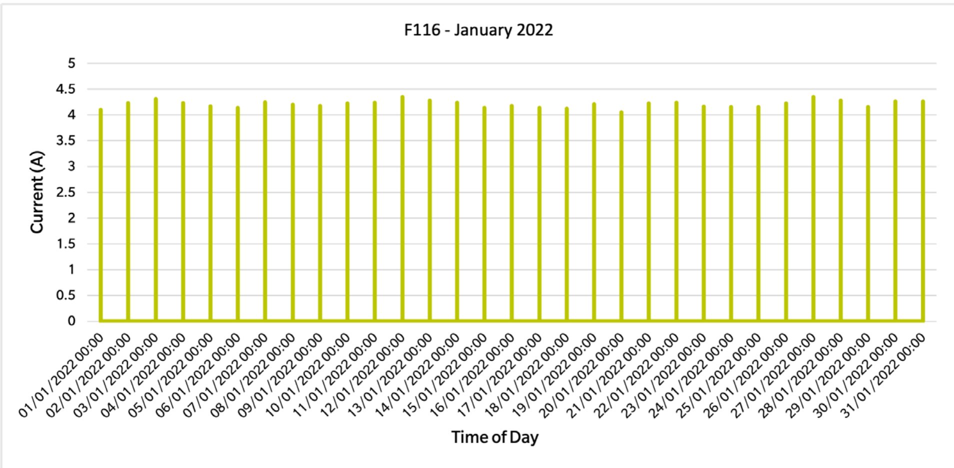


Figure 28: Monthly milking pattern for device F116



Milking Time

Once the milking patterns had been identified for the 5 devices, an analysis of the total milking time was done. The duration of time where the milking event was happening was considered the total milking time and that was evenly divided across the number of lactating cows for each device. Table 6 presents a summary of the morning and evening milking time and yield.

Table 6: Daily yield and milking time per cow

			Milk yield		Total milking time		Yield per cow		Milking time per cow			Self-reported milking time	
Device	Date	No of lactating cows	Total morning yield (l)	Total evening yield (l)	Morning (min)	Evening (min)	Morning (l)	Evening (l)	Morning (min)	Evening (min)	Measured average (min)	Before machine (min)	Self-reported average (min)
F10C	17/01/2022	3	24	24	20	15	8	8	7	5	6	9	6
F101	17/01/2022	6	36	36	25	10	6	6	4	2	3	15	7
F105	20/03/2022	3	10	10	25	20	3	3	8	7	8	15	5
F107	26/02/2022	4	15	7	25	10	4	2	6	3	4	15	5
F116	22/01/2022	4	35	35	20	30	9	9	5	8	6	10	6

The measured milking time per cow was compared against what had been reported by the farmers during the interview sessions with the SELCO enumerator. Figure 31 presents the comparison between the measured average milking time per cow and what had been reported before and after the SpMM intervention. To verify the accuracy of the observation, the measured time was compared with the self-reported milking time after the intervention, and it was confirmed that the figures were closely related.

We observe that across all 5 devices, the measured average milking time per cow is lower than the milking time before the intervention. The range of improvement is between 80% of time saved per cow (F101) and 30% of time saved (F10C).

The morning and evening milking times were also considered separately to try and establish whether there was a distinct pattern to be observed. However, as limited information was available on the milking time for different breeds of cow or the lactating times and hormonal changes per specific cow, the variations in milking time could not entirely be attributed to the usage of the milking machine. Figure 32 below illustrates the milking times per session for each of the devices.

It was observed that for 4 devices – F10C, F101, F105 and F107 took more time milking in the morning while F116 took longer to milk in the evening as compared to the morning. The reported yield for F10C, F101, F105 and F116 was equal for both morning and evening. F107 had higher yield in the morning.

