A model of energy management analysis, case study of a sugar factory in Turkey

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Abstract. This study presents a case study of energy management in a sugar factory in Turkey. The main idea of the study is to analyse energy consumption, the quantity of material production, and figure out a suitable energy efficiency for the case study of a sugar factory subsequently. Firstly, a material production and energy consumption audit were performed for the sugar factory. Secondly, energy efficiency was calculated from the energy data. The SPSS (Statistical Package for the Social Sciences) statistical software was used to ensure the accuracy of the data. The factory's energy consumption was calculated as 43,590.25 toe (tons of oil equivalent) over the last year. These results were used for CUSUM (Cumulative Sum Deviation Method) graphics. This research poses the consumption of energy, cost of energy and the relationship between energy usage and material production of sugar. The unit of energy cost was 688.22 [\$/toe] for the last year. This result showed that the factory decreased the unit of energy by optimisation. The results indicated that the investigated sugar factory should pay attention to the energy management issue in order to comply with the Energy Efficiency of Turkish Law and Directives.

Keywords. Energy management; CUSUM; consumption of energy; material production; SPSS statistical software; data accuracy.

1. Introduction

Energy management is an important issue for the Turkish food industry. The Turkish economy depends on sugar material production strongly, and the world's most important sugar factory is located in Turkey. A high quantity stream of energy that is important for a sugar factory should be managed in tandem.

In this study, it was posed a case study of energy management in a sugar factory in Turkey. The main idea of this study is to analyse energy consumption, the quantity of material production, and figure out a proper energy efficiency for the case study of a sugar factory respectively. Once, it was investigated a material production and energy consumption audit for the sugar factory. Then, energy data

was taken for the calculation of energy efficiency for the factory. The accuracy of the data was verified by using the SPSS (Statistical Package for the Social Sciences) statistical software.

Finding the results referred, as the sugar factory should watch out the energy management issue because of respect to the Energy Efficiency of Turkish Law and Directives. Sugar factories are very significant for the Turkish economy. In this study, Çumra Sugar Integrated Plant, which is one of the integrated facilities in the food sector of Turkey and the World, was chosen for the research of energy management. This study was supported by a Scientific Research (Date of work: February 2010 to January 2013) for the case of a sugar factory in Turkey.

Palensky and Dietrich [1] defined energy management as a means to optimise the energy system. They stated that industry and research groups have been working to

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optimise energy material production (energy generator) and energy dispensing in the factory for energy conservation.

Wang [2] described the phase of energy management as follows: After energy consumption data have been accumulated and analysed and the energy movement plan for energy savings has been recommended for the plant, an energy management program should be set up to implement the audit advice. The report should begin with an executive summary that provides the manager of the facility with a briefing of the total savings available and the highlights of each energy saving opportunity. The report can begin with an executive summary that provides a manager of the facility with a brief of the total savings available and the highlights of each energy saving opportunity. The report should describe the facility that has been audited and provide information on the operation of the facility that is related to energy costs. The energy costs can be analysed. Energy saving opportunities are recommended along with the analyses of the associated costs and benefits and the cost effectiveness [2].

Taner and Sivrioglu [3] indicated that sugar factories need more energy due to their product processing. Abdelaziz *et al* [4] clarified as energy is a vital factor for the economic competition capacity and employment. Petrecca [5] indicated that energy management should include four main sections. These sections are data of the production and energy consumption, audit of energy and accounting, analysis of energy (feasibility study for investment cost), and personnel training and information [5]. A strategy of appointment energy demand is an important issue for energy management. Throttling and optimizing energy using systems may result in procedures with a view to decrease energy demands per unit of output while maintaining or decreasing the total costs of material production output in the system [4, 5].

When energy values increased and indicated the upcoming depletion of world energy resources, energy management became a significant function of a management of the industrial in the 2000s. Taner [6] remarked that energy consumption must be analysed carefully and determined the energy efficiency of a production of food processes.

Nowadays, a role of the energy management has expanded into industry. Kannan and Boie [7] found that energy management is disadvantageous for monetary, social and ecological causes in all industries. The senior management of firms plan various energy management projects regularly. Many factories refer to their energy saving events specifically in their annual reports. In order to be successful, energy management should include 4 major parts as a historical data analysis, an audit of energy and cost, an engineering analysis of investments based on the recommendations of the feasibility study, engineering analysis of investments based on the recommendations of the feasibility study, and staff's training and their knowledge [4, 5, 7].

