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Bir Süt Tesisinin Enerji Etüdüne Bağlı Enerji Tasarruf Potansiyelinin İncelenmesi

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ÖZET

Süt ve ürünlerinin gıda sektöründe enerji tüketimindeki payı oldukça yüksektir. Bu nedenle enerji tasarrufu bu sektörde gerçekten önemlidir. Bu çalışmada bir süt işletmesinin enerji denetimine dayalı enerji tasarruf potansiyeli incelenmiştir. Öncelikle işletmenin mevcut enerji tüketimine göre oluşturulan standart ve hedef denklemlerle enerji tasarruf potansiyeli belirlenmiştir. Enerji tüketen cihazlarda bazı ölçümler yapılmıştır. Ölçümlerle verimli çalışmayan cihazlar ve enerji kaçağı olan noktalar belirlenmiştir. Enerji tasarrufu için bazı projeler önerilmiştir. Önerilen projeler sayesinde yıllık 332,51 TEP (ton eşdeğer petrol) enerji tasarrufu sağlanacağı belirlenmiştir. Ayrıca oluşturulan sonuç denklemiyle önerilen projelerin enerji tasarrufunda faydalı olabilmesi için işletmenin üretiminin 3810 Ton/Ay altına düşmemesi gerektiği anlaşılmıştır.

Examining the Energy Saving Potential of a Dairy Enterprise Based on an Energy Audit

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ABSTRACT

The share of milk and its products in terms of energy consumption in the food sector is quite high. Therefore, energy saving is really important in this sector. In this study, the energy saving potential of a dairy enterprise was examined based on energy audit. First, energy saving potential was determined with standard and target equations that were generated according to the current energy consumption of enterprise. Some measurements were made on energy-consuming devices. The devices that do not work efficiently and points with energy leakage have been determined with the measurements. Some projects were suggested for energy saving. It was determined that 332.51 TOE (tons of oil equivalent) of energy would be saved annually thanks to the suggested projects. It was also understood, with the result equation generated, that the production of the enterprise should not fall below 3810 Tons/Month in order the suggested projects to be useful in energy saving.

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INTRODUCTION

For centuries, energy has been one of the indispensables of humanity. Energy has a large share of all our needs and its use is increasing day by day. That's why generating energy with the least harm to our environment and using it in the most efficient way has become the subject of very different scientific disciplines. For example, while the reuse of coal waste in energy generation is a subject of materials engineering, designing buildings according to minimum energy needs is a subject of architecture [1,2].

Energy audit is one of the most popular methods to examine the efficient use of energy. It has a large scale of application for residences, hotels, hospitals and factories etc. Energy audits have become mandatory in many countries in businesses with high energy consumption. According to the law prepared by the Ministry of Energy and Natural Resources in Turkey, in the industrial facilities with an average energy consumption value of 1000 TOE (tons of oil equivalent) or more for the last three years or with a total construction area more than 20,000 m², in the commercial enterprises with an energy consumption above 500 TOE or with a total construction area more than10,000 m², in the public buildings with an energy consumption of 250 TOE and in the facilities generates electricity above 100 MW is mandatory to appoint an energy manager. [3].

According to the Food and Agriculture Organization (FAO) reports, world milk production in 2023 is approximately 950 million tons [4]. Turkey is one of the leading countries in milk production. It is the 8th largest milk producer in the world and the 3rd largest milk producer in Europe. Total milk production in 2021 is determined as 23.2 million tons [5]. Therefore, it is important to reduce the energy consumption of dairies by researching energy saving methods in that sector.

