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Enhancing Energy Efficiency in a Palestinian Dairy Factory Utilizing RETScreen Expert

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Abstract: This research delves deeply into the optimization of energy utilization in a dairy manufacturing facility located in Palestine, employing RETScreen Expert as a tool. A comprehensive energy audit is conducted to meticulously analyze and understand the current energy landscape within the dairy factory. The focus of this investigation is to evaluate seven distinct energy efficiency strategies, covering areas such as improvements in lighting, upgrades in insulation, maintenance of steam traps, mitigation of steam leaks, utilization of heat recovery mechanisms, and the implementation of a solar water heating system. The study also extends its scope to address environmental concerns by estimating CO2 emissions and conducting a thorough assessment of the economic feasibility associated with these proposed measures. The results of this investigation unequivocally demonstrate significant potential for reducing energy consumption and lowering CO2 emissions, while concurrently improving economic viability through the strategic implementation of the aforementioned energy efficiency initiatives. Essentially, this scholarly work serves as a valuable reference, highlighting the beneficial outcomes achieved by integrating energy efficiency measures within industrial frameworks. It emphasizes the necessity of a comprehensive approach that harmonizes both environmental and economic considerations in decision-making processes related to energy initiatives

Keywords: Energy Efficiency, RETScreen Expert, Palestine, Energy Management.

Introduction

The Palestinian population increased drastically over the last two decades (1), and with that, the energy demand increased. The Palestinians used up to 30 to 40 thousand barrels per day of petroleum in 2017 (2), (3). But, unlike other middle eastern countries, Palestine highly depends on imported energy, with 100% of its fossil fuels and 89% of its electricity, due to the ongoing political situation and the inability to reach natural resources (4–6). This scarcity has put Palestine's energy industry a risk, with unrealistic energy prices that match the world's most expensive cities (2,7). This scarcity increased the desirability for all individuals, companies, and the nation to search for methods to have cheaper, more efficient, and cleaner energy (7).

Many companies who desire to be more energy efficient face challenges in implying energy auditing as it should be technically and environmentally feasible and financially viable, which is the case for the studied dairy factory in Nablus, Palestine. A frightening article published in ASHRAE Journal illustrates the 10 most common problems in energy auditing, with problems like overestimated savings: 53% of audits, inadequate billing analysis: 57% of audits, poor improvement selection: 63% of audits, and missed improvements: 80% of audits (8).

The primary problem lies in the lack of a straightforward and uncomplicated method for undertaking energy analysis. As a result, energy auditing frequently encounters frequent challenges, and companies begin to view it as an extravagant and costly burden that only specialized firms with the expertise to handle intricate computations can undertake, as was the case in our dairy factory case study in Nablus, Palestine (32.2287, 35.21395).

Developed by the Government of Canada with several partners, RETScreen is used by the public and private sectors to help analyze, plan, implement, and monitor energy projects, and by universities and colleges worldwide for teaching and research. The primary objective of this paper is to showcase the extensive capabilities of the RETScreen Expert simulator in energy auditing for our dairy factory. The approach entails conducting an energy audit by entering the necessary data for our baseline scenario into the software, followed by comparing and analyzing various energy measures to assess their financial, economic, technical, and environmental impacts. The end goal is to identify a practical, feasible, and sustainable project that can be implemented at our dairy factory in Nablus.

There are studies focused on feasibility studies for power plants, like the geothermal power plants in Ecuador (9) and the one showing its methods (10), the wind energy power plants in the south-west of Algeria (11) or the photovoltaic solar power plants in Iran (12), in Chile (13), and in Nigeria (14), using the RETScreen software. There are even studies for simulating a whole district's energy system using RETScreen, like the study of the Chongming district in China (15).Other than the huge scale of cities and districts, other researchers studied the feasibility and viability of residential photovoltaic systems in the Iranian and Pakistani domestic sectors using RETScreen (16), (17), while others worked in Measurement and Verification (M&V) analysis

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using RETScreen expert for a retrofit residential building in Korea (18).

