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Research Article

Energy and production analysis of a dairy milk factory: A case of study

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ABSTRACT

This study illustrates a factory's production efficiency by demonstrating its energy efficiency in the dairy milk industry. Determining the thermal energy to save energy enhances the profitability of the factory. The aim of this study is to conduct a thermal energy and production analysis of a dairy milk factory based on annual production. This study intends to make the conclusions more realistic by using production and energy data dependability analysis. The overall power consumption for the thermal and electric energy processes was found to be as 180,520 [W]. The target-specific energy consumption value was computed for Case 1 as 6,352.14 [MJ/t], for Case 2 as 5,898.67 [MJ/t], and for Case 3 as 5,445.21 [MJ/t]. The annual thermal (steam boiler) and electrical energy expenditures were obtained, with 315.87 [kW] of thermal (steam) energy and 80.98 [kW] of electrical energy. The total thermal and electrical energy reached 396.85 [kW]. Despite the factory's expenditure on thermal and electrical energy, the energy efficiency was determined to be as 45.5%. The input energy was obtained to be 374.24 [kW] in Case 1, 356.33 [kW] in Case 2, and 342.08 [kW] in Case 3. The energy efficiency was calculated as 48.2 [%] for Case 1, 50.7 [%] for Case 2, and 52.8 [%] for Case 3. This study, which is expected to inspire future research, is also likely to assist livestock and agriculture in the energy field. The novelty of this study is that optimizing product efficiency and energy consumption in the production of milk and dairy products positively increases the energy efficiency of factories.

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INTRODUCTION

The energy performance of a factory is determined by ensuring the synchronization of factory milk, product production, and energy consumption. Energy analysis, which concerns energy management, is also an effective concept in the food industry. Energy density is an important part of the dairy industry's processes and has an important place in the food industry. Bringing energy under control and making it more efficient are effective in the processing of milk and its products. In this study, the energy performance of a dairy facility was determined using the optimization method, accompanied by sample findings. The focus of this research is to establish an appropriate energy performance efficiency through optimization by demonstrating the mathematical relationship between dairy products and

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energy consumption based on the dairy facility's results and data. First, energy performance and management were determined by considering milk production and energy consumption values for the dairy plant, accompanied by data from the milk processing plant.

Dairy products, one of Turkey's principal agricultural products, play an important role in the economy. A plant that manufactures dairy products was adopted for this study on energy efficiency analysis and management. This study was supported by the scientific research, statistics, and dairy plant procedures. In the case of dairy product manufacturing in Turkey, the facility model was disclosed by developing a link with production based on energy usage for modeling and simulation. The proportion of dairy products produced as a plant output is mathematically related to energy consumption. Model simulations (calculations of cheese, cream, butter, yoghurt, ayran, and other cheese types with raw milk values) were used to assess the amount of goods and by-products that could be made from the facility's present milk vats (boilers) based on product characteristics and capacity [1-3].

Life Cycle Assessment (*LCA*) has also been used in dairy production by developing a model for the facility based on the association between energy consumption and production for modeling and simulation [1, 4–8]. Greenhouse gas emissions have been found to be reduced by energy use, proving the system's efficiency [9]. This dairy factory is located in the Cappadocia region and produces dairy products, such as cheese (white, cheddar, curd, and tulum), yogurt, butter, and ayran. The annual production capacity of the dairy products is for white cheese at 1,089 [t/y], for cheddar cheese at 259 [t/y], for curd cheese at 9 [t/y], for tulum cheese at 144 [t/y], for yoghurt at 2,513 [t/y], for butter at 3.27 [t/y], and for ayran at 1,224 [t/y]. The daily raw milk processing capacity of this dairy plant varies between 10,000 and 100,000 liters.

The production departments for milk and other products in the factory are presented in Figure 1. Cheese (white, cheddar, curd, and tulum), yoghurt, butter, and ayran were produced in dairy and product manufacturing departments. In the production department of milk and its products, energy is used intensively and humidity is maintained under control. Fluid mechanics control is also provided in piping systems between boats and boilers, where milk and its products are produced. The piping and tub-boiler materials consist of high-quality stainless steel.

Figure 1. Production department for milk and products in the factory.

The Statistical Software Programme (SPSS) was recommended for comparative analyses of the literature for consistency and validity of energy data [10-14]. The energy values of the plant were determined using mathematical expressions in this research using SPSS data analysis techniques and data reliability and accuracy testing.

Many previous studies have focused on energy consumption, production charts, and specific energy consumption [15-19]. The annual energy efficiency of factories is indicated by an effective analysis of production and energy, as well as a numerical calculation for energy consumption analysis [20-28]. Furthermore, some energy analysis algorithms have been proposed in the literature and are presented as an analysis of the relationships between energy consumption and facility production [21-22, 29].

The study analyzes data accuracy, reliability, and SPPS analysis, highlighting energy consumption and production values and facility efficiency improvements. Energy management and performance analysis also affect the future planning of the facility and encourage an increase in production and energy efficiency. Beginning at the facility's entrance, controlling raw materials and energy is achievable for efficient energy use with an energy management unit and control of all inputs and outputs.

The novelty of this study is that optimizing product efficiency and energy consumption in the production of milk and dairy products positively increases the energy efficiency of factories. Furthermore, optimal conditions for milk and dairy product production can be derived, and energy savings can be proven in milk dairy factories' similar product processes.

MATERIALS AND METHODS

The production processes of dairy factories begin with the purchase of raw milk and continue through separation, pasteurization, cooling, calcium chloride addition, starter culture, pre-maturation, fermentation, clot technique, portioning, brine technique, ripening processes, packaging, storage, and shipment (Figure 2). The capacity of milk and its products varies depending on the product, and is related to energy-consuming machines. In this study, energy-efficient instances are presented by attempting various optimizations through case studies [24, 30].

All processes, from raw material input to packaging, storage, and shipment, were evaluated during the dairy factory production process. Thus, calculations are made with the help of thermodynamic laws by developing methods based on the specific energy consumption, energy efficiency, and production amounts of milk and products.

Cheese (white, cheddar, curd, and tulum), yoghurt, butter, and ayran production capacity can be calculated according to the plate pasteurizer capacity using Eq. (1) to Eq. (16) [30–31]. Some assumptions can be made regarding the production of dairy milk products (working days, milk efficiency of the products, and number of charges). 1 ton

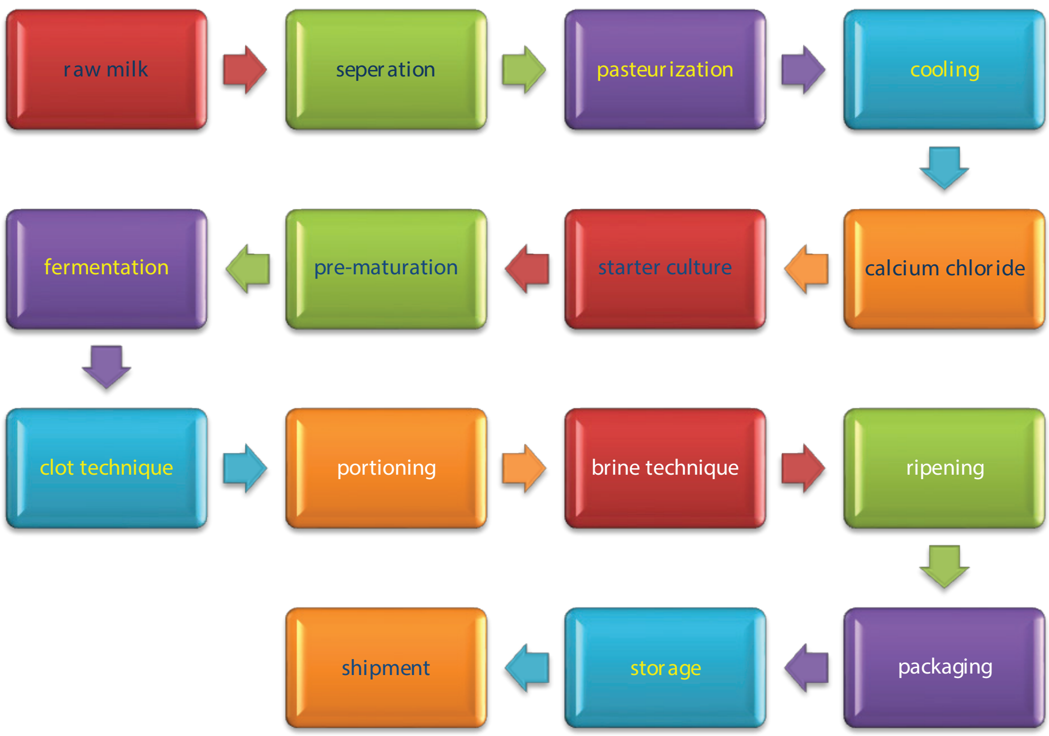

Figure 2. A scheme of the production of dairy milk processes.