A high amount of energy is used in dairy and other food industries processing, manufacture and storage of various products [6-7]. So, the use of energy and its saving is one of the important subjects of the dairy sector. The energy audit and analysis of energy saving potential in the dairy sector have been carried out by some researchers. Of these, Altan and Kayışoğlu [8] conducted an energy audit in a raw milk production enterprise in Tekirdağ province and identified energy saving opportunities by making cost analyzes of efficiency-increasing projects. They determined that there will be an energy saving potential of 16 kW through the implementation of some energy saving projects. Josijević et al [9] conducted a case study for a medium dairy production company from Central Serbia. They determined that the proposed energy conservation measures can ensure 11-15% energy savings for electricity and 20-23% of heat energy annually. Boutaghriout et al [10] carried out the energy use and cost analysis of three dairies in Algerian that their main energy sources were electricity and natural gas. They suggested the possibilities of replacing old pumps with high-efficiency ones and integrating solar thermal energy into the system. Söğüt et al [11] developed energy consumption equations for a tomato paste factory based on its production and energy consumption data. They calculated that the energy saving potential of the enterprise at a rate of 10.13% depending on the specific energy consumption. Işık and Akan [12] carried out the energy saving study of the industrial double face sheepskins manufacturing plant. They calculated that the energy saving potential of the enterprise can be realized as 9.9%, that is, 36,168 TOE per year. Aydın and Çankaya [13] examined energy consumption of an enterprise with an annual energy consumption of over thousand TOE in the food sector. They determined 128 TOE annual energy savings thanks to some proposed solutions.

In this study, the energy saving potential of a dairy enterprise with an annual energy consumption above 1000 TOE was examined based on energy audit. Within this scope, energy consumption data of the enterprise was obtained and its energy saving potential was determined with standard and target equations that were generated according to the current energy consumption of enterprise. By making some measurements on energy consuming devices, the inefficient devices and points where energy leaks were determined. Some projects were suggested for energy saving. According to the projects to be

implemented, the annual energy saving amount of the business and how much of the energy saving potential of the business can be achieved have been determined.

MATERIALS AND METHODS

The enterprise where energy audit was conducted is a dairy facility with a daily milk processing capacity of 900 tons and the primary product group being milk powder, as well as producing cheese, kashar, butter, clarified butter, cream, yoghurt and derivatives. Natural gas and electrical energy are used as energy sources in the facility. Within the scope of the energy audit, first, the energy consumption amounts of the enterprise in the last three years were determined. Subsequently, the energy consumption points of the enterprise were determined, and their energy performances were measured with some devices such as energy analyzer, compressed air flow meter, thermal camera, flue gas analyzer, ultrasonic liquid flow meter, air quality probe, ultrasonic leak detector, pitot tube and propeller speed probe. The brands and intended uses of the measurement devices used in the energy audit are presented in Table 1.

Table 1
The brands and intended uses of the measurement devices

	Purpose of the measurement	Device	Brand of the device
Boilers	Determination of heat losses	Thermal camera	Testo 883-2
	Determination of flue gas components	Flue gas analyzer	Nova Plus
	Determination of linear velocity of fluid	Speed Probe	Testo/440 dP
Insulation	Determination of liquid temperature	Immersion Temperature Probe	Testo 435
	Determination of heat losses	Thermal camera	Testo 883-2
	Determination of surface temperature	Surface Temperature Probe	Testo 435
Compressors	Determination of air flow rate	Compressed air flow meter	VP Instruments/VPS
	Determination of compressed air leakage	Ultrasonic leak detector	UE Systems /UP3000SL
Electric Motors	Determination of energy consumption, harmonics and power factor	Energy analyzer	Fluke / 1732
	Determination of power consumption	Clamp ammeter	Unit Clamp Ammeter
Pumps	Determination of energy consumption, harmonics and power factor	Energy analyzer	Fluke / 1732
	Flow measurements	Ultrasonic liquid flowmeter	GE Transport / PT 878
Cooling	Determination of energy consumption	Energy analyzer	Fluke / 1732
	Flow measurements	Ultrasonic liquid flowmeter	GE Transport / PT 878
Fans	Determination of linear velocity of fluid	Speed Probe	Testo/440 dP
Lightings	Determination of lightening	Luxmeter	UNIT Luxmeter

Energy Saving Projects

Depending on the measurements, the energy audit study was evaluated under eight main projects in the inefficient devices and points where energy leaks were determined.

Boilers

There are two natural gas-fired steam boilers in the enterprise: Selnikel boiler and Theta boiler. The efficiencies and waste heat potentials of the boilers were determined according to the measurements.