Several researchers worked on studying the accuracy of RETScreen software, which showed that the simplicity of use and cost savings for the PV sector more than compensate for the little drop in accuracy caused by the use of monthly data rather than the hourly data utilized in most other PV simulation models. The RETScreen PV model's accuracy is considered sufficient for initial feasibility investigations (19). Other researchers mainly focused on comparing those hourly data-driven simulation models, like the study comparing HOMER with RETScreen that concluded that the PV standalone system (PVSS) had very little difference in the COE calculated by both software, RM 1.959 per kWh and RM 1.952 per kWh respectively, which was cheaper than the wind standalone system (WSS) or the PV-wind hybrid system (PVWHS) for that study case in Malaysia (20).

The novelty of this study stems from its pioneering use of RETScreen tools to apply energy-saving measures in a Palestinian dairy factory. By imploying RETScreen as a primary analytical tool, the research offers a comprehensive approach to optimize energy usage in this industry. Beyond this specific context, the study's methodology holds promise for similar industries globally. The systematic use of RETScreen and precise energy assessments create a scalable model applicable to various industrial landscpaes, making it a valuable resource for broader energy optimization efforts.

Methodology

To optimize energy usage in a dairy factory in Palestine using RETScreen Expert software, the first step involves identifying energy efficiency measures, followed by reviewing existing literature on such energy efficiency measures within the dairy industry. Data on energy consumption patterns and equipment specifications of the factory were gathered by conducting an energy audit study. Create an energy model using RETScreen Expert encompassing potential energy efficiency measures. Then use the model to determine potential energy savings and return on investment of each energy efficiency measure. From these findings, the most promising energy efficiency measures will be selected for implementation in the dairy factory. Ultimately, conclusions will be drawn, and recommendations for further energy efficiency improvements will be made based on the results. The RETScreen software offers a broad range of adjustable parameters; however, it does not specify how to adjust them. Its purpose is to assist researchers in comprehending the impact of various energy measures on different parameters so that they can manually modify them.

Energy Efficiency Measures

As previously mentioned, an energy audit was conducted at the factory to gather the necessary energy data and obtain a comprehensive understanding of the equipment currently in use at the facility. The boiler, which operates at 74% efficiency as found and noticed from the software, is one of the primary pieces of equipment at the factory and runs on diesel #2 oil as its fuel source. The factory's cooling system which operates using electricity, is another crucial component, with a coefficient of performance (COP) of 3. As noticed the factory relies on two energy sources: fuel and electricity, the current rate for diesel in Palestine is 1.67 $/L according to the General Petroleum Authority and Ministry of Finance, while the electricity rate varies depending on the category, and for the proposed of this case, it is assumed to be 0.17 $/kWh. It is known that number of occupants in a space for a specific affects the needed cooling and heating temperature to maintain a comfortable indoor working environment, thus detailed data as shown in Table (**1** were entered into the software to simulate the factory environment with 5 working days per week, and 11 working hour per day.

Table (1): Factory's Schedule.

System	Space heating temperature (°C)	Space cooling temperature (°C)
Occupied	22	24
Unoccupied	20	26

Since heating water accounts for more than 30% of the energy usage in the dairy industry (21) and to reduce the energy consumption in different treatments like sterilization and optimize the usage of the steam system within the factory, process steam was adopted by incorporating a solar water heater as an "optimized supply" measure. The system's purpose is to heat the makeup water for the steam distribution system. Since the solar water heater can heat the water to 75°C, the makeup water temperature in the hot water load is increased from 20°C in the base case as seen from the audit study to 75°C in the proposed case. This increase in temperature will reduce the heating load, as demonstrated by the following equation (1).

$$Q = m * Cp * \Delta T \quad (1)$$

Q = heat required to raise the temperature of water (Wh), m = mass of water (kg), Cp = specific heat of material (J/kg·K), and ∆T = temperature difference in Kelvin.