Figure 29: Average milking time per cow

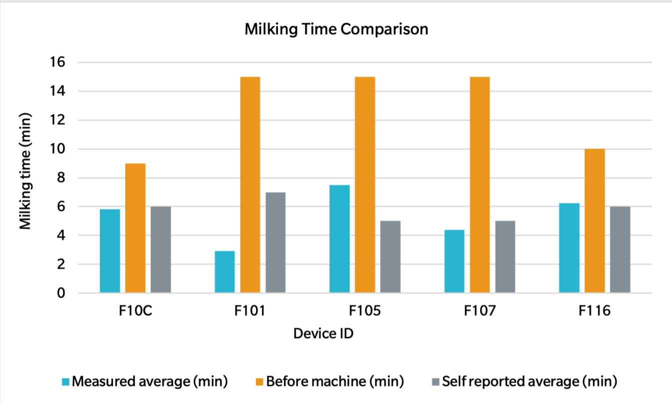
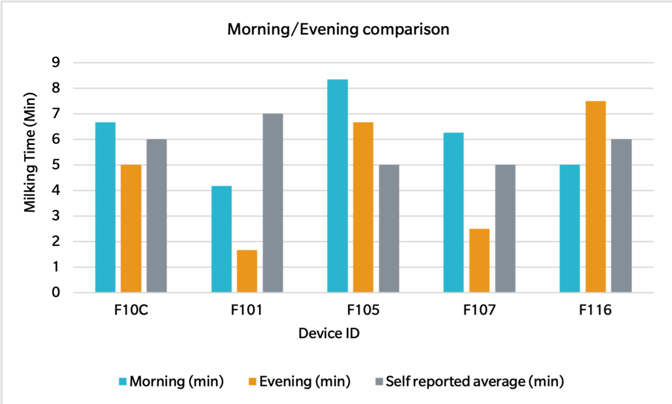


Figure 30: Comparison of average morning and evening milking times per cow



Energy Consumption

To analyze the energy consumed by the devices during the milking events, the current drawn was multiplied by the voltage recorded to obtain the real power in Watts (W) and that was then multiplied by the milking time to get energy readings in Watt-Hours (Wh). From the 5 devices, F105 was not eligible for energy performance assessment because the milk yield reported was a weekly average self-reported and that would introduce large rounding errors and thus those two devices were eliminated. Table 7 presents a summary of the energy consumption of the remaining devices during a milking event.

Table 7: Energy consumption of milking devices

			Milk yield		Total milking time		Total energy consumption		Energy performance	
Device	Date	No Of Lactating Cows	Total Morning Yield (l)	Total Evening Yield (l)	Morning (Min)	Evening (Min)	Morning (Wh)	Evening (Wh)	Morning (Wh/l)	Evening (Wh/l)
F10C	17/01/2022	3	24	24	20	15	18.3	12.6	0.76	0.53
F101	17/01/2022	6	36	36	25	10	25.1	7.7	0.70	0.21
F107	26/02/2022	4	15	7	25	10	17.1	15.1	1.14	2.16
F116	22/01/2022	4	35	35	20	30	17.5	25.6	0.50	0.73

To further understand the energy performance of the milking machines, the energy consumed to pump a litre of milk during both milking events was analyzed and presented in Figure 33.

It is observed that devices F101 had the lowest energy requirement to produce a litre of milk. The male farmer was based in Ramanagara district and had had the SpMM installed in 2019 which suggests that he had 2 years of experience using it before the time of the study. It is possible that having experience improved his technique leading to him using the least energy for pumping.

For the 6 devices, the daily total energy consumed during both milking events and the total milking time were plotted. The energy consumed was directly proportional to the milking time, which is consistent with the expectation for the motor. Whenever a milking event happens, we expect the power drawn to be higher than when the machine is not working. The graph below presents the relationship between the energy consumed and the milking time on the analysed day.