To determine the efficiency of the boiler system, flue gas content and temperature were measured with a flue gas analyzer in the boiler chimneys. The linear velocity must be known to determine the flue gas flow rate. Dynamic pressure was measured with a pitot tube to determine the linear velocity. Chimney dimensions were also measured. The surface temperatures of the boiler were measured with a probe to determine the thermal losses on the surfaces. The boiler efficiencies were calculated with the following equation:

$$\mu_b = \frac{m_b * i_b - m_s * i_s}{B * H_u} \quad (1)$$

$\boldsymbol{\mu_b}$: Boiler efficiency, $\boldsymbol{m_b}$: Steam flow rate (kg/h), $\boldsymbol{m_s}$: Water flow rate (kg/h), $\boldsymbol{i_b}$**:** Steam enthalpy (kcal/kg), $\boldsymbol{i_s}$: Feed water enthalpy (kcal/kg), **B**: Fuel flow rate (kg/h), $\boldsymbol{H_u}$: Fuel lower heating value (kcal/kg)

The waste heat amount of the boilers was calculated with the following equation:

$$Q = m * (c_1 * T_1 - c_2 * T_2) \quad (2)$$

Q: Waste heat amount (kcal), $\boldsymbol{m}$: Air/Water flow rate (kg/h), $\mathbf{c_1}$**,** $\mathbf{c_2}$: Air/Water specific heat (kcal/Nm^3°C), $\mathbf{T_1}$ **,** $\mathbf{T_2}$: Heat transfer fluid temperatures (°C)

As a result, it was concluded that it was necessary to apply combustion adjustment to the Theta steam boiler, to apply an economizer to the Selnikel boiler and to operate the Theta steam boiler as the primary boiler.

Insulation

Energy leaks in the prosses were measured with a thermal camera and surface temperature probe. The heat losses were calculated with the following basic heat transfer equations. The target surface temperature intended to be at 50ºC after insulation. According to the calculations, some insulation applications were suggested for valves, hot lines and surfaces in order to prevent heat losses.

$$Q_C = U * (T_1 - T_1) \quad (3)$$

$$Q_R = \varepsilon * \sigma * (T_1^4 - T_3^4) \quad (4)$$

$\boldsymbol{Q_C}$: Heat flow density by conduction and convection (W/m²), $\boldsymbol{Q_R}$: Heat transfer by radiation (W), $\mathbf{T_1}$: Surface temperature (K), $\mathbf{T_2}$: Ambient Temperature (K), **U**: Heat transfer coefficient by conduction and convection (W/m²K), **σ**: Boltzmann's constant (5,67 x 10^{-8} W/m²K⁴), **ε**: Emission Coefficient (0< ε<1), $\mathbf{T_3}$: Ambient wall temperature (K)

Compressors

There are three compressors in the enterprise: two active and one spare. Electrical and mechanical measurements were conducted for compressors and air lines. Electrical measurements included measurements of electric motors that drive the compressors. Mechanical measurements included measurements of pressure, temperature values, air flow rates and air leaks of compressors. The amount of electricity consumed in the compressors was measured with an energy analyzer. The amount of air leaks and power loss of compressors were calculated with the following equation. Periodic inspection and maintenance are recommended to prevent air leaks.

The amount of leakage is determined with the following equation:

$$\dot{L} = \frac{\dot{C} * t_1}{t_1 + t} \quad (5)$$

L̇: The amount of air leakage (lt/s), **Ċ**: Compressor Capacity (lt/s), $\mathbf{t_1}$: Compressor loaded working time (s), **t**: Compressor unloaded working time (s)

The power loss in compressor was calculated with the following equation:

$$P = \frac{\dot{L}}{3}(kW) \quad (6)$$

Electric Motors

The power of electric motors was measured with an energy analyzer from the electrical supply panels. Annual energy consumption was determined with the following equations. In measurements, the number of motors, label value, power consumption, efficiency and operating hours were taken into consideration. As a result, it was recommended to replace the existing electric motors with high-efficiency electric motors.