Because the system has the same amount of material and the same type (same m and Cp), when a decrease in the temperature rise of the material, a decrease in the heat required to raise the temperature of the water will have resulted. The second measure involves enhancing the insulation of tanks and pipes in the steam distribution system. thus, an additional process steam energy end-use load is added, with the base case with the insulation losses, and proposed cases with zero losses after the addition of the improved insulation. Equation (1) reveals that losses of the same type of fluid and weight will raise the material's temperature increase, thereby increasing the heating requirement. On the other hand, when losses are minimized, the temperature increase will decrease, leading to a reduction in the required heating. The third measure involved the installation of a steam trap to remove any accumulated condensate from steam tracers, distribution lines, and other steam-consuming machinery promptly. By preventing steam leaks and eliminating non-condensing gases like air, a steam trap can help to conserve energy. The cost of wasted 100-psig steam is determined based on the diameter of the leak, the loss rate does not go down in direct proportion at lower steam pressures but declines at a rate proportional to the square root of the pressure as shown in below.

Table (2): Annual Cost of Steam Leaks (22).

Leak Diameter (in.)	Steam Wasted per Month (lb)	Cost per Month ($)	Cost per Year ($)
1/16	13,300	40	480
1/8	52,200	156	1,890
1/4	203,000	626	7,800
1/2	833,000	2500	30,000

To incorporate this measure into RETScreen, a steam leak loss of 0.048 inches to the end-use load was added. The base case required additional heating to compensate for steam losses and produce extra steam, while the proposed case required no additional heating after the steam trap was installed minimizing the leak size to 0.015 inches. According to equation (1), when the same type of fluid and the same temperature increase are needed, reducing the material's weight will decrease the required heating by minimizing the size of the leak in the system.

A heat recovery load was directly incorporated as a fourth measure. In this process, two milk streams of 75°C and 40°C exchange heat to reduce the load by increasing the temperature of the 40°C stream. Similarly, a heat recovery load was added for cooling by facilitating heat exchange between two milk streams of 30°C and 5°C to prevent the growth of microorganisms. According to equation (1), this technique helps decrease the material's temperature rise, which in turn reduces the amount of heat required to elevate the water temperature. The fifth measure and after investigating an energy audit it was noticed that the pump system in the factory consumes energy more than needed, so it was decided to replace the four standard pumps in the base case of the pump load with two premium efficiency pumps while keeping the same manufacture (Baldor-Resilience).

In addition to optimizing the sizing of the pump system an adjustment to the flow was done. The flow changed from being constant to variable using variable speed drive. This can significantly enhance the overall efficiency of the system and will reduce the maintenance costs and the wear on the pump and motor, extending their lives. Applying that resulted in an 87.3% reduction in electricity consumption, as noticed in the equations below.

$$Pump\ Efficiency\ = Output/Input \quad (2)$$

$$\%\ efficiency\ saving\ = \frac{\eta\ new - \eta\ old}{\eta\ new} \times 100\% \quad (3)$$

$$Energy\ Saving\ = \text{Energy consumption} \times\ \%\ efficiency\ saving \quad (4)$$

This replacement directly reduced the energy consumption of the pump, thereby contributing to a decrease in overall energy consumption as seen from equations 2,3, and 4 above.

The sixth adjustment involved upgrading the lighting system in the factory to better suit the use of each space. The factory was divided into categories based on the use of the area, such as the office, warehouse, main production zone, lobby, manufacturing area, and sterilization rooms. Depending on the type of activity being done, each room needs a unique level of lighting. For instance, office spaces need bright, focused lighting to boost productivity, whereas manufacturing spaces need more diffuse lighting to reduce glare and guarantee safety. Equation (5) shows the saving calculation for the lighting system.

$$Lighting\ saving\ (W) = number\ of\ fixtures \times \begin{bmatrix} present\ watt\ per\ fixture\ - \\ proposed\ watt\ per\ fixture \end{bmatrix} \quad (5)$$

Each of the 6 defined zones was adjusted according to the suggested data from the RETScreen Expert guide which follows international standards, in Using the energy absorbed to heat the makeup water for the steam distribution system can significantly reduce energy consumption and costs instead of traditional heating methods, such as gas or electricity. Using the angle system at a slope of 45 will maximize the collection of solar radiation in winter and minimize snow accumulation.