Several previous studies performed in the energy management field. For instance, Giacone and Manco [8] focused on energy management to control the consumption and cost of energy. Bunsea *et al* [9] defined energy management as useful regarding a factory for economic, environmental and social reasons. Tanaka [10] measured energy efficiency performance (energy consumption) in his study. Gielen and Taylor [11] found that energy is a key production factor in many industries. Palamutcu [12] remarked that one of the greatest energy costs is electric energy for factories. Taner [13] showed that energy consumption was important for the calculation of energy management. It should be noted that the General Directorate of Renewable Energy [14] is an official organisation that helps Turkish factories with research into energy saving. Ramirez *et al* [15] conducted a cross-country consumption of energy analysis and analysis of energy efficiency for the dairy industry in four European countries. Ramirez *et al* [16] used energy and physical production data to develop energy efficiency indicators for the meat industry. Xu *et al* [17] studied energy usage in existing cheese markets and compared to the energy performance of individual plants and systems. Dörr *et al* [18] defined energy performance as energy efficiency, energy use and consumption. Zhang *et al* [19] surveyed an empirical relationship between economic development and consumption of energy by material production, nonmaterial production and households. The Department of Minerals and Energy Pretoria [20] defined energy management as an important component of an effective energy management strategy. Morvay and Gvozdenac [21] presented a model of efficient energy performance in the industrial plants. Beggs [22] included data analysis techniques that are generally used in the energy management programmes. The Sustainable Energy Authority of Ireland [23] indicated the importance of an energy manager in the energy management programme. The energy manager should not manipulate the energy and energy cost data [23]. Blatt [24] focused on the impact of energy efficiency on energy management. Turner and Doty [25] defined energy management as a significant role to support many factories.

In this study, energy management defines energy performance. Several similar studies have been performed. Chen *et al* [26] described energy management as the factor by which energy performance can vary. Reilly *et al* [27] investigated the energy performance of a building. Mavromatidis *et al* [28] presented diagnostic tools for the energy performance of supermarkets. Diaz *et al* [29] provided a comparison of the energy performance in buildings. Gul and Patidar [30] examined the optimum energy performance of a building. Granderson *et al* [31] described energy performance data as being important to national efforts to improve building efficiency.

A sugar factory was chosen for this study because of the importance of sugar factories in Turkey. It is a significant factory and is one of the integrated facilities in the food

Figure 1. Detailed photos of the sugar factory.

sector of Turkey and the World. This study was supported by a Scientific Research (Date of work: February 2010 to January 2013) for the case of a sugar factory in Turkey. This study was carried out in Çumra Sugar Integrated Plant. The energy data were taken with permission from the factory administration having in collaboration with the Department of Factory Central Monitoring and Directorate of Maintenance and Energy. The investigated sugar factory is a liquid sugar plant, bioethanol plant and other sugar production plant. The annual production of crystal sugar is 280,000 tonnes, the annual production of cube sugar is 100,000 tonnes, the annual production of liquid sugar is 140,000 tonnes, the annual production of chocolate is 2,000 tonnes, the annual production of brown sugar is 2,160 tonnes, the annual production of bioethanol is 84,000,000 litres, and the annual production of brown sugar is 2,160 tonnes. The beet processing capacity is 170 tonnes per day. The total investment cost of the sugar factory is \$340,000,000.

Detailed photos of the sugar factory are shown in figure 1. At the top of the photo is a general view of the factory. At the bottom of the left photo is power plant energy turbine. The bottom right photo is a fluidized bed boiler.

Previous similar studies also used SPSS (the Statistical Package for the Social Sciences) software for the analysis of the energy management data. In this study, data of energy consumption and production of the factory were controlled before any comparisons. These results were analysed in SPSS for the data's distribution.

Chen *et al* [26] performed statistical analysis of the parameters using the SPSS software. Chen *et al* [32]

remarked that SPSS was one of the most popular software packages in statistics. Aranda *et al* [33] performed graphical and regression analysis by using Minitab and SPSS. Turhan *et al* [34] indicated a SPSS solution for evaluation, estimation and prediction, and developed regression models with good accuracy. Huebner *et al* [35] used the detailed results of the ANOVA (Analysis Of Variance) from the SPSS software. Orosa and Oliveira [36] also used the ANOVA method for their energy data. Choi *et al* [37] analysed their collected data via SPSS software. Kalayci [38] referred to SPSS in detail. Aksozen *et al* [39] exploited SPSS software for their energy consumption data. Farreny *et al* [40] conducted analysis with the aid of PASW (Predictive Analytics Software) Statistics 17 from SPSS software. Farreny *et al* [40] defined statistical analysis including descriptive statistics, variance analysis, correlation analysis, curvilinear estimation and lineal multiple regression. Chen *et al* [41] used the SPSS software for model calculation. All of these studies were compared each other in this study.

CUSUM (Cumulative Sum Deviation Method) is a numerical calculation for energy consumption analysis that determines the annual energy efficiency for factories. Similar studies use the cumulative sum (CUSUM). These previous studies are as follows:

Sun and Anwar [42] and Bastola and Sapkota [43] described CUSUM as the cumulative sum. CUSUM can examine the stability of the estimated model [42]. Farhani *et al* [44] used CUSUM to determine the stability in the parameters of the selected model. Lin and Moubarak [45] and Lim *et al* [46] testified to the stability of the model by using the cumulative sum (CUSUM) and CUSUMSQ (cumulative sum of squares test) of recursive residuals tests. Braga *et al* [47] also used the cumulative sum (CUSUM) to analyse the channel residuals. Ouyang and Lin [48] employed the cumulative sum of recursive residuals (CUSUM) and the CUSUM of squares (CUSUMSQ) to determine parameter balance. Wang *et al* [49] used the standard CUSUM control charts to view the residuals that were statistically independent.