$$P_{m,n} = A * V * 1{,}73 * LF \quad (7)$$

$$P_{m,i} = \frac{P_{m,n}}{\mu_m} * 100 \quad (8)$$

$$AC = P_{e,i} \times h_a \quad (9)$$

$\mathbf{P_m}$: Nominal motor power (kW), **LF**: Load factor, $\mathbf{P_{m,i}}$: Instantaneous motor power (kW), $\boldsymbol{\mu_m}$: Motor efficiency, $\mathbf{h_a}$: Annual working hours, **AC**: Annual energy consumption (kWh)

Pumps

Flow rates, fluid pressures, fluid temperatures and active power values of the pumps were determined with flow meters, manometers, thermometers and electrical supply panels to determine their efficiency with the following equations. As a result of measurements, it was recommended to replace low-efficiency pumps in the system with more efficient pumps.

$$P_P = \frac{\rho * g * Q * H}{1000 * \mu_p} \quad (10)$$

$\mathbf{P_P}$: Pump shaft power (kW), **ρ**: Density of fluid (kg/m^3), **g**: Gravitational acceleration, **Q**: Flow rate (m^3/s), **H**: Total differential height (m), $\boldsymbol{\mu_p}$: Pump efficiency

Cooling

The cooling load and COP (coefficient of performance) of the chillers were determined according to the measurements. It has been determined that the cooling load and COP value of chillers was slightly below the ideal levels. So, no project was recommended for cooling units.

$$COP = \frac{\dot{m} * (i_o - i_i)}{P_{chill}} \quad (11)$$

$\boldsymbol{\dot{m}_b}$: Refrigerant flow rate (kg/s), $\boldsymbol{i_i}$: Refrigerant evaporator inlet enthalpy (kcal/kg), $\boldsymbol{i_o}$**:** Refrigerant evaporator outlet enthalpy (kcal/kg), $\mathbf{P_{chill}}$: Chiller power (kW)

Fans

There were five tower units in the enterprise that produced milk powder and whey powder. There was a chimney fan in each tower. Mechanical and electrical measurements were carried out to examine the operating regime of the fans and determine their total efficiency. The efficiency of fans was determined with the following equations. The results were compared with higher efficiency fans. Then, it was suggested to replace the fans with more efficient fans.

$$\mu_{total} = \mu_f * \mu_{ds} * \mu_{em} \quad (12)$$

$$P_f = \frac{\Delta p * V * A}{3.600 * 102} \quad (13)$$

$$\mu_f = \frac{P_f}{P_s} \quad (14)$$

$$\mu_{ss} = \frac{P_s}{P_{em}} \quad (15)$$

$$\mu_{em} = \frac{P_{em}}{P_e} \quad (16)$$

$\boldsymbol{\mu_{total}}$: Total efficiency (%), $\mathbf{P_f}$: Fan power (kW), **V**: Velocity (m/s), **A**: Cross Section Area (m²), **ΔP**: Pressure Difference (mmSS), $\mathbf{P_s}$: Shaft power power (kW), $\boldsymbol{\mu_f}$: Fan efficiency (%), $\mathbf{P_{em}}$: Elektrik motoru gücü (kW), $\boldsymbol{\mu_{ss}}$: Shaft system efficiency (%), $\mathbf{P_e}$: Power from the grid (kW), $\boldsymbol{\mu_{em}}$: Electric motor efficiency (%)

Lighting

There were 280 lighting armatures with 2x18 W power in the enterprise. It is recommended to replace old types with LEDs that can provide the same function with less energy consumption. Annual energy saving was determined with the following equation:

$$E_{a,s,l} = (P_{led} - P_{std}) * t_{a,lig} \quad (17)$$

$\mathbf{E_{a,s,l}}$: Annual lighting saving(kWh), $\mathbf{P_{LED}}$: LED lighting armature power (W), $\mathbf{P_{std}}$: Standard lighting armature power (W), $\mathbf{t_{a,lig}}$: Annual lighting time (h)

Determination of Energy Saving Potential

First, the standard and the target equations and lines were created according to current monthly production and energy consumption amounts. Then, the annual energy saving of the enterprise to be achieved through the implementation of the projects was determined. The projects result equation and line were created according to annual energy saving values. Lastly, it was evaluated how close to the targeted energy saving could be achieved with the help of target and projects result lines.