The facility's heating and other needs are served by steam the steam distribution system, which typically consists of tanks, pipelines, and valves. Ultrasonic leak detectors are used to show the leaks so insulation can be done, the system has proposed a 65% reduction in leaks after insulating the steam distribution system while preserving the other variables. Minimizing the losses means that less energy is required to heat the same amount of steam, which results in reduced energy consumption and costs and also improve safety and reduce maintenance costs since insulated pipes and tanks are less likely to corrode or sustain other types of damage, which can result in fewer repairs and replacements.

Condensate in a steam distribution system can lead to many problems, such as heat loss, poor system efficiency, and equipment failure. Steam traps function as a valve that automatically opens to release condensate and non-condensing gases like air then closes to preserve the steam in place.

Condensate in the steam distribution system should be kept at a minimum to assist in saving cost and energy. Using a steam trap to remove the accumulated condensate help to conserve energy and ensure optimal system performance. A 68% leak reduction has been estimated after installing a steam trap in the stem distribution system which led as mentioned earlier to a reduction in energy consumption.

The process of recovering and utilizing waste heat produced by the different processes is known as heat recovery. Waste heat is caught and transported to a heat sink where it may be utilized for other purposes.

the detailed description of each zone before and after adopting the suitable lighting.

Compressed air accounts for a significant portion of the industrial process energy consumption. The final measure is upgrading the compressed air system by enhancing the capacity control of the compressor using variable speed drive instead of inlet throttle resulting in a significant reduction in energy consumption.

Table (3): Lighting System Adjustments.

Zone	Base case		Proposed case		
	Lux	Lamp type	Lux	Lamp type	Illumination level variance (%)
Office	500	F T12 – magnetic ballast	500	F T8 – electronic ballast	19.5
Warehouse	150	F T12 – magnetic ballast	150	F T8 – electro	4

				nic ballast	
Main production zone	750	F T8 – magnetic ballas	350	F T8 – electronic ballast	8.9
Lobby	300	F T12 – magnetic ballast	0	F T8 – electronic ballast	45.1
Manufacturing area	500	F T12 – magnetic ballast	300	F T8 – electronic ballast	5.3
Sterilization rooms	200	F T12 – magnetic ballast	100	F T8 – electronic ballast	4.2

Results and Discussion

This study used the RETScreen Expert software to implement and assess the energy measures in a dairy factory at Nablus. The climate data calculated by the National Aeronautics and Space Administration (NASA) is reliable and provides valuable information for the feasibility analysis. The estimated annual horizontal solar radiation is 5.72 kWh/m2/day, 68.6% average annual humidity and about 20 C degree average air temperature are important key variables that might have an impact on the dairy factory's efficiency and energy use,

Figure (**1** shows the daily solar radiation (GHI) and air temperature in Nablus during the year as taken from NASA database. A thorough feasibility analysis has been carried out on the proposed factory upgrades. The analysis includes technical, economic, and environmental assessments, which provide a comprehensive view of the proposed upgrades.

1) Technical Viability

Technical resilience is one of the main key factors to consider which involves designing the system in a way that is efficient, durable, and environmentally friendly.

A fixed-glazed solar water heater system was added with 10 solar collectors that are designed to absorb solar radiation and convert it into heat, the system heats the makeup water from 20°C to 75°C, which is then circulated to the steam distribution system.

Using the energy absorbed to heat the makeup water for the steam distribution system can significantly reduce energy consumption and costs instead of traditional heating methods, such as gas or electricity. Using the angle system at a slope of 45 will maximize the collection of solar radiation in winter and minimize snow accumulation.