Besides, many methods can be used in the energy management issues that are the various evolutionary algorithms like Genetic Algorithm, Particle Swarm Optimization, and Ant Colony Optimization etc. for solving the problems related with modelling of energy management analysis in previous literature. The application of evolutionary algorithms can be useful for considered problem. A multi-objective evolutionary algorithm was investigated for energy management of agricultural systems by Shamshirband *et al* [50]. Mogale *et al* [51] indicated a multi-period inventory transportation model for tactical planning of food grain. Mogale *et al* [52] researched the multi-period multi-modal bulk wheat transportation and storage problem in a two-stage supply chain network of PDS (Public Distribution System). Banos *et al* [53] posed in computational optimization methods applied to renewable and sustainable

Table 1. Material production – consumption and energy equation table.

Period	Year/months	Material production P_i [t]	Energy consumption E_j [Gcal]	P_i^2	E_j^2	$E_i \times P_i$
1	January	P_1	E_1	P_1^2	E_1^2	$E_1 \times P_1$
2	February	P_2	E_2	P_2^2	E_2^2	$E_2 \times P_2$
3	March	P_3	E_3	P_3^2	E_3^2	$E_3 \times P_3$
4	April	P_4	E_4	P_4^2	E_4^2	$E_4 \times P_4$
5	May	P_5	E_5	P_5^2	E_5^2	$E_5 \times P_5$
6	June	P_6	E_6	P_6^2	E_6^2	$E_6 \times P_6$
7	July	P_7	E_7	P_7^2	E_7^2	$E_7 \times P_7$
8	August	P_8	E_8	P_8^2	E_8^2	$E_8 \times P_8$
9	September	P_9	E_9	P_9^2	E_9^2	$E_9 \times P_9$
10	October	P_{10}	E_{10}	P_{10}^2	E_{10}^2	$E_{10} \times P_{10}$
11	November	P_{11}	E_{11}	P_{11}^2	E_{11}^2	$E_{11} \times P_{11}$
12	December	P_{12}	E_{12}	P_{12}^2	E_{12}^2	$E_{12} \times P_{12}$
Year	Total	ΣP_i	ΣE_j	P_i^2	E_j^2	$\Sigma E_j P_i$

energy. Maiyar and Thakkar [54] figured out particle swarm based optimization approach for a combined tactical and operational two-stage food grain transportation model. Mendes *et al* [55] investigated on the planning and analysis of Integrated Community Energy Systems. De *et al* [56] used PSO (Particle Swarm Optimization) – DE (Differential Evolution), GA (Genetic Algorithm) to validate their result of the study. Fong *et al* [57] researched HVAC (Heating, Ventilating and Air Conditioning) system optimization for energy management by evolutionary programming. Ene *et al* [58] studied a genetic algorithm for minimizing energy consumption in warehouses. Elsied *et al* [59] posed an advanced real time energy management system for microgrids in their study. Ruiz *et al* [60] studied a genetic algorithm for building envelope calibration. Paulo *et al* [61] and Benet *et al* [62] investigated genetic algorithms for maintenance plan optimization in these studies.

In this study, calculations of data analysis are an important issue for suggestions of energy saving to the management of factory. In addition, accurate and reliable data is crucial for energy management calculations. Therefore, SPPS was used to ensure the data's accuracy in this study (See in Appendix). Moreover, it can be said that the aim of an energy audit is to minimize the cost of energy, raw material and water. Thus, an audit can be useful in energy management for energy performance.

2. A thermo-economic model on the calculation of energy consumption, material production and drawing the CUSUM chart

Controlling the energy consumption and cost of processes is a boarding significant step for the energy efficiency survey. Therefore, there are many studies on energy efficiency and the use of energy in industries, recently [8–12]. Energy consumption, SEC (specific energy consumption), a

material production amount and energy efficiency are calculated from these literature studies [7, 20, 22, 23, 25].

Energy consumption and a material production of the factory are shown in table 1. Hereby, energy consumption means all of the energy used (electricity energy consumption, fuel consumption and other energy consumption) by the factory. Total energy consumptions are the sum of all energy consumptions in the same units for 12 months. Material production is the sum of the material production amounts in the same units for 12 months. In table 1, the material production and energy consumption amounts are calculated by the constants a and b. These variables are determined by the recursive least squares method. Thus, the energy equation can be obtained from this method.