of milk and product is equivalent to 1000 [kg], and since 1 ton of milk and product is 971 [L], capacity calculations are made by assuming that 1 ton of milk is approximately 1 [m^3]. The annual value of the plate pasteurizer capacity (*PPA*) can be determined using Eq. (1) as follows [30]:

$$PPA \text{ [t/y]} = PPH \text{ [t/h] x 300 [d/y] x 8 [h/d] x } \eta_{eff} \text{ [\%]} \quad (1)$$

where *PPH* is the mass per unit time of the plate pasteurizer at 10 [t/h] (catalogue value of the plate pasteurizer), and η_{eff} is the efficiency factor of the *PPA* (85%). The white cheese production capacity (*CWP*) can be obtained using Eq. (2) and Eq. (3) as follows [30]:

$$CW_{ML} \text{ [t/y]} = V_{CW} \text{ [t] x } NC \text{ [-] x } n \text{ [d/y] x } \eta_{eff} \text{ [\%]} \quad (2)$$

$$CWP \text{ [t/y]} = CW_{ML} \text{ [t/y] x } \eta_{CW} \text{ [\%]} \quad (3)$$

where CW_{ML} is the dairy milk production for white cheese, V_{CW} is the fermentation vessel volume of white cheese (m^3=t), *NC* is the number of charges (1.0) for white cheese, *n* is the number of working days per year (300 days per year), η_{eff} is the efficiency factor of CW_{ML} (80%), and η_{CW} is milk efficiency (16.5% for white cheese). Cheddar cheese capacity production (*CCP*) can be obtained using Eq. (4) and Eq. (5) [30]:

$$CC_{ML} \text{ [t/y]} = V_{CC} \text{ [t] x } NC \text{ [-] x } n \text{ [d/y] x } \eta_{eff} \text{ [\%]} \quad (4)$$

$$CCP \text{ [t/y]} = CC_{ML} \text{ [t/y] x } \eta_{CC} \text{ [\%]} \quad (5)$$

where CC_{ML} is the dairy milk production for cheddar cheese, V_{CC} is the vessel volume of cheddar cheese (m^3=t), *NC* is the number of charges (2.0) for cheddar cheese, η_{eff} is the efficiency factor of CC_{ML} (80%), and η_{CC} is milk efficiency (9.0% for cheddar cheese). Curd cheese capacity production (*CUP*) can be obtained from Eq. (6) and Eq. (7) [30]:

$$CU_{ML} \text{ [t/y]} = V_{CU} \text{ [t] x } NC \text{ [-] x } n \text{ [d/y] x } \eta_{eff} \text{ [\%]} \quad (6)$$

$$CUP \text{ [t/y]} = CU_{ML} \text{ [t/y] x } \eta_{CU} \text{ [\%]} \quad (7)$$

where CU_{ML} is the dairy milk production for curd cheese, V_{CU} is the vessel volume of curd cheese (m^3=t), *NC* is the number of charges (0.5) for curd cheese, η_{eff} is the efficiency factor of CU_{ML} (80%), and η_{CU} is milk efficiency (9.0% for curd cheese). Tulum cheese capacity production (*TUP*) can be obtained using Eq. (8) and Eq. (9) [30]:

$$TU_{ML} \text{ [t/y]} = V_{TU} \text{ [t] x } NC \text{ [-] x } n \text{ [d/y] x } \eta_{eff} \text{ [\%]} \quad (8)$$

$$TUP \text{ [t/y]} = TU_{ML} \text{ [t/y] x } \eta_{TU} \text{ [\%]} \quad (9)$$

where TU_{ML} is the dairy milk production for tulum cheese, V_{TU} is the vessel volume of tulum cheese (m^3=t), *NC* is the number of charges (1.0) of curd cheese, η_{eff} is the efficiency factor of TU_{ML} (80%), and η_{TU} is milk efficiency (10.0% for curd cheese). The Yoghurt capacity production (*YOP*) can be obtained using Eq. (10) and Eq. (11) [30]:

$$YO_{ML} \text{ [t/y]} = V_{YO} \text{ [t] x } RA \text{ [-] x } FMR \text{ [-] x } NC \text{ [-] x } n \text{ [d/y]} \quad (10)$$

$$YOP \text{ [t/y]} = YO_{ML} \text{ [t/y] x } \eta_{YO} \text{ [\%] x } \rho_{YO} \text{ [kg/L]} \quad (11)$$

where YO_{ML} is the dairy milk production for the yoghurt, V_{YO} is the amount of fermented milk put in each cart (basket) according to the packaging type volume (0.5 m^3=t), *RA* is the room amount (2 pieces), *FMR* is the number of carts (baskets) for each room (6 pieces), *NC* is the number of charges (amount 2.0) of the yoghurt, ρ_{YO} is the specific weight of the yoghurt (1.042 kg/L), and η_{YO} is the milk efficiency (67% for the yoghurt). Butter capacity production (*BTP*) can be obtained using Eq. (12) and Eq. (13) [30]:

$$BT_{ML} \text{ [t/y]} = V_{BT} \text{ [t] x } CR \text{ [\%] x } NC \text{ [-] x } n \text{ [d/y]} \quad (12)$$

$$BTP \text{ [t/y]} = BT_{ML} \text{ [t/y] x } \eta_{BT} \text{ [\%] x } EF \text{ [\%]} \quad (13)$$

where BT_{ML} is the dairy milk production for the butter, *CR* is the volume of crema in the churn volume (60%), V_{BT} is the vessel volume of the butter (0.05 m^3=t), *NC* is the number of charges (1.0) of the butter, *EF* is the efficiency factor (85%), an dη_{BT} is the butter efficiency (42.7%). The Ayran capacity production (*AYP*) can be obtained using Eqs. (14), Eq. (15) and Eq. (16) [30]:

$$AY_{ML} \text{ [t/y]} = V_{AY} \text{ [t] x } AY \text{ [\%] x } \rho_{AY} \text{ [kg/L] x } n \text{ [d/y]} \quad (14)$$

$$AYP \text{ [t/y]} = AY_{ML} \text{ [t/y] x } WA \text{ [\%]} \quad (15)$$

$$AY_{FMC} \text{ [t/y]} = AYB \text{ [pcs/h] x } m_{AYB} \text{ [kg] x 300 [d/y] x 8 [h/d] x } \eta_{AY} \text{ [\%] / 1000} \quad (16)$$

where AY_{ML} is the dairy milk production for the ayran, V_{AY} is the vessel volume of the ayran (1.1 m^3=t), *NC* is the number of charges (1.0) of the ayran, *AY* is the vessel volume efficient (70%), ρ_{AY} is the specific weight of the yoghurt (1.042 kg/L), *WA* is the water addition rate to the ayran (120%), AY_{FMC} is the ayran filling machine capacity (t/y), *AYB* is the number of bottles/boxes (3000 pieces/h),

m_{AYB} is the net ayran mass in a bottle box (0.2 kg), and η_{AY} is the ayran efficiency (85%).

SPSS (version 18.0) was used for the data analysis software was included. Regression analysis was used to examine the data reliability of the scenarios. The R^2 values are presented in graphs. Thus, the fact that R^2 is close to 1 indicates that the results of the study provide reliable data and are expressed mathematically. A p (< 0.05) value was shown to be statistically significant.

Specific Energy Consumption (*SECT*) and Energy Target Plan (Food Engineering Fundamental Operations)

The specific energy consumption and energy target plan (food engineering core operations) for the *SECT* (specific energy consumption) table of the dairy processing plant were laid out based on the current situation and case studies. Energy consumption expenditures according to the production of food products were applied according to the following equations [15, 24, 32–34].