RESULTS AND DISCUSSIONS

The monthly average production and energy consumption data of the enterprise for the last three years were determined within the scope of energy audit. The average monthly production and energy consumption values of the enterprise for three years were presented in Table 2. The annual average production of enterprise was 44378 tons. The total energy consumption of the business was 5666 TEP, including 1453 TEP electricity and 4243 TEP natural gas. The distribution of the energy types used in the enterprise is given in Figure 1. It was determined that 74.9% of the energy consumption was natural gas while 25.1% was electricity.

Table 2

The production and energy consumption values of enterprise

Months	Production TON	Electricity TOE	Natural Gas TOE	Total TOE
January	3690	116	478	594
February	3732	107	404	511
March	4065	117	450	567
April	4410	114	445	560
May	3968	126	374	500
June	3960	128	365	493
July	3751	144	259	402
August	3541	140	228	368
September	3424	126	251	377
October	3315	101	288	390
November	3202	92	345	437
December	3319	112	355	467
TOTAL	44378	1423	4243	5666

Energy Saving Projects

Depending on the measurements, the energy audit study was evaluated under eight main projects in the inefficient devices and points where energy leaks were determined

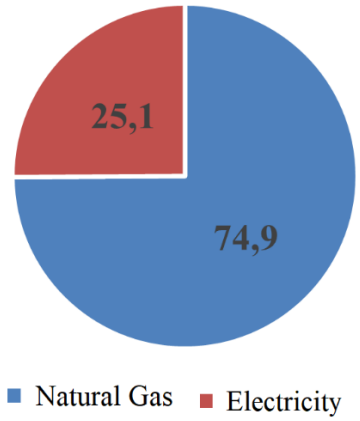

Figure 1
Distribution of energy consumption types

The annual energy saving values to be achieved by the implementation of the projects were presented collectively in Table 3. It was calculated that with the proposed projects, 332.51 TOE can be saved annually from natural gas energy and 133.69 TOE from electricity. It has been determined that by realizing these projects, a profit of $654460 can be saved as a result of an investment cost of $545082. It was seen that the highest energy gain among the projects will be with the application of economizer to the Selnikel steam boiler with 199.96 TOE. Although this application has an investment cost of $81382 it has been recommended that it should be a priority project with a very short payback period of 0.4 years. The change of compressors can be postponed due to its low energy savings and long payback periods. In general, a ranking can be made in the implementation of projects by taking into account the payback periods.

The energy consumption values of the current, targeted and after the project's situations depending on the monthly production amounts were presented in Table 4. The sum of annual energy consumption in the current situation by natural gas and electricity was determined as 5666 TOE. The standard equation has been created according to the monthly production and energy consumption amounts in the current situation. The standard equation was found to be y=0.1408x-48.676 with the regression compatibility coefficient of R^2=0.42. The target equation relation was obtained as y=0.1858x-258.72 by using the points under the standard line. The target line was created by applying all monthly production values to the target equation. The target line expresses the amount of ideal energy consumption depending on the monthly production. The annual energy saving that corresponds to 9.2% of annual energy consumption was determined as 525 TOE according to the target equation. The monthly energy consumption values after the implementation of projects were determined by subtracting the monthly saving from the current energy consumption values. It has been determined that as a result of the implementation of the projects 466.2 TOE annually and 38.85 TOE monthly energy savings will be achieved. The projects result equation was determined as y=0.1408x-87.526. Standard, target and projects result lines and equations are presented in Figure 2-4 depending on monthly production and energy consumption values. The energy saving after the projects was determined to be 8.2% of annual energy consumption.

Table 3
Total results of the energy savings projects

	Projects	Annual Energy Saving Potential (TOE)		Benefit and Investment Cost of the Project ($)		Payback Period (Year)
		Natural Gas	Electricity	Benefit	Investment Cost	
Boilers	Applying Combustion Adjustment to Theta Steam Boiler	39.43		40969	1595	0.04
	Economizer Application to Selnikel Steam Boiler	199.96	-	206962	81382	0.40
	Application of Operating Theta Steam Boiler as Primary Boiler	59.92	-	62265	-	-
Insulation	Insulation on Valves, Lines and Surfaces	33.20	-	34495	18771	1.65
Compressors	Replacement of Compressors	-	31.77	74287	239866	6.45
	Elimination of Losses and Leaks in Compressed Air Lines	-	26.29	61469	-	-
Electric Motors	Replacement of Electric Motors	-	41.86	96308	57527	0.60
Pumps	Replacement of Electric Pumps	-	18.29	42072	62223	4.85
Cooling Fans	No project was suggested.					
	Replacement of Fans	-	11.84	27256	71069	13.67
Lightings	Replacement of Armatures	-	3.64	8377	12649	1.51
	TOTAL	332.51	133.69	654460	545082	