The least squares method can be used to determine the energy equation. Cumulative sum (CUSUM) can be used to draw a CUSUM graph for these results. Using the least squares method, the linear (Energy) equation is as follows [13, 14, 19, 42, 43];

$$E_j = a + b \times P_i \quad (1)$$

To obtain the energy equation, a and b are constants that are determined by the data of energy consumption. P_i is a specific variable that also indicates the material production amount in the calculation. E_j is the consumption of energy (Gcal and toe) on the vertical axis, P_i is the material production amount (t) on the horizontal axis, b is the slope of the line, and a is a slide in the horizontal axis. The calculation of the slope of the line b is as follows in Eq. (2);

$$b = \frac{n \times \sum E_j P_i - (\sum P_i)(\sum E_j)}{n \times \sum P_i^2 - (\sum P_i)^2} \quad (2)$$

where b is the slope value of the line, $\sum E_j P_i$ is the multiplication of the amount of total energy consumption and material production, $\sum P_i$ is the sum of material production (unit is t), $\sum E_j$ is the sum of energy consumption (unit is

Table 2. Calculation of the material production and energy consumption values table [13, 14, 20, 22, 25].

Period	Material production value, P_i	Current energy consumption value, E_i	Theoretical energy consumption value, $(a + b \times P_i)$	Difference value, D_i	Sum of CUSUM value, CS_i
January	P_1	E_1	TE_1	$D_1 = (E_1 - TE_1)$	$CS_1 = (D_1)$
February	P_2	E_2	TE_2	$D_2 = (E_2 - TE_2)$	$CS_2 = (CS_1 + D_2)$
March	P_3	E_3	TE_3	$D_3 = (E_3 - TE_3)$	$CS_3 = (CS_2 + D_3)$
April	P_4	E_4	TE_4	$D_4 = (E_4 - TE_4)$	$CS_4 = (CS_3 + D_4)$
May	P_5	E_5	TE_5	$D_5 = (E_5 - TE_5)$	$CS_5 = (CS_4 + D_5)$
June	P_6	E_6	TE_6	$D_6 = (E_6 - TE_6)$	$CS_6 = (CS_5 + D_6)$
July	P_7	E_7	TE_7	$D_7 = (E_7 - TE_7)$	$CS_7 = (CS_6 + D_7)$
August	P_8	E_8	TE_8	$D_8 = (E_8 - TE_8)$	$CS_8 = (CS_7 + D_8)$
September	P_9	E_9	TE_9	$D_9 = (E_9 - TE_9)$	$CS_9 = (CS_8 + D_9)$
October	P_{10}	E_{10}	TE_{10}	$D_{10} = (E_{10} - TE_{10})$	$CS_{10} = (CS_9 + D_{10})$
November	P_{11}	E_{11}	TE_{11}	$D_{11} = (E_{11} - TE_{11})$	$CS_{11} = (CS_{10} + D_{11})$
December	P_{12}	E_{12}	TE_{12}	$D_{12} = (E_{12} - TE_{12})$	$CS_{12} = (CS_{11} + D_{12})$
Final total	ΣCS_i				

Gcal), n is the data's number (period numbers are 12), and P_i^2 is the square of the total material production quantity. In Eq. (3), a is a slide value on the horizontal axis. The calculation slide in the horizontal axis is as follows in Eq. (3);

$$a = \frac{\sum E_j - b \times \sum P_i}{n} \quad (3)$$

This analysis is important for defining a significant relationship between two variables. Therefore, a base line standard performance equation can be established using in regression analysis to measure the subsequent energy consumption for the CUSUM technique. The standard performance equation is first calculated, and the theoretical performance equation can be produced. CUSUM plot is produced by following steps. A standard performance equation is obtained to plot a scatter graph of the two variables under consideration. This technique uses the standard performance equation to calculate the estimated consumption of energy for each month that is deducted from the current consumption for each data point. CUSUM (Cumulative Sum Deviation Method) is acquired from the estimated consumption of energy for each month. Finally, the CUSUM value is plotted against time [13, 14, 20, 25, 42].

In table 2, the calculation of the material production and energy consumption values can be observed as follows. The linear equation is determined using the regression analysis of the values of material production and energy consumption. The theoretical energy consumption for the sum of the CUSUM value can then be determined. Eq. (1) can be used to find the difference in the current energy consumption values and the theoretical energy consumption values, which can be used in the final total. Finally, the CUSUM graph is drawn with the result of the CUSUM values from the theoretical energy consumption values.

Thus, standard, SEC (specific energy consumption) and CUSUM can be calculated for any level of material

production. The linear relationship between energy consumption and the material production indicator in the regression curve is determined as the accuracy of data [13, 14, 17, 19, 20]. In addition, in the calculations performed in Excel, the r value is subtracted from the regression curve. The sum of the CUSUM values must be zero at the end of December. If it does not reach zero, there is an error in the calculations [22, 23, 25, 42, 47]. Wang *et al* [49] indicated that the CUSUM value will be reset to zero. When the r value is close to 1, the accuracy of calculation is better [13, 14, 19, 20, 42].