In this generation-energy model, in addition to *SECT* and *ECT* (energy consumption), modeling is performed by establishing a mathematical relationship between the heat and electric energy. Owing to the energy consumption (month/year) correlations, functional relationships between the production amount and heat-electrical energy consumption were established and revealed by linear regression analysis in the estimation method. In this estimation method, the R^2 value (determination coefficient) represents the basic annual energy equation [24, 32, 35].

Under the details of all energy disclosures, the energy consumption for the dairy milk production plant was calculated using Eq. (17) [24, 32]:

$$ECT_{p,i+1}[GJ] = ECT_{k,i} + m_{s,i} \cdot (Q_{g,i+1} - Q_{k,i}) - \sum_{i=1}^{n_j} \left(\frac{ECTR_{i+1,j}}{100}\right) \cdot ECT_{k,i} \quad (17)$$

where *ECT* is the energy consumption of the dairy milk plant (GJ), j is the number of equal energy measurements per year up to n_j, Q is the volume of production [kg], and i is a symbol. m is the mass of production, which can be expressed as $m_{s,i} = (ECT_{p,i} - ECT_{k,i}) / (Q_{g,i+1} - Q_{k,i})$ [24, 32].

The total estimated project of the specific energy consumption ($SECTT_{p,i+1}$) can be determined using Eq. (18) as follows:

$$SECT_{p,i+1}[GJ/ton] = \frac{ECT_{p,i+1}}{Q_{g,i+1}} \quad (18)$$

The total target project of the specific energy consumption ($SECTT_{p,i+1}$) can be determined using Eq. (19) as follows:

$$SECTT_{p,i+1}[GJ/ton] = SECT_{p,i+1} \quad (19)$$

LCA and Waste Water Management of the Factory

Life-cycle assessment is available for dairy products. The product characteristics of the milk boats currently in use at the milk processing facility were used to calculate the capacity amounts of dairy products. The life cycle assessment in this model was established by estimating the expenses associated with processing and recycling raw milk [1, 4–7, 36].

Because of the basic facility procedures, calculations were performed for the *LCA* of the milk production facility, as shown in Figure 3. The milk supplied is processed at the plant using power, fuel, packaging and cleaning procedures, water, raw materials, and fuel to create cheese (white, cheddar, curd, and tulum), yoghurt, butter, and ayran, respectively. Water and wastewater are released after production, which highlights their environmental impact.

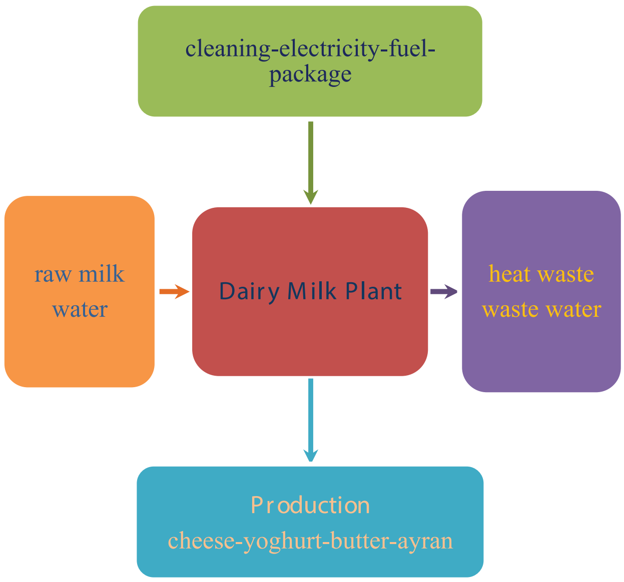

Figure 3. A scheme of the life cycle assessment for the dairy milk plant.

Figure 3 depicts the *LCA* of the milk production facility with respect to wastewater consumption. Underground water resources are being treated and a facility certificate for water use is in place. Administrative building wastewater management was also implemented in the facility, and a total of 3600 L/d of wastewater was generated daily with an individual water consumption of 150 L/d of 24 personnel. This wastewater is discharged into the municipal sewer system (Sewer Connection Permit). In industrial wastewater management, whey formed as a result of milk processing in the facility is collected and disposed of in the tank with the help of pumps.

Data and Equipment Analysis of the Production: Uncertainty Analysis

Uncertainty analysis, which shows the precision of measured data, is useful for analyzing production data and tools

Table 1. Evaluation of experimental equipment's relative error and uncertainty of the result

Sensor of equipment	Parameter	Accuracy of data (*AD*)	Value of measurement (*VM*)	Uncertainty in a relative sense z_C, (*AD/VM*) [%]
DC power source with voltage and current control	V_o [V]	± 0.4 % [V]	4.0 [V]	± 0.01
	I_o [A]	±0.4 % [A]	2.0 [A]	± 0.20
Thermocouple of type T	T [°C]	±0.8 [°C]	*ECT* inner apparatus= 4 [°C]	± 0.20
			ECT wall apparatus= 5 [°C]	± 0.16
			ECT inner tool design= 2 [°C]	± 0.40
			ECT wall design= 4 [°C]	± 0.20

[7, 36–42]. To enhance the trustworthiness of data analysis, it was necessary to perform an uncertainty analysis of the collected measurements. This highlights the degree of uncertainty in both the systematic and predictive aspects of the data in Eq. (20) [7, 39–40, 42–46]:

$$z_C = \left[\left(\frac{\partial C}{\partial k_1} z_1\right)^2 + \left(\frac{\partial C}{\partial k_2} z_2\right)^2 + \ldots + \left(\frac{\partial C}{\partial k_j} z_j\right)^2\right]^{1/2} \quad (20)$$

where z_j is the uncertainty of the dependent variable, z_C is the uncertainty of the result, and C is an independent variable. Uncertainty analysis can be used to generate an analytical expression for energy measurement error. The analysis of the uncertainty method describes what is expected from the data of the output or suggests the strategy of the data (the experiment or determination results) from Eq. (21) to Eq. (23) [43, 45, 47–48] as follows:

$$\frac{\partial ECT_{p,i+1}}{\partial Q_{g,i+1}} = SECT_{p,i+1} \quad (21)$$

$$\frac{\partial ECT_{p,i+1}}{\partial SECT_{p,i+1}} = Q_{g,i+1} \quad (22)$$

$$\frac{z_{ECT_{p,i+1}}}{ECT_{p,i+1}} = \left[\left(\frac{z_{SECT_{p,i+1}}}{SECT_{p,i+1}}\right)^2 + \left(\frac{z_{Q_{g,i+1}}}{Q_{g,i+1}}\right)^2\right]^{1/2} \quad (23)$$

where $\frac{z_{ECT_{p,i+1}}}{ECT_{p,i+1}}$ is the uncertainty of the result, and C is the independent variable of the result.

In Table 1, a sensor of equipment can be defined as a DC power source with voltage control and a type-T thermocouple; uncertainty in a relative sense is obtained from the accuracy of the data and the value of the measurement. The uncertainty in the relative sense range was estimated to be between 0.01% and 0.4%, and it was revealed that these values were within the uncertainty analysis values. The study of uncertainty was premised on the fact that it is difficult to quantitatively evaluate all the many components involved. An overall dependability of 99.99% was obtained after analyzing the uncertainty of the four primary analytical parameters.

Calculation of the process's thermal and electrical energy

The total energy consumption was calculated from the thermal and electric energy of the machines and equipment in the factory process. It was received from the factory because of the calculations and measurements of the thermal and electrical energy in all machinery and equipment. As a result, the thermal and electrical energies of each process carried out within the factory were analyzed in this study. The thermal and electric energies of the machine and equipment were provided by a homogenizer, cheddar packing machine, coolant tank, cheddar melting-transferring machine, cold storage, separator, tulum cheese filling machine, milk pump, heat exchanger, evaporator, cheddar dry scalding machine, ayran process tank, heating boiler, walled cooking vessel, cooking vessel, compressor, vacuum machine cooling unit, tulum cheese pressing machine, weighing machine, churning machine, cheddar fermentation tank, brine vessel, pressing machine, chopping machine, and ayran filling machine.