Table 4
The energy consumptions of the current, targeted and projects result situations

	Current		Targeted		Projects Results	
	Production	Consumption	Consumption	Saving Potential	Consumption	Saving
	TON	TOE	TOE	TOE	TOE	TOE
January	3690	594	427	167	555	38.85
February	3732	511	435	77	472	38.85
March	4065	567	497	70	528	38.85
April	4410	560	561	-1	521	38.85
May	3968	500	479	22	462	38.85
June	3960	493	477	16	454	38.85
July	3751	402	438	-36	364	38.85
August	3541	368	399	-31	329	38.85
September	3424	377	377	-1	338	38.85
October	3315	390	357	32	351	38.85
November	3202	437	336	101	398	38.85
December	3319	467	358	109	428	38.85
TOTAL	44378	5666	5141	525	5200	466.2
PERCENTAGE				9.2%		8.2%

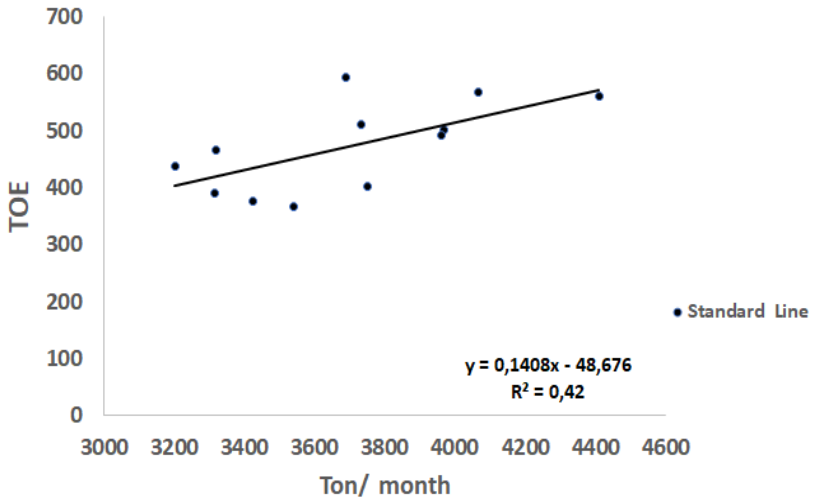

Figure 2
The standard equation and line

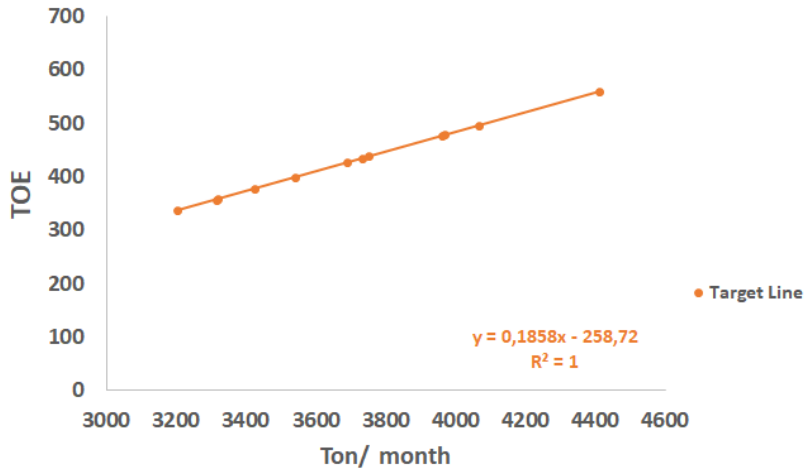

Figure 3
The target equation and line

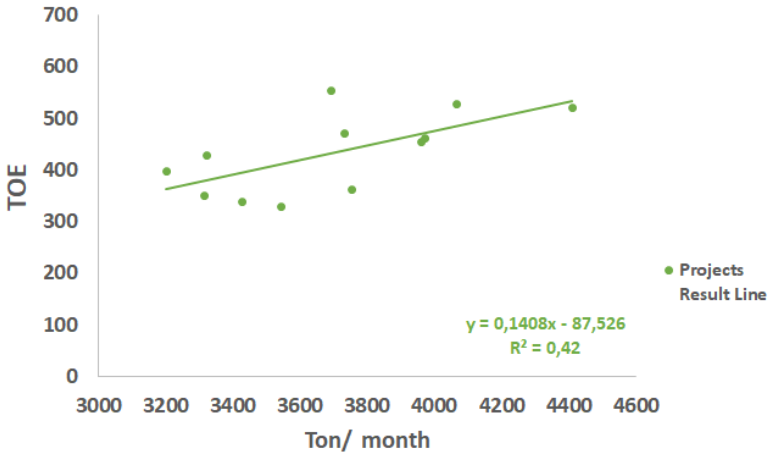

Figure 4
The Projects result equation and line

As a result of the energy audit study, it was determined that the targeted annual energy saving was 525 TOE as 9% of annual energy consumption. It has been calculated that the energy savings of the enterprise will be 466.2 TOE as 8.2% of annual energy consumption according to implementation of the projects. That means that the targeted energy saving is near to be approached. In addition, the combination of the standard, target and projects result equations and lines are presented in Figure 5.