3. Results and Discussion

In this section, the result of the energy consumption and production was calculated for the energy performance of the factory. Energy consumption and material production relationship was analysed for energy management programme. A cost of energy was determined for a techno-economic analysis.

3.1 The result of the energy consumption and production for the energy performance of the factory

The last four years of energy consumption and material production data were taken from the sugar factory's administration and given in table 3 including the monthly production of sugar. The production rates are variable throughout the year, as shown in this table. Although there is no production in the spring and summer terms due to the campaign period, production decreases in autumn and winter. In tables 2, 3 and 4, the measured energy data and energy performance [27–31] are shown.

Table 3. Monthly production of factories by year.

Years Period	Production of raw sugar P [t]			
	1 st year	2 nd year	3 rd year	4 th year
January	34,648	53,030	56,739	48,833
February	0	19,093	34,885	21,879
March	0	0	0	0
April	0	0	0	0
May	0	0	0	0
June	0	0	0	0
July	0	0	0	0
August	0	0	0	0
September	10,232	0	2,537	0
October	52,462	62,385	56,633	67,963
November	58,872	66,470	58,793	73,782
December	59,361	62,781	56,028	76,396
Total production [t]	215,575	263,759	265,618	288,853

Table 4. Calorific values of energy consumption [13, 14].

Quantity	Source of energy	The heating value	Convert to toe unit
1 [t]	Pulverized coal	2300 [kcal/kg]	0.61 [toe]
1000 [m ³]	Natural gas	8250 [kcal/m ³]	0.825 [toe]
1000 [kWh]	Electricity	860 [kcal/kWh]	0.086 [toe]

1 [toe] = 10 [Gcal] = 10⁷ [kcal], 1 [Gcal] = 0.1 [toe] and 1 [kcal] = 10⁻⁶ [Gcal].

The consumption of energy data were taken from the factory's department of production. The energy consumption values were calculated from the calorific values for the heating value of pulverized coal, electricity and natural gas

for the case of the factory. In table 4, these heating values and converted units were used in the calculations.

In this way, the consumption value was converted to Gcal units. In addition, the total consumption of energy was summed to include pulverized coal, network electricity, and natural gas, and the production of electricity from the energy of power plant for the factory was subtracted. The production of electricity has been determined for the energy management. These results are given in tables 5, 6, 7 and 8.

Table 5 shows the results of energy consumption of the 1st year. The sum of the energy consumption of coal was 230,885 Gcal. The sum of the energy consumption of network electricity was 8,998.61 Gcal. The sum of the energy consumption of the production of electricity was -31,921.1 Gcal. The sum of the energy consumption of natural gas was 20,925.84 Gcal.

Table 6 shows the results of energy consumption of the 2nd year. The sum of the energy consumption of coal was 335,846 Gcal. The sum of the energy consumption of network electricity was 40,121.70 Gcal. The sum of the energy consumption of the production of electricity was -9,724.02 Gcal. The sum of the energy consumption of natural gas was 59,332.56 Gcal.

Table 7 shows the results of energy consumption of the 3rd year. The sum of the energy consumption of coal was 372,255 Gcal. The sum of the energy consumption of network electricity was 11,476.52 Gcal. The sum of the energy consumption of the production of electricity was -52,337.07 Gcal. The sum of the energy consumption of natural gas was 78,019.01 Gcal.

Table 8 shows the results of the energy consumption of the 4th year. The sum of the energy consumption of coal was 328,246 Gcal. The sum of the energy consumption of network electricity was 22,001.54 Gcal. The sum of the energy consumption of the production of electricity was

Table 5. Monthly energy consumption of the factory in the 1st year.

1 st year Month	Energy consumption							
	Pulverized coal		Network electricity		Production of electricity		Natural gas	
	Gcal	t	Gcal	kWh	Gcal	kWh	Gcal	m ³
January	28,060	12,200	541.80	630,000	-4,713.6	-5,481,032	5,693.97	690,178
February	0	0	1,089.02	1,266,300	0	0	0	0
March	0	0	958.99	1,115,100	0	0	0	0
April	0	0	1,050.40	1,221,400	0	0	0	0
May	0	0	996.91	1,159,200	0	0	0	0
June	0	0	980.66	1,140,300	0	0	0	0
July	0	0	1,067.35	1,241,100	0	0	0	0
August	0	0	1,121.53	1,304,100	0	0	0	0
September	18,680	8,122	834.37	970,200	-2,041.9	-2,374,385	710.57	86,130
October	62,067	26,986	75.85	88,200	-7,989.4	-9,290,088	8,247.19	999,659
November	54,887	23,864	119.20	138,600	-8,460.2	-9,837,456	2,660.86	322,528
December	67,189	29,213	162.54	189,000	-8,715.8	-10,134,663	3,613.25	437,970
Sum	230,885	100,385	8,998.61	10,463,500	-31,921.1	-37,117,624	20,925.84	2,536,465

Table 6. Monthly energy consumption of the factory in the 2nd year.