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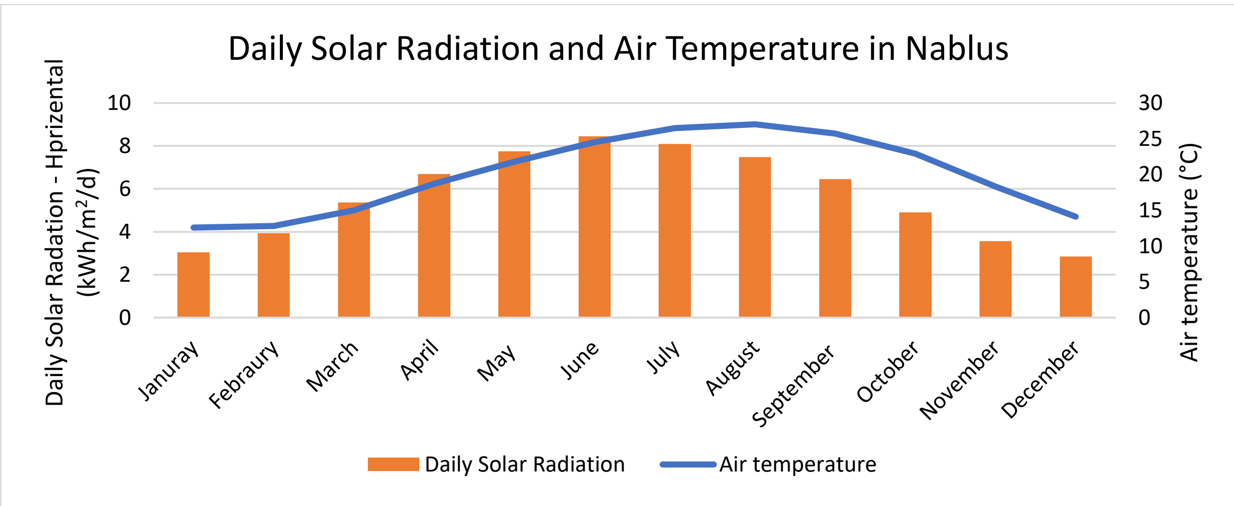

Figure (1): Daily Solar Radiation (columns) and Air Temperature (green line) in Nablus.

In this instance, we employed a heat recovery system to exchange heat between two mild streams of 75°C and 40°C to lower the temperature of the cooler without the need for further heating, hence lowering the amount of heat required to raise the temperature. A similar procedure was implemented for cooling by allowing heat exchange between two milk streams of 30°C and 5°C, by doing that the energy efficiency of the system increased by 68%.

Pumps account for 20% of the total electrical energy consumed by motors (23). The factory's energy consumption will increase as a result of using conventional pumps in the base case, which will raise operating costs and CO_2 emissions.

Checking the production lines requirements, we determined that the flow needed to be variable but was set at a constant rate, thus a variable speed drive was installed with new premium efficiency pumps to replace the existing standard pumps system. This resulted in saving in energy consumption, operation, and maintenance costs, and reduced the emission by using less energy than before.

Successful application for lighting systems is not solely dependent on achieving energy savings and quick payback periods, it is also linked to the well-being and contentment of employees (24). Therefore, the lighting system was upgraded to meet international standards based on the database used in the RETScreen Expert software.

As mentioned before, the factory was divided into categories depending on the usage of the area, each area has its specific illumination level that is measured in lux, so the proposed case is offering an ideal lux/m2 for each area. All light types were upgraded from the old fluorescent T12 with magnetic ballast to the more efficient fluorescent T8 with electronic ballast. This not only resulted in a reduction in energy consumption but also led to a reduction in the number of fixtures required and the number of lamps needed per fixture.

It is proven that having the proper size and control system in air compressors will provide the lowest energy consumption and most efficient operation regardless of the demand (25).

Energy loss can result from the use of valve throttling for flow control and they can potentially be prone to problems including corrosion, erosion, cavitation as well as the ability to produce pollutants. According to the affinity law, brake horsepower varies with the cube of centrifugal pump speed, which leads to a reduction in pressure thus a reduction in power consumption (26).

2) Economic Viability

RETScreen Expert software allows users to input prices of fuel, water, electricity, and any other added new components. The total initial cost is $164,190 which includes the lighting system, the new premium pumps, insulations, heat recovery, the new compressor control system, and the new solar water heater system. The fuel rate is 1.76 $/L, and the electricity price is 0.17 $/kWh based on the current rates, comparing the difference between the base case and the proposed case with all the new additions and adjustments resulted in $239,222 per year, the numbers were calculated considering that the factory is operating 11 hours a day, 5 days a week for a project life of 20 years and a discount rate of 9%. Replacing the pumps saves up to 87.3%of the electricity consumption used by the pump system with a payback period of 1.2 years and the lighting system has 1.5 years payback period, so the first-year net cash flow equals $84,041. Table (**4** below summarizes all the measures of fuel saving in US dollars ($) and the payback period of the systems.