The total power ($\dot{P}$) amounts of the processes (electric energy) were calculated according to the following from Eq. (24) to Eq. (25) as follows [49]:

$$\sum \dot{P}_{out}\,[\mathrm{W}] = \dot{P}_1 + \dot{P}_2 + \dot{P}_3 + \cdots + \dot{P}_{25} \quad (24)$$

$$\dot{P}_n\,[\mathrm{W}] = I_n\,[\mathrm{A}] \times U_n\,[\mathrm{V}] \quad (25)$$

where $\sum \dot{P}_{out}$ is total energy of the process, n is denoted of the process number, l_n is the consumption of the current, and U_n is the consumption of the voltage energy.

The total heat transfer of the processes ($\sum \dot{Q}$) was determined by considering the Thermodynamic Tables based on the temperature changes in the process (thermal energy) from Eq. (26) to Eq. (28) by the 1st Law of Thermodynamics as follows [49]:

$$\sum \dot{Q}\,[\mathrm{W}] - \sum \dot{P}\,[\mathrm{W}] = \Delta\dot{U}[\mathrm{W}] + \Delta\dot{KE}[\mathrm{W}] + \Delta\dot{PE}[\mathrm{W}] \quad (26)$$

$$\dot{Q}_{in}[\mathrm{W}] = \dot{m}_c \left[\frac{\mathrm{kg}}{\mathrm{s}}\right] \times C_p \left[\frac{\mathrm{J}}{\mathrm{kg}}\mathrm{K}\right] \times \Delta T[\mathrm{K}] \tag{27}$$

$$\sum \dot{Q}_{in}\,[\mathrm{W}] = \sum \dot{P}_{in}\,[\mathrm{W}] \tag{28}$$

where $\sum \dot{Q}_{in}$ is the process of total heat transfer input, $\sum \dot{P}_{in}$ is the process of work power, $\dot{m}_c$ is the mass flow rate, C_p is the specific heat capacity, $\Delta\dot{U}$ is an internal energy difference, $\Delta\dot{KE}$ is a kinetic energy power, $\Delta\dot{PE}$ is a potential energy power, and ΔT is a difference temperature. However, the internal energy, kinetic energy power, and potential energy power were ignored because of the low energy in the energy calculations.

This system is generally regarded as an open system that features steady flow output. The 1st Law of Thermodynamics is given by Eqs. (29) to Eq. (30) [45-46]:

$$\sum \dot{P}_{in}[\mathrm{W}] + \dot{Q}\,[\mathrm{W}] = \sum \dot{P}_{out}[\mathrm{W}] + \dot{P}\,[\mathrm{W}] \tag{29}$$

$$\sum \dot{Q} - \sum \dot{P} = \sum \dot{P}_{out} - \sum \dot{P}_{in} \tag{30}$$

The amount of steam energy generated in all the processes was determined by considering the thermodynamic tables according to the enthalpy changes of the steam at a certain pressure from Eq. (31) as follows [49-50]:

$$\sum \dot{P}_{in}\,[\mathrm{W}] = \sum \dot{Q}_{in} = \sum \dot{Q}_{steam} = \sum \dot{m}_{steam} \times (h_{steam} - h_{condense}) \tag{31}$$

where $\dot{Q}_{stream}$ is the steam heat transfer of the process, $\dot{m}_{steam}$ is the mass flow rate of the steam, h_{steam} is the enthalpy of the steam, and $h_{condense}$ is the enthalpy of the condense.

The energy efficiency (η_I, The 1st Law of Thermodynamics) can be formulated from Eq. (32) and Eq. (33) as follows [49-50]:

$$\dot{P}_{out}[\mathrm{W}] = \dot{P}_{out,t} + \dot{P}_{out,e} \tag{32}$$

$$\eta_I[\%] = \frac{\dot{P}_{out}}{\dot{P}_{in}} \tag{33}$$

where $\dot{P}_{out,t}$ is the thermal (steam) energy, $\dot{P}_{out,e}$ is the electric energy, and η_I is the energy efficiency of the factory.

RESULTS AND DISCUSSIONS

The total amount of production that took place in the dairy and product plant was used as a contributing factor in determining the amount of energy consumed overall. The dairy industry consumes thermal energy [51]. Thermodynamic modeling was applied to the thermal performance of a dairy factory in this study [52]. Therefore, an investigation of the efficiency of the factory's utilization of energy was carried out using statistics on the production and consumption of energy at the plant. To make the manufacturing facility as effective as possible, an investigation was conducted on the connection between the use of energy and the creation of materials. Table 2 presents the dairy milk facility data for the energy consumption analysis in this study. Pasteurization shows only the raw milk processing capacity and is not included in the production of milk and its products. The pasteurizer capacity was estimated as 20,400 [t/y]. In case studies of dairy production, various optimization data were determined according to tank capacity and work time.

Table 2 displays the results of the case studies using the optimization method based on the current yearly capacity. When assessing a dairy milk facility's data profile, the

Table 2. Analyze the data profile of a dairy milk facility

Processing capacity of products	***ACP***		**Case 1**		**Case 2**		**Case 3**	
	Prod. [t/y]	**Eff. [%]**	**Prod. [t/y]**	**Eff. [%]**	**Prod. [t/y]**	**Eff. [%]**	**Prod. [t/y]**	**Eff. [%]**
PPA	20,400.0	100	20,400.0	100	20,400.0	100	20,400.0	100
CWP	1,089	5.3%	1188	5.8%	1287	6.3%	1386	6.8%
CCP	259.2	1.3%	302.4	1.5%	345.6	1.7%	388.8	1.9%
CUP	9.0	0.8%	11.3	0.9%	13.5	1.0%	15.8	1.1%
TUP	144	0.7%	168	0.8%	192	0.9%	216	1.1%
YOP	2,513	12.3%	2932.19	14.4%	3351.07	16.4%	3769.96	18.5%
BTP	3.27	0.02%	9.42	0.05%	12.57	0.06%	15.71	0.08%
AYP	285.52	1.4%	311.47	1.5%	337.43	1.7%	363.38	1.8%
CRE	9	0.04%	18	0.09%	36	0.18%	54	0.26%
TDP	4,311.99	21.1%	4,940.73	24.2%	5,575.17	27.3%	6,209.60	30.4%

Note: *PPA*: pasteurizer; *CWP*: white cheese; *CCP*: cheddar cheese; *CUP*: curd cheese; *TUP*: tulum cheese; *YOP*: yoghurt; *BTP*: butter; *AYP*: ayran; *TDP*: total dairy products; *ACP*: annual current production; *Eff*: efficiency; *Prod*: Production; t/y: tons/year total daily milk yield was derived by subtracting the energy analysis production efficiencies, which were based on the production and efficiency of the various milk products. Annual production efficiency can be calculated using the product per total dairy product [53]. The total dairy product was determined as 4,311.99 [t/y] with a production efficiency of 21.1% for *ACP*; 4,940.73 [t/y] with a production efficiency of 24.2% for Case 1; 5,575.17 [t/y] with a production efficiency of 27.3% for Case 2; and 6,209.60 [t/y] with a production efficiency of 30.4% for Case 3.

Table 3 presents the energy consumption of the dairy milk factory using machinery and equipment. The output power capacity was calculated using the dairy milk factory process. In factories, there are many machines and equipment used for the processing of dairy milk products. These conditions were considered in the computation. The total power of the process was calculated at 180.52 [kW] in the factory.

In Table 3, the energy consumption of the dairy milk factory by the machinery and equipment homogenizer can be obtained as follows: the cheddar packing machine, coolant tank, cheddar melting-transferring machine, cold storage, separator, tulum cheese filling machine, milk pump, heat exchanger, evaporator, cheddar dry scalding machine, ayran process tank, heating boiler, walled cooking vessel, cooking vessel, compressor, vacuum machine cooling unit, tulum cheese pressing machine, weighing machine, churning machine, cheddar fermentation tank, brine vessel, pressing machine, chopping machine, and ayran filling machine.

Table 4 presents the dairy products of the existing products based on a worldwide asset evaluation. These dairy products are pasteurizers, total cheese, crema, yoghurt, and butter, which were estimated by averaging the energy machinery and equipment estimates of the enterprise's daily milk and products per final product mass according to Table 2 [5]. In Table 4, the total energy consumption (*ECT*) was found to be 29,303.18 [GJ] for the input of the annual current production. The total energy was found to be 31,663.1 [GJ] for the input of annual current production for Case 1. In Case 2, the *ECT* was found to be 34,019.2 [GJ/kg] for the input of the annual current production. In Case 3, the *ECT* was found to be 36,375.4 [GJ/kg] for the input of annual current production. Table 4 shows the relationships between the optimizations and energy and production based on these values. These optimization values were generated and graphed using 3 case studies.