Figure 31: Energy used by each device to pump a litre of milk

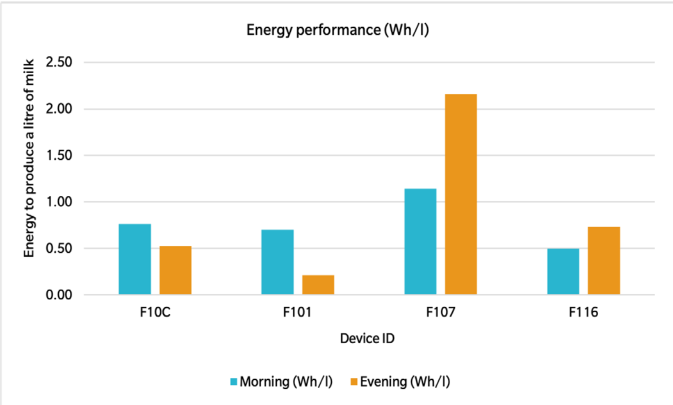
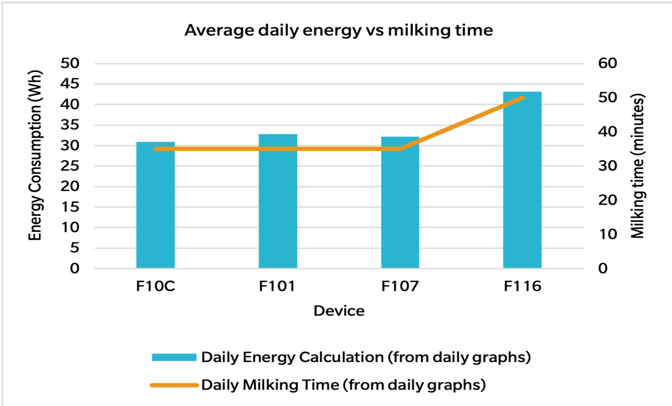


Figure 32: Energy consumed and milking time per device



Yield vs Time

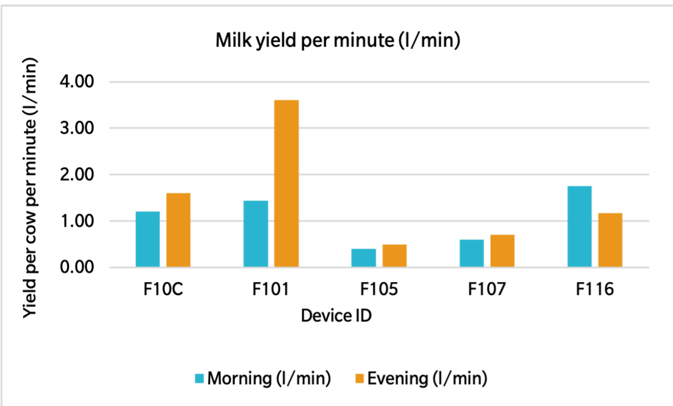
For the 5 devices analyzed, the relationship between the milk yield and pumping time was analyzed and is presented in Figure 35.

There is a notable variance across the devices with the highest output per minute being recorded as 3.5 litres per minute (F101) while the lowest output is shown to be 0.4 litres per minutes (F105). This could potentially be influenced by:

- The cows breed
- The cow's hormonal cycle
- How experienced the farmer is in handling the milking machine

More data over a longer period of time would be required to understand the primary contributor to the variance so it is assumed that all the factors contribute equally.

Figure 33: Yield per minute per device



Annex 2: Customer Information

Table 2: General characteristics of the customers selected for the study

Gender	State	District	RMS Device ID
Female	Karnataka	Dakshina Kannada	F111
Female	Karnataka	Dakshina Kannada	F112
Female	Karnataka	Dakshina Kannada	F115
Male	Karnataka	Dakshina Kannada	F102
Male	Karnataka	Dakshina Kannada	F10E
Male	Karnataka	Dakshina Kannada	F10F
Male	Karnataka	Dakshina Kannada	F114
Male	Karnataka	Dakshina Kannada	F117
Female	Karnataka	Mandya	F106
Female	Karnataka	Mandya	F10B
Female	Karnataka	Mandya	F110
Male	Karnataka	Mandya	F105
Male	Karnataka	Mandya	F109
Male	Karnataka	Mandya	F116
Female	Karnataka	Ramanagara	F100
Male	Karnataka	Ramanagara	F101
Male	Karnataka	Ramanagara	F104
Male	Karnataka	Ramanagara	F10C
Male	Karnataka	Ramanagara	F113
Female	Karnataka	Udupi	F103
Female	Karnataka	Udupi	F107
Female	Karnataka	Udupi	F108
Female	Karnataka	Udupi	F10A
Female	Karnataka	Udupi	F10D
Female	Karnataka	Udupi	F118

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