2 nd year	Energy consumption							
	Pulverized coal		Network electricity		Production of electricity		Natural gas	
	Gcal	t	Gcal	kWh	Gcal	kWh	Gcal	m ³
January	62,385.20	27,124	8,564.48	9,958,696	−140.87	−163,800	10,728.17	1,300,384
February	29,900.00	13,000	4,076.53	4,740,152	−590.56	−686,700	5,255.70	637,054
March	0	0	0	0	−1,289.48	−1,499,400	5,643.00	684,000
April	0	0	0	0	−980.66	−1,140,300	5,172.00	626,850
May	0	0	0	0	−1,099.08	−1,278,000	3,978.00	482,156
June	0	0	0	0	−1,202.28	−1,398,000	3,604.00	436,820
July	0	0	0	0	−1,452.02	−1,688,400	3,652.00	442,700
August	26,523.60	11,532	0	0	−1,262.39	−1,467,900	257.00	31,150
September	4,365.40	1,898	0	0	−845.21	−982,800	1,054.00	127,757
October	69,000.00	30,000	8,775.24	10,203,773	−232.97	−270,900	5,839.36	707,801
November	71,760.00	31,200	9,170.97	10,663,921	−222.14	−258,300	6,968.92	844,717
December	71,911.80	31,266	9,534.55	11,086,684	−406.35	−472,500	7,181.11	870,437
Sum	335,846.00	146,020	40,121.70	46,653,226	−9,724.02	−11,307,000	59,332.56	7,191,826

Table 7. Monthly energy consumption of the factory in the 3rd year.

3 rd year	Energy consumption							
	Pulverized coal		Network electricity		Production of electricity		Natural gas	
	Gcal	t	Gcal	kWh	Gcal	kWh	Gcal	m ³
January	74,945	32,585	357.59	415,800	−9,247.46	−10,752,856	5,835.21	707,298
February	54,949	23,891	249.23	289,800	−7,019.09	−8,161,734	4,051.76	491,123
March	0	0	1,714.80	1,993,950	0	0	5,982.24	725,120
April	0	0	1,370.75	1,593,900	0	0	5,117.97	620,360
May	0	0	547.22	636,300	−2,609.71	−3,034,552	3,284.56	398,128
June	0	0	363.01	422,100	−3,225.18	−3,750,206	1,436.75	174,152
July	0	0	893.97	1,039,500	−2,037.22	−2,368,866	1,091.57	132,312
August	0	0	1,349.08	1,568,700	0	0	1,129.94	136,962
September	0	0	1,344.65	1,563,541	−971.66	−1,129,840	977.04	118,429
October	86,434	37,580	1,193.42	1,387,701	−8,857.53	−10,299,456	14,519.97	1,759,996
November	80,624	35,054	621.82	723,051	−8,923.88	−10,376,600	17,464.45	2,116,903
December	75,302	32,740	1,470.99	1,710,450	−9,445.33	−10,982,946	17,127.55	2,076,067
Sum	372,255	161,850	11,476.52	13,344,793	−52,337.07	−60,857,056	78,019.01	9,456,850

−48,772.70 Gcal. The sum of the energy consumption of natural gas was 134,426.54 Gcal.

According to table 9, the greatest energy consumption occurred in the 4th year and the lowest energy consumption took place in the 1st year.

In this study, the current unit of energy was used in the calculation of energy management. Previous studies used the toe unit in their energy calculation. Ashnani *et al* [63], Halder *et al* [64], Chadwick *et al* [65], Valero and Valero [66], and Popp *et al* [67] used the toe unit (tonnes oil equivalent) in their studies. In table 9, the results of the consumption of energy were converted from Gcal to toe. Thus, the energy calculation can use toe [63–67].

3.2 Analysing the energy consumption and material production relationship

The result of the 1st year, 2nd year, 3rd year and 4th year of production and energy consumption are given in tables 10, 12 and 13, based on the energy consumption analysis tables created with the least squares method. The analysis of energy is performed according to the following energy equation in Excel. The results of the analysis of the energy consumption were taken into consideration based on table 2 for the last four years. The CUSUM values were also calculated from Eq. (4).

$$E_j = a + b \times P_i \quad (4)$$

Table 8. Monthly energy consumption of the factory in the 4th year.