The total energy and raw milk data in Table 4 were analyzed using the current status of the 3 case study comparisons. Thus, statistical analysis was performed between the energy and production values in this study.

Figure 4 shows the *ECT* and *TDP* results for the case study. In the regression analysis, the R^2 was 0.9989 for *ECT* and 0.9973 for *TDP*. When the regression curves in Figure 4 were evaluated with logarithmic slopes, it was determined

Table 3. Output power capacity of the dairy milk factory process

Energy (power capacity)	Pcs	Power [W]	Energy (power capacity)	Pcs	Power [W]
1. Homogenizer	1	37,000	14. Walled cooking vessel	2	3,000
2. Cheddar packing machine	1	21,000	15. Cooking vessel	2	3,000
3. Coolant tank	2	18,000	16. Compressor	1	2,500
4. Cheddar melting-transfer machine	1	16,000	17. Vacuum machine cooling unit	1	2,500
5. Cold storage	4	12,000	18. Tulum cheese press machine	1	2,500
6. Separator	1	15,000	19. Weighting machine	2	2,370
7. Tulum cheese filling machine	2	6,500	20. Churning machine	1	2,200
8. Milk pump	5	5,500	21. Cheddar fermentation tank	1	2,000
9. Heat exchanger	1	5,500	22. Brine vessel	1	1,500
10. Evaporator	1	5,500	23. Pressing machine	2	1,500
11. Cheddar dry scalding machine	2	5,200	24. Chopping machine	1	750
12. Ayran process tank	1	4,500	25. Ayran filling machine	1	500
13. Heating boiler	1	4,500	$\dot{P}_{out}$ [W]		**180,520**

Table 4. Dairy product of the annual actual existing products (process energy) based on worldwide asset evaluation

energy	Unit	*ACP*	Case 1	Case 2	Case 3
electric	[GJ]	14,319.35	15,413.7	16,507.6	17,601.5
thermal	[GJ]	14,983.83	16,249.4	17,511.6	18,773.8
ECT	**[GJ]**	**29,303.18**	**31,663.1**	**34,019.2**	**36,375.4**

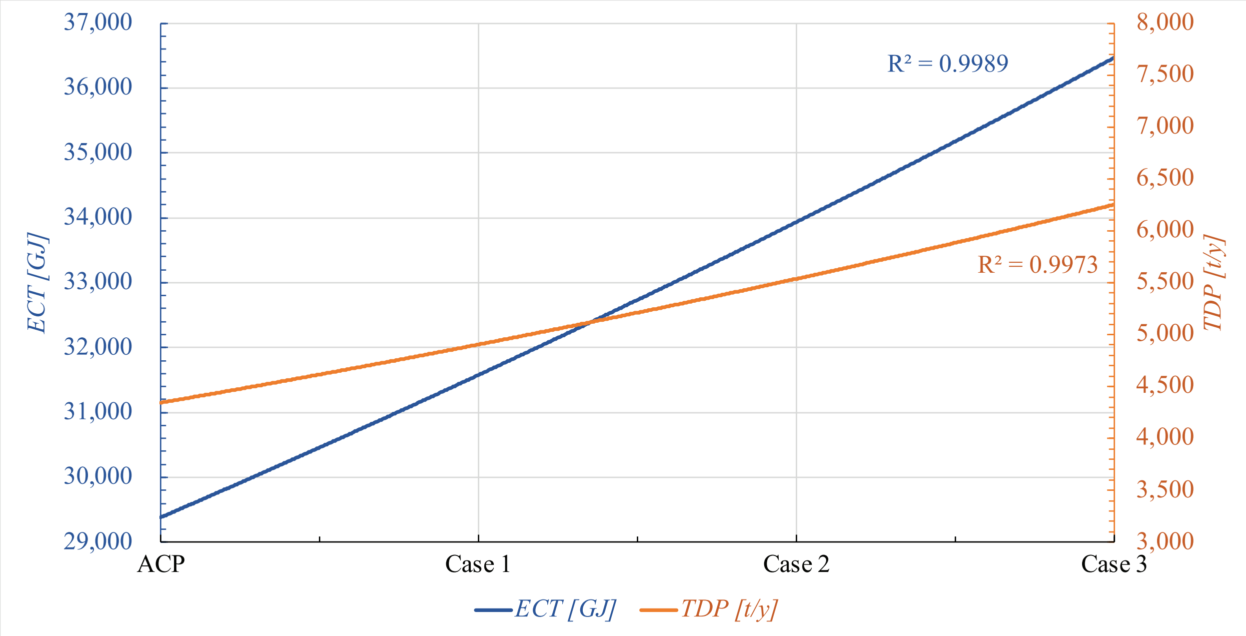

Figure 4. *ECT* and *TDP* of the dairy milk plant for the case study.

that the values for Cases 1 and 2 reached the optimum point. Thus, the most efficient and optimal situation for dairy plants was revealed.

In Table 5, calculations were made according to the energy consumption values (heat boiler and electric energy) taken from the dairy and products facility for a period of 1 year. The annual energy consumption (*ACP*) of the total factory was 29,303,200 [MJ/y]. Based on these calculated values, the *SECT* values of the factory were optimized according to the case studies. The result of the *SECT* value was found to be Case 1 at 6,408.60 [MJ/t], Case 2 at 6,101.92 [MJ/t], and Case 3 at 5,857.92 [MJ/t]. The *SECTT* value was calculated for Case 1 as 6,352.14 [MJ/t], for Case 2 as 5,898.67 [MJ/t], and for Case 3 as 5,445.21 [MJ/t]. Therefore, the case study results (*SECT* and *SECTT*) are available according to the study by Nathaphan and Therdyothin [24]. The results of the 3 case studies are compatible with the results of the specific energy consumption in Table 5.

The SEC values of the dairy milk plant in each of the three case studies are shown in Figure 5. The overall estimated energy consumption of the dairy plant demonstrates the relationship between the specific energy consumption and the total goal-specific energy consumption. The *SECT* of *ACP* was calculated to be 6,795.75[MJ/t]. The *SECT* was determined to be 6,408.60 [MJ/t] for Case 1, 6,101.92[MJ/t] for Case 2, and 5,857.92 [MJ/t] for Case 3. Case 1 had an *SECTT* of 6,352.14[MJ/t], Case 2 had an *SECTT* of 5,857.92[MJ/t], and Case 3 had an *SECTT* of 5,445.21[MJ/t]. Cases 2 and 3 illustrate the energy efficiency of the case study. SPSS software (version 18.0) was also used for data analysis and evaluation. The reliability of the scenario data was investigated using regression analysis. The R^2 value was 0.9609 for *ECT*, 0.9903 for *SECT*, and 0.9587 for *SECTT,* and the equations are depicted in the graph.

Table 6 shows that the factory operates nearly full time for 150 days per year. The steam boiler uses 244.6 [t/y] powdered lignite coal for annual thermal energy. The calorific value of the coal used in the heat duct was

Table 5. Total energy consumption of the dairy facility for 3 case studies

	ACP	**Case 1**	**Case 2**	**Case 3**
ECT [MJ]	29,303,200	31,663,140	34,019,250	36,375,359
SECT [MJ/t]	4,803.09	6,408.60	6,101.92	5,857.92
SECTT [MJ/t]	4,803.09	6,642.70	6,482.41	6,322.13

Note: *ECT* is the energy consumption of the dairy milk plant [MJ], $SECT_{p,i+1}$ is total estimated project of the specific energy consumption [MJ/t], and $SECTT_{p,i+1}$ is total target project of the specific energy consumption [MJ/t].