Table (4): Systems Fuel Savings.

System	Fuel Saving ($)	Simple Payback Period (Year)
Lighting System	6,265	1.5
Pump System	8,651	1.2
Process Steam System	9,851	0.8
Heat Recovery System (Preheating Milk)	34,170	1.8
Heat Recovery System (Cooling Milk)	82,339	1.1
Steam Trap	2,111	0.5
Compressed Air System	18,946	1.8
Solar Water Heater System	2,134	5.6
Total	164,467	1.3

Below in Figure (**2** illustrates the percentage of the savings in fuel for each system.

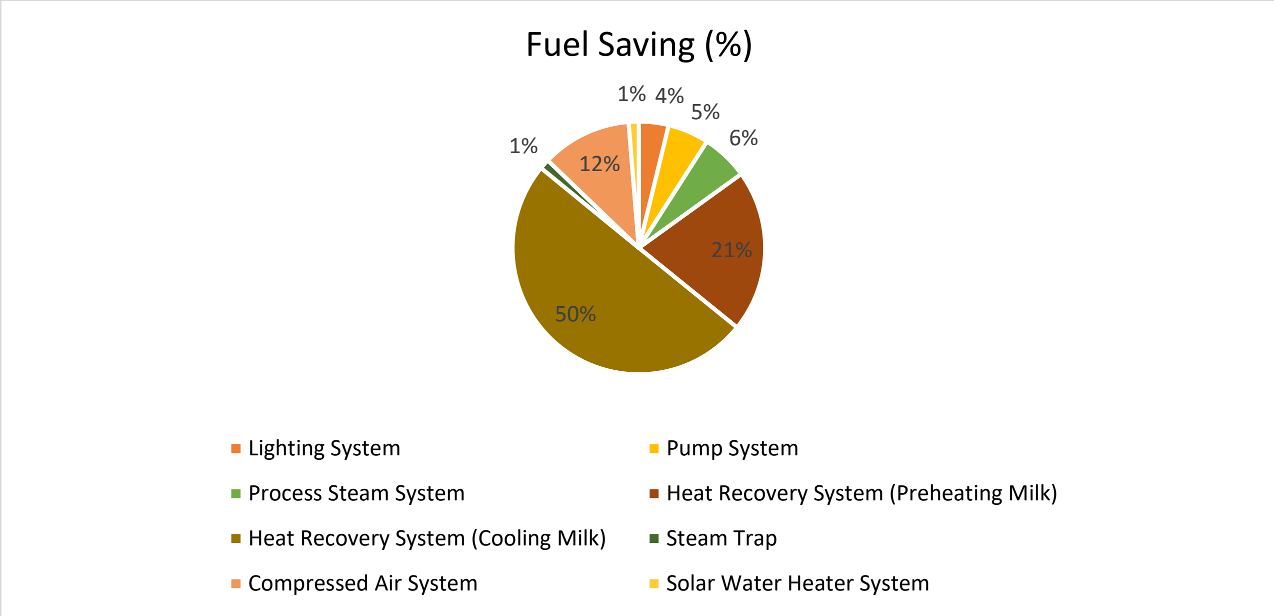

Figure (2): Systems Fuel Savings (%).

Figure (**3** below illustrates the annual cash flow after applying the energy efficiency measures mentioned earlier with all the needed data submitted to the software to generate the results in different forms.