4 th year	Energy consumption							
	Pulverized coal		Network electricity		Production of electricity		Natural gas	
	Gcal	t	Gcal	kWh	Gcal	kWh	Gcal	m ³
January	73,082	31,775	1,544.13	1,795,500	−9,936.67	−11,554,262	18,677.65	2,263,958
February	29,012	12,614	1,576.64	1,833,300	−4,709.99	−5,476,734	9,355.62	1,134,014
March	0	0	2,167.20	2,520,000	0	0	6,039.89	732,108
April	0	0	1,945.06	2,261,700	0	0	5,052.48	612,422
May	0	0	1,799.98	2,093,004	0	0	3,252.23	394,210
June	0	0	1,997.62	2,322,810	−646.82	−752,116	7,802.12	945,712
July	0	0	2,215.96	2,576,700	−1,213.20	−1,410,700	15,116.62	1,832,317
August	0	0	2,329.74	2,709,000	0	0	3,901.06	472,856
September	0	0	2,403.05	2,794,239	−288.27	−335,192	1,058.90	128,352
October	79,455	34,546	1,039.71	1,208,970	−9,978.19	−11,602,552	18,604.95	2,255,146
November	71,187	30,951	1,289.86	1,499,841	−10,423.18	−12,119,980	21,615.49	2,620,059
December	75,509	32,830	1,692.58	1,968,120	−11,576.38	−13,460,908	23,949.88	2,903,016
Sum	328,246	142,716	22,001.54	25,583,184	−48,772.70	−56,712,444	134,426.90	16,294,170

Table 9. Total energy consumption of factories for four years.

Year	Total energy consumption							
	1 st year		2 nd year		3 rd year		4 th year	
	Gcal	toe	Gcal	toe	Gcal	toe	Gcal	toe
January	29,582.08	2,958.21	81,536.98	8,153.70	71,890.84	7,189.08	83,367.62	8,336.76
February	1,089.02	108.90	38,641.66	3,864.17	52,231.20	5,223.12	35,234.46	3,523.45
March	958.99	95.90	4,353.52	435.35	7,697.04	769.70	8,207.09	820.71
April	1,050.40	105.04	4,190.85	419.09	6,488.72	648.87	6,997.54	699.75
May	996.91	99.69	2,878.71	287.87	1,222.06	122.21	5,052.22	505.22
June	980.66	98.07	2,401.49	240.15	−1,425.42	−142.54	9,152.92	915.29
July	1,067.35	106.73	2,200.25	220.03	−51.68	−5.17	16,119.38	1,611.94
August	1,121.53	112.15	25,518.19	2,551.82	2,479.02	247.90	6,230.80	623.08
September	18,183.57	1,818.36	4,574.19	457.42	1,350.02	135.00	3,173.68	317.37
October	62,401.36	6,240.14	83,381.63	8,338.16	93,289.86	9,328.99	89,122.27	8,912.23
November	49,207.04	4,920.70	87,677.75	8,767.77	89,786.60	8,978.66	83,669.47	8,366.95
December	62,249.88	6,224.99	88,221.10	8,822.11	84,455.21	8,445.52	89,575.08	8,957.51
Sum	228,888.79	22,888.88	425,576.32	42,557.63	409,413.47	40,941.35	435,902.54	43,590.25

The result of the 1st year analysis of the total energy consumption is given in table 10. The 1st year energy equation is shown in Eq. (5);

$$E = 163.89 + 0.0971 \times P \quad (5)$$

The result of the 2nd year analysis of the total energy consumption is given in table 11. The 2nd year energy equation is shown in Eq. (6);

$$E = 744.84 + 0.1275 \times P \quad (6)$$

The result of the 3rd year analysis of the total energy consumption is given in table 12. The 3rd year energy equation is shown in Eq. (7);

$$E = 200.96 + 0.1451 \times P \quad (7)$$

The result of the 4th year analysis of the total energy consumption is given in table 13. The 4th year energy equation is shown in Eq. (8);

$$E = 896.56 + 0.1137 \times P \quad (8)$$

From tables 10, 11, 12 and 13, the results of the analysis of the energy consumption were taken into consideration based on table 2 for the last four years. The CUSUM values were also calculated. From tables 14, 15, 16 and 17, the 1st, 2nd, 3rd and 4th years' CUSUM values of December were zero, respectively. This result demonstrates the value's accuracy. The least squares method was used in this energy equation.

Table 10. Energy equation of the 1st year.

Period	Months	Production, P [t]	Energy consumption, E [toe]	P ²	E ²	E × P
1	January	34,648.00	2,958.21	1,200,483,904.00	8,750,995.15	102 495 994.18
2	February	0	108.90	0	11,859.60	0
3	March	0	95.90	0	9,196.54	0
4	April	0	105.04	0	11,033.49	0
5	May	0	99.69	0	9,938.34	0
6	June	0	98.07	0	9,616.90	0
7	July	0	106.73	0	11,392.27	0
8	August	0	112.15	0	12,578.21	0
9	September	10,231.80	1,818.36	104,689,731.24	3,306,423.42	18,605,068.63
10	October	52,461.64	6,240.14	2,752,223,356.72	38,939,301.13	327,367,765.77
11	November	58,872.39	4,920.70	3,465,958,068.82	24,213,327.70	289,693,594.18
12	December	59,360.97	6,224.99	3,523,724,996.78	38,750,478.49	369,521,352.14
1 st year	Sum	215,574.80	22,888.88	11,047,080,057.57	114,036,141.23	1,107,683,774.90

$$b = 0.0971.$$

$$a = 163.89.$$

$$E = 163.89 + 0.0971 \times P.$$

Table 11. Energy equation of the 2nd year.