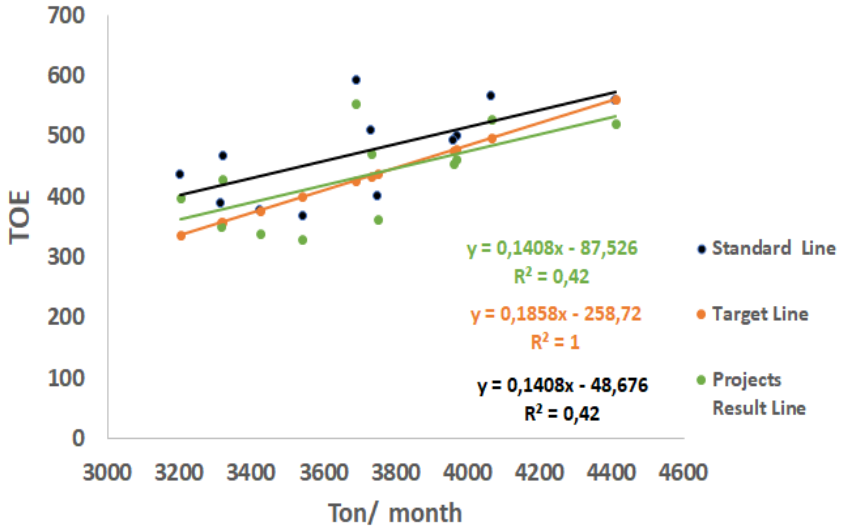

Figure 5
Combination of the standard, target and projects result equations and lines

A monthly production value was determined as 3810 Tons/Month at the intersection of the target and the project's result lines. That means that the proposed projects do not provide the targeted energy savings below that production amount, however they cause them to exceed the targeted energy saving above that amount. In this case, to reduce the effect of constant energy consumptions, independent of the production amount, the monthly milk process should not be less than the mentioned amount. In addition to the eight projects proposed to improve the current situation in the enterprise, additional energy input can be provided by installing solar energy systems that produce both heat and electricity. In this case, it will be possible to exceed the targeted savings values.

Ethical Statement
This study is derived from a master's thesis entitled "ENERGY AUDIT OF A MILK PROCESSING PLANT" by İsmail Buğrahan ÖZSAN, submitted under the supervision of Assistant Professor Dr. Fatih AKKURT in January 2024.

Author Contributions
Research Design (CRediT 1) F.A. (%50) – İ.B.Ö. (%50)
Data Collection (CRediT 2) F.A. (%20) – İ.B.Ö. (%80)
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