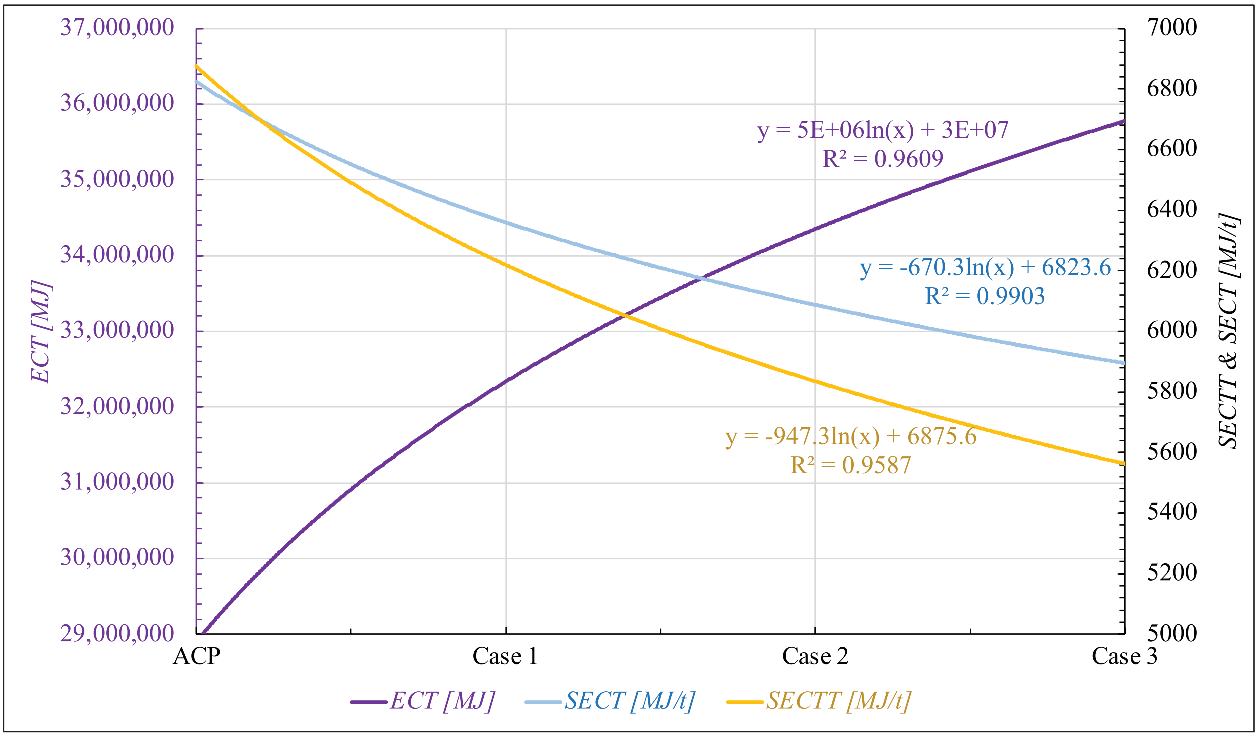

Figure 5. The dairy milk plant's *ECT*, *SECT*, and *SECTT* for the case studies.

Table 6. Total energy efficiency of the dairy milk factory for *ACP*

***ACP* (annual current production of the dairy milk factory)**				
Energy/unit	**[GJ/y]**	**[kcal/y]**	**[kWh/y]**	**[kW]**
$\dot{P}_{in,t}$, thermal (steam) energy	4,093.63	978,400,000.00	1,137,118.22	315.87
$\dot{P}_{out,e}$, electric energy	1,049.55	250,841,876.40	291,541.00	80.98
			$\dot{P}_{in}$, total input energy	396.85
			$\dot{P}_{out}$, total output energy	180.52
			η_I, energy efficiency	45%

determined to be 4,000 [kcal/kg], according to the value received from the factory. The annual thermal (steam boiler) and electrical energy expenditures are detailed, with the thermal (steam) energy being 315.87 [kW] and electrical energy being 80.98 [kW]. The annual total electricity consumption of the factory was calculated to be 1,049.55 [GJ/y], and the coal consumption was 4,093.63 [GJ/y]. Thus, despite the factory's thermal and electrical energy expenditures, the energy efficiency was calculated to be 45.5%. Although the energy efficiency is calculated to be approximately 45.5%, the main reasons for the waste of the remaining 54.5% are the energy losses in the processes due to the fluid nature of milk, large amount of energy consumed, and high amount of waste heat. It is recommended to further optimize the processes that need to be initiated in the factory and install a recycling waste heat system. Thus, the energy efficiency of a factory can be further increased using these methods.

In Table 6, the electrical energy results in this case study are in agreement with studies in the literature, as are the *SECT* values. Lincoln et al. [54] investigated a milk evaporator system case study that presents the processes and end creation of a novel, fully electric milk evaporator system design that uses 3593 [kW] of energy. According to this case study, the results of Buhler et al. [55] are similar to those of the energy efficiency of a milk processing factory. Basaran et al. [50] discovered that a unique design for 10 [t/h] milk could be completed with 44.35% less energy

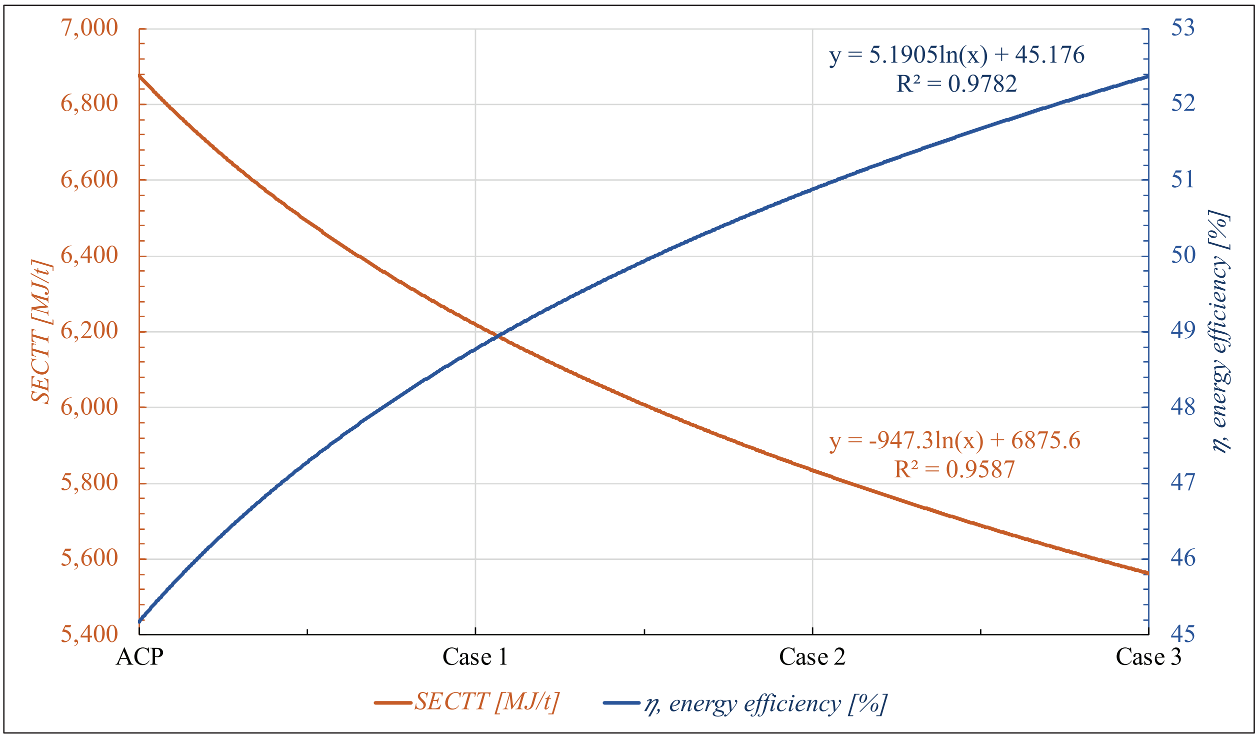

Figure 6. Total energy efficiency of the dairy milk factory for 3 case studies.

input than a standard application. Considering the total energy efficiency of the dairy milk factory, case studies were optimized, and the energy efficiencies were separately revealed. The energy efficiency of the factory was determined according to 3 different scenarios optimized for thermal and electrical energies according to the actual total energy efficiency.

Figure 6 demonstrates the energy efficiency of the dairy milk factory in the three case studies. The input energy was calculated to be 374.24 [kW] in Case 1, 356.33 [kW] in Case 2, and 342.08 [kW] in Case 3. The energy efficiency in this case study was assessed to be 48.2% for Case 1, 50.7% for Case 2, and 52.8% for Case 3, indicating an increase in energy efficiency. Regression analysis was used to examine the data reliability of the scenarios. The R^2 value for η is 0.9609, and 0.9587 for *SECTT*, and the equations are shown in the graph. Consequently, numerous similar energy efficiency studies of dairy companies have been conducted, and a few are included in this study. Lincoln et al. [54] achieved energy savings of 21% in process integration and electrification for efficient milk-evaporation systems. Buhler et al. [56] reduced the electricity input by 48% and heat rate by 35% in the electrification scenario. This case study is consistent with past research, and it has been demonstrated that energy efficiency would grow in various situations owing to optimization approaches in dairy plants.

CONCLUSIONS

In this study, because of the thermal and electrical energy, the energy consumption of dairy milk factories has a considerable impact on the energy efficiency of applications. The dairy plant's total estimated energy consumption exhibits a relationship between the specific energy consumption and the target specific energy consumption for the energy consumption in each of the three case studies. The target-specific energy consumption was computed to be 6,352.14 [MJ/t] in Case 1, 5,898.67 [MJ/t] in Case 2, and 5,445.21 [MJ/t] in Case 3. In this study, Cases 2 and 3 exhibited optimized results in terms of energy efficiency.

The annual thermal (steam boiler) and electrical energy expenditures were obtained, with 315.87 [kW] of thermal (steam) energy and 80.98 [kW] of electrical energy. The total thermal and electric energy was summarized as 396.85 [kW]. The factory's annual total electricity usage was determined to be 1,049.55 [GJ/y], while its coal consumption was 4,093.63 [GJ/y]. Despite the factory's expenditure on thermal and electrical energy, its energy efficiency was determined to be 45.5%. The energy efficiency of the factory was 45.5%, but 54.5% of the waste was due to energy losses, fluid milk, energy consumption, and high waste heat. Optimizing processes and installing a recycling waste heat system can increase the efficiency. The input energy was calculated to be 374.24 [kW] for Case 1, 356.33 [kW] for Case 2, and 342.08 [kW] for Case 3. The energy efficiency was assessed to be 48.2 [%] for Case 1, 50.7 [%] for

Case 2, and 52.8 [%] for Case 3, demonstrating increasing energy efficiency in this case study.

The dairy factory's capacity was obtained by performing specific energy consumption estimations based on the energy consumption data (heat boiler and electric energy) received from the dairy and product plant over a one-year period. This study demonstrates the performance of a manufacturing facility by providing details on the operation of energy analysis in a dairy milk plant. The use of milk and milk-derived products in the dairy industry results in a high energy density. As a result, determining the factory's energy performance to save energy will increase profitability.

The aim of this study is to make the conclusions more realistic by using dependability analysis of the production and energy data. The study's task is to collect the dairy plant's energy and production performance, as well as to make the energy costs and efficiencies as precise as possible over the course of a year. A plant's energy performance can be measured by ensuring that the production of milk and goods in the factory is synchronized with the use of energy.

NOMENCLATURE

Abbreviations

ACP	Annual current production
AYP	Ayran
BTP	Butter
CA	Cleaning agent
CCP	Cheddar cheese
CHE	Total cheese
CRE	Crema
CUP	Curd cheese
CWP	White cheese
DMP	Dairy Milk Plant
ECT	Energy Consumption
Eff	Efficiency
LCA	Life Cycle Assessment
PPA	Pasteurizer
Prod	Production
SECT	Total Specific Energy Consumption
SECTT	Target Specific Energy Consumption
TDP	Total dairy products
TUP	Tulum cheese
YOP	Yoghurt

Symbols and Units

$\dot{m}_c$	Mass flow rate, kg/s
$\dot{m}_{in}$	Total of the mass flow rate input, kg/s
$\dot{m}_{out}$	Total of the mass flow rate output, kg/s
$\dot{m}_{steam}$	Mass flow rate of the steam, kg/s
$\dot{P}_{in}$	Process of work power input, W
$\dot{P}_{out}$	Total energy of the process output, W
$\dot{Q}_{in}$	Process of total heat transfer input, W
$\dot{Q}_{out}$	Process of total heat transfer output, W
$\dot{Q}_{stream}$	Steam heat transfer of the process, W
C_p	Specific heat capacity, J/kg K
$h_{condense}$	Enthalpy of the condense, J/kg
h_{steam}	Enthalpy of the steam, J/kg
I_n	Consumption of the current, A
$\dot{KE}$	Kinetic energy power, W
$\dot{PE}$	Potential energy power, W
U_n	Consumption of the voltage, V
$\dot{U}$	Internal energy, W
z_C	Uncertainty of the result, -
z_j	Uncertainty of the dependent variables, -
η_I	Energy efficiency (1st Law of Thermodynamics), %
R^2	Regression square value, -
T	Temperature, K

Greek Symbols

Σ	total
Δ	difference

Subscripts

in	input
n	process number
out	output
t	tons
y	year

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AUTHORSHIP CONTRIBUTIONS

Authors equally contributed to this work.

DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

REFERENCES

[1] Geary U, Lopez-Villalobos N, Garrick Dj, Shalloo L. An analysis of the implications of a change to the seasonal milk supply profile in the Irish dairy industry utilizing a seasonal processing sector model. J Agric Sci 2012;150:389−407. [CrossRef]

[2] Munir M, Zhang Y, Yu W, Wilson D, Young B. Virtual milk for modelling and simulation of dairy processes. J Dairy Sci 2016;99:3380−3395. [CrossRef]

[3] Madoumier M, Azzaro-Pantel C, Tanguy G, Gésan-Guiziou G. Modelling the properties of liquid foods for use of process flow sheeting simulators: Application to milk concentration. J Food Eng 2015;164:70−89. [CrossRef]

[4] Morales-Mendoza LF, Azzaro-Pantel C. Bridging LCA data gaps by use of process simulation for energy generation. Clean Technol Environ Policy 2017;19:1535−1546. [CrossRef]

[5] Djekic I, Miocinovic J, Tomasevic I, Smigic N, Tomic N. Environmental life-cycle assessment of various dairy products. J Clean Prod 2014;68:64−72. [CrossRef]

[6] Dalgaard R, Schmidt J, Flysjö A. Generic model for calculating carbon footprint of milk using four different life cycle assessment modelling approaches. J Clean Prod 2014;73:146−153. [CrossRef]

[7] Rajendran N, Han J. Techno-economic analysis and life cycle assessment of poly (butylene succinate) production using food waste. Waste Manag 2023;156:168−176. [CrossRef]

[8] Ünal F, Akan AE, Demir B, Yaman K. 4E analysis of an underfloor heating system integrated to the geothermal heat pump for greenhouse heating. Turkish J Agric Forest 2022;46:762−780. [CrossRef]

[9] Ünal F, Temir G, Köten H. Energy, exergy and exergoeconomic analysis of solar-assisted vertical ground source heat pump system for heating season. J Mech Sci Technol 2018;32:3929-3942. [CrossRef]

[10] Khanna A, Kaur S. An empirical analysis on adoption of precision agricultural techniques among farmers of Punjab for efficient land administration. Land Use Policy 2023;126:106533. [CrossRef]

[11] Suryanarayanan R, Sridhar VG, Natrayan L, Seeniappan K, Merneedi A, Sathish T, et al. Improvement on mechanical properties of submerged friction stir joining of dissimilar tailor welded aluminum blanks. Adv Mater Sci Eng 2021;2021:1−6. [CrossRef]

[12] Gu J, Hu M, Wang X, Ji Y, Li L, Yu J, et al. Data mining analysis reveals key acupoints and meridians for the treatment of chemotherapy-induced peripheral neuropathy. Explore (NY) 2023;19:71−77. [CrossRef]

[13] Guna D, Vinodh D. Comparison of material removal rate of AA2014 aluminum alloy using HSS M42 and Titanium Nitride coated drill tools. Mater Today Proceed 2023;77:409−413. [CrossRef]

[14] Kanishka D, Ramesh Kumar G. Compressive strength of novel polymer coated concrete with polypropylene fiber. Mater Today Proceed 2023;77:401−404. [CrossRef]

[15] Sarkar D. Advanced materials management for Indian construction industry by application of statistical process control tools. Material Today: Proceed 2022;62:6934−6939. [CrossRef]

[16] Sarkar D, Bhattacharjee B. Design and application of multivariate CUSUM for quality monitoring of ready mixed concrete. Int J Quality Eng Technol 2014;4(2):161. [CrossRef]

[17] Xue L, Qiu P. A nonparametric CUSUM chart for monitoring multivariate serially correlated processes. Int J Quality Eng Technol 2021;53(4):396−409. [CrossRef]

[18] Ünal F, Bulut H, Kahraman A. Energy and cost analysis of horizontal type corn drying plant using LPG fuel. Dicle Univ J Eng 2020;11(1):161−170. [CrossRef]

[19] Ünal F. Energy and exergy analysis of an industrial corn dryer operated by two different fuels. Int J Exergy 2021;34:475−491. [CrossRef]

[20] Boullosa-Falces D, Gomez-Solaetxe MA, Sanchez-Varela Z, García S, Trueba A. Validation of CUSUM control chart for biofouling detection in heat exchangers. Appl Therm Eng 2019;152:24−31. [CrossRef]

[21] Nawaz M, Maulud AS, Zabiri H, Taqvi SAA, Idris A. Improved process monitoring using the CUSUM and EWMA-based multiscale PCA fault detection framework. Chinese J Chem Eng2021;29:253−265. [CrossRef]

[22] Bellotti M, Qian J, Reynaerts D. Self-tuning breakthrough detection for EDM drilling micro holes. J Manufactur Process 2020;57:630−640. [CrossRef]

[23] Li Z, Paredis CJ, Augenbroe G, Huang G. A rule augmented statistical method for air-conditioning system fault detection and diagnostics. Energy Build 2012;54:154−159. [CrossRef]

[24] Nathaphan S, Therdyothin A. Effectiveness evaluation of the energy efficiency and conservation measures for stipulation of Thailand energy management system in factory. J Clean Prod 2023;383:135442. [CrossRef]

[25] Benedetti M, Bonfà F, Introna V, Santolamazza A, Ubertini S. Real Time energy performance control for industrial compressed air systems: Methodology and applications. Energies 2019;12:3935. [CrossRef]

[26] Fichera A, Volpe R, Cutore E. Energy performance measurement, monitoring and control for buildings of public organizations: Standardized practises compliant with the ISO 50001 and ISO 50006. Dev Built Environ 2020;4:100024. [CrossRef]

[27] Riaz M, Abbas N, Does RJMM. Improving the performance of CUSUM charts. Qual Reliab Eng Int 2011;27:415−424. [CrossRef]

[28] Montgomery DC. Introduction to Statistical Quality Control. 7th ed. New York: John Wiley & Sons; 2013.
[29] Li Y, Deng X, Liu B, Ma J, Yang F, Ouyang M. Energy management of a parallel hybrid electric vehicle based on Lyapunov algorithm. eTransport 2022;13:100184. [CrossRef]
[30] The Union of Chambers and Commodity Exchanges of Turkiye. Industry Directorate, Capacity Criteria 3112 Milk and products capacity calculation. https://tobb.org.tr/Sayfalar/Eng/AmaciveYapisi.php Last Accessed Date 22.09.2023.
[31] Prabhakar P, Srivastav P, Murari K. Energy consumption during manufacturing of different dairy products in a commercial dairy plant: A case study. Asia J Dairy Food Res 2015;34:98. [CrossRef]
[32] Montgomery DC, Peck EA, Vining GG, Introduction to Linear Regression Analysis. 3rd ed. New York: John Wiley & Sons; 2001.
[33] Li J. Nonparametric adaptive CUSUM chart for detecting arbitrary distributional changes. J Quality Technol 2021;53:154−172. [CrossRef]
[34] Huang W, Shu L, Jiang W. A gradient approach to the optimal design of CUSUM charts under unknown mean-shift sizes. J Qual Technol 2016;48:68−83. [CrossRef]
[35] Wen X, Cao H, Hon B, Chen E, Li H. Energy value mapping: A novel lean method to integrate energy efficiency into production management. Energy 2021;217:119353. [CrossRef]
[36] Siddique ARM, Bozorgi M, Venkateshwar K, Tasnim S, Mahmud S. Phase change material-enhanced solid-state thermoelectric cooling technology for food refrigeration and storage applications. J Energy Storage 2023;60:106569. [CrossRef]
[37] Zhang W, Huang J, Zhang T, Tan Q. A risk-based stochastic model for supporting resources allocation of agricultural water-energy-food system under uncertainty. J Hydrol 2022;610:127864. [CrossRef]
[38] Tan Q, Zhang T. Robust fractional programming approach for improving agricultural water-use efficiency under uncertainty. J Hydrolog 2018;564:1110−1119. [CrossRef]
[39] Li M, Fu Q, Singh VP, Ji Y, Liu D, Zhang C, Li T. An optimal modelling approach for managing agricultural water-energy-food nexus under uncertainty. Sci Total Environ 2019;651(Pt 1):1416−1434. [CrossRef]
[40] Jing R, He Y, He J, Liu Y, Yang S. Global sensitivity based prioritizing the parametric uncertainties in economic analysis when co-locating photovoltaic with agriculture and aquaculture in China. Renew Energy 2022;194:1048−1059. [CrossRef]
[41] Zheng Z, Ji L, Xie Y, Huang G, Pan J. Synergic management of crop planting structure and biomass utilization pathways under a food-energy-water nexus perspective. J Clean Prod 2022;335:130314. [CrossRef]
[42] Beck MB, Chen C, Walker RV, Wen Z, Han J. Multisectoral analysis of smarter urban nitrogen metabolism: A case study of Suzhou, China. Ecol Model 2023;478:110286. [CrossRef]
[43] Esen H, Inalli M, Esen M. Technoeconomic appraisal of a ground source heat pump system for a heating season in eastern Turkey. Energy Convers Manag 2006;47:1281−1297. [CrossRef]
[44] Holman JP. Experimental methods for engineers. 7th ed. New York: McGraw Hill; 2001.
[45] Esen M, Yuksel T. Experimental evaluation of using various renewable energy sources for heating a greenhouse. Energy Build 2013;65:340−351. [CrossRef]
[46] Erbay Z, Koca N. Energetic, Exergetic, and Exergoeconomic Analyses of Spray-Drying Process during White Cheese Powder Production. Dry Technol 2012;30:435−444. [CrossRef]
[47] Figliola RS, Beasley D. Theory and Design for Mechanical Measurements. 6th ed. New Jersey: John Wiley & Sons Inc; 2015.
[48] Bobovnik G, Kutin J. Uncertainty analysis of the air velocity standard based on LDA and wind tunnel. Measure 2023;206:112228. [CrossRef]
[49] Cengel YA, Boles MA, Kanoglu M. Thermodynamics: An Engineering Approach. New York: Mcgraw-Hill Education; 2019.
[50] Başaran A, Yılmaz T, Azgın Şükrü T, Çivi C. Comparison of drinking milk production with conventional and novel inductive heating in pasteurization in terms of energetic, exergetic, economic and environmental aspects. J Clean Product 2021;317:128280. [CrossRef]
[51] Solanki A, Pal Y. A comprehensive review to study and implement solar energy in dairy industries. J Therm Eng 2021;7(5):1216-1238. [CrossRef]
[52] Heydari A, Forati M, Khatam SM. Thermal performance investigation of a hybrid solar air heater applied in a solar dryer using thermodynamic modeling. J Therm Eng 2021;7:715-730. [CrossRef]
[53] Margolies B, Adams MC, Pranata J, Gondoutomo K, Barbano DM. Effect of uncertainty in composition and weight measures in control of cheese yield and fat loss in large cheese factories. J Dairy Sci 2017;100:6822−6852. [CrossRef]
[54] Lincoln BJ, Kong L, Pineda AM, Walmsley TG. Process integration and electrification for efficient milk evaporation systems. Energy 2022;258:124885. [CrossRef]
[55] Bühler F, Nguyen T-V, Jensen JK, Holm FM, Elmegaard B. Energy, exergy and advanced exergy analysis of a milk processing factory. Energy 2018;162:576−592. [CrossRef]
[56] Bühler F, Zühlsdorf B, Nguyen T-V, Elmegaard B. A comparative assessment of electrification strategies for industrial sites: Case of milk powder production. Appl Energy 2019;250:1383−1401. [CrossRef]