Period	Months	Production, P [t]	Energy consumption, E [toe]	P ²	E ²	E × P
1	January	53,030.42	8,153.70	2,812,225,445.38	66,482,788.73	432,394,021.86
2	February	19,092.78	3,864.17	364,534,362.69	14,931,782.14	73,777,690.97
3	March	0	435.35	0	189,531.02	0
4	April	0	419.09	0	175,632.61	0
5	May	0	287.87	0	82,869.54	0
6	June	0	240.15	0	57,671.30	0
7	July	0	220.03	0	48,411.04	0
8	August	0	2,551.82	0	6,511,782.00	0
9	September	0	457.42	0	209,231.89	0
10	October	62,384.71	8,338.16	3,891,851,542.71	69,524,960.60	520,173,841.28
11	November	66,469.78	8,767.77	4,418,231,786.19	76,873,877.24	582,792,079.52
12	December	62,781.32	8,822.11	3,941,494,140.94	77,829,631.01	553,863,732.90
2 nd year	Sum	263,759.01	42,557.63	15,428,337,277.90	312,918,169.11	2,163,001,366.53

$$b = 0.1275.$$

$$a = 744.84.$$

$$E = 744.84 + 0.1275 \times P.$$

The CUSUM graphs were plotted according to the results of the CUSUM values (in compliance with tables 10, 11, 12 and 13) in Microsoft Excel Software. The regression curve increased each year. The CUSUM chart's curve shows that the factory makes a profit in the negative zone and suffers a loss in the positive zone [13, 14, 20, 23, 25].

In figure 2, the energy efficiency of the factory was good with low energy consumption. The linear regression analysis of the chart resulted in an R^2 value of 0.2909. The energy efficiency increased through August in the 1st year for the factory. The maximum energy efficiency of the factory decreased in October.

Figure 3 shows that the energy consumption of the factory increased and the energy efficiency of the factory

decreased in the 2nd year. The linear regression analysis is shown, in which the R^2 is 0.2108. The maximum energy efficiency increased in July, and the energy efficiency of the factory fell in February.

Figure 4 illustrates that the energy consumption of the factory decreased and the energy efficiency of the factory increased in the 3rd year. The linear regression analysis is shown, in which R^2 is 0.3004. The maximum energy efficiency increased in February and September, and the energy efficiency of the factory fell in April and November.

Figure 5 depicts that the energy consumption of the factory increased and the energy efficiency of the factory decreased in the 4th year. This year was the worst for energy efficiency. The linear regression analysis is shown,

Table 12. Energy equation of the 3rd year.

Period	Months	Production, P [t]	Energy Consumption, E [toe]	P ²	E ²	E × P
1	January	56,739.53	7,189.08	3,219,374,718.54	51,682,929.25	407,905,277.98
2	February	34,885.75	5,223.12	1,217,015,413.52	27,280,984.11	182,212,453.36
3	March	0	769.70	0	592,443.79	0
4	April	0	648.87	0	421,035.39	0
5	May	0	122.21	0	14,934.29	0
6	June	0	−142.54	0	20,318.14	0
7	July	0	−5.17	0	26.71	0
8	August	0	247.90	0	61,455.33	0
9	September	2,537.50	135.00	6,438,906.25	18,225.60	342,568.11
10	October	56,633.47	9,328.99	3,207,350,377.31	87,029,975.50	528,332,873.05
11	November	58,793.79	8,978.66	3,456,709,154.63	80,616,331.10	527,889,391.58
12	December	56,028.06	8,445.52	3,139,143,619.42	71,326,818.53	473,186,144.42
3 rd year	Sum	265,618.10	40,941.35	14,246,032,189.66	319,065,477.73	2,119,868,708.49

$$b = 0.1451.$$

$$a = 200.96.$$

$$E = 200.96 + 0.1451 \times P.$$

Table 13. Energy equation of the 4th year.

Period	Months	Production, P [t]	Energy Consumption, E [toe]	P ²	E ²	E × P
1	January	48,833.14	8,336.76	2,384,675,562.26	69,501,597.61	407,110,257.01
2	February	21,879.04	3,523.45	478,692,391.32	12,414,673.31	77,089,620.92
3	March	0	820.71	0	673,563.43	0
4	April	0	699.75	0	489,656.15	0
5	May	0	505.22	0	255,248.86	0
6	June	0	915.29	0	837,759.60	0
7	July	0	1,611.94	0	2,598,342.58	0
8	August	0	623.08	0	388,228.94	0
9	September	0	317.37	0	100,722.73	0
10	October	67,962.89	8,912.23	4,618,954,009.37	79,427,797.19	605,700,703.57
11	November	73,782.47	8,366.95	5,443,853,026.87	70,005,797.43	617,334,003.80
12	December	76,395.56	8,957.51	5,836,281,282.13	80,236,957.31	684,313,854.95
4 th year	Sum	288,