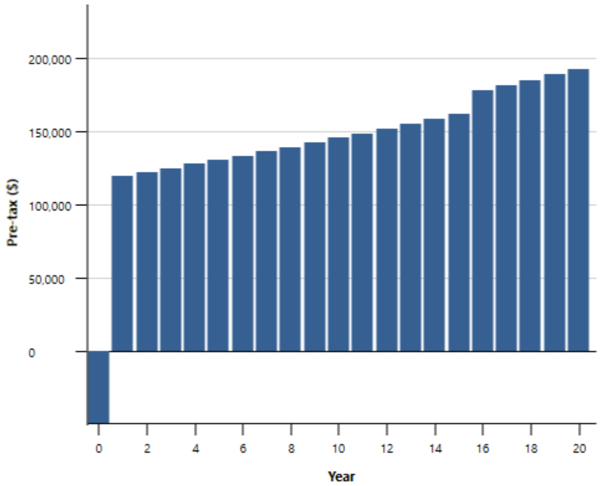

Figure (3): Annual Cash Flow from RETScreen Analysis.

Environmental Viability

The emission analysis worksheet is used to calculate the greenhouse gas (GHG) emissions reduction resulting from carrying out the proposed measures for the factory. The work considers various factors such as the type of energy used and the efficiency of the equipment. This resulted in 259 tonne CO2 reduction in the proposed case which represents a 59.8% reduction in GHG emissions compared to the base case. To put this into perspective this reduction is equalizing to the recycling of 89.3 tonnes of waste. Figure (**4** demonstrates the savings in GHG comparing the base case and the proposed case in this study by adapting various energy efficiency measures.

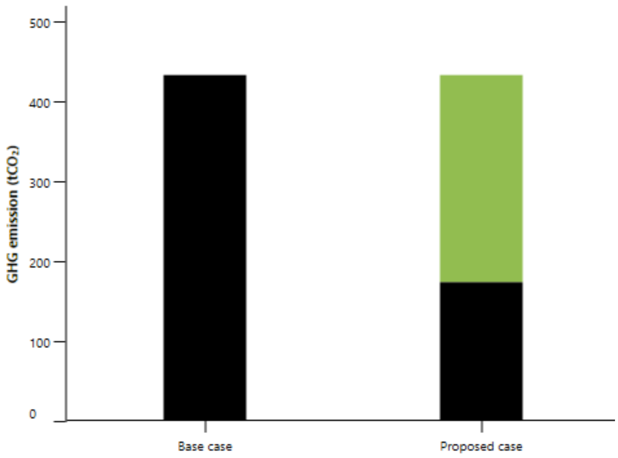

Figure (4): Gross Annual GHG Emission Reduction.

Conclusion

This study involved a comprehensive analysis of the feasibility of implementing seven different measures in various systems within the factory. The aim was to identify ways to improve the facility's efficiency and extend the system's life expectancy while also reducing the GHGs, making the facility more environmentally sustainable. Evaluation for the technical, economic, and environmental feasibility of energy upgrades in the factory was done.

To conduct the analysis, RETscreen expert software was used to analyzes the technical, finical, and environmental impact of each applied measure on the factory and its surrounding.

It was found that all applied measures showed positive investment action, with a payback period that varied from 0.5 to 5.6 for each measure, making them either no/low cost or moderate cost investments. Furthermore, implementing these measures would help improve the facility's efficiency, reduce operational costs, extend the systems' life expectancy, and contribute in GHGs reduction by about 259 tonne CO2. A properly insulated steam system, well-sized pump system, suitable lighting system, and the adoption of renewable energy will lead to significant savings in the electrical and fuel bills as noticed from Table (**4**. For instance, the installation of a VFD to control the speed of a motor in a pump system and new high efficient pump resulted in an energy saving of 87.3%. Using

RETScreen Expert to optimize the energy usage in the dairy factory was a successful approach. It allowed the researchers to estimate the potential effects of proposed actions depending on the facility and its working purpose.

Ethics approval and consent to participate

Not applicable

Consent for publication

Not applicable

Availability of data and materials

The raw data required to reproduce these findings are available in the body and illustrations of this manuscript.

Author's contribution

The authors confirm contribution to the paper as follows: study conception and design: Yasin, A, Qutaina, B., Modeling and simulation: Yasin, A, Qutaina, B., B. Al-Saqqa, S.; data analysis and validation, Yasin, A, Qutaina, B., draft manuscript preparation: Yasin, A, Qutaina, B. All authors reviewed the results and approved the final version of the manuscript.

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Conflicts of interest

The authors declare that there is no conflict of interest regarding the publication of this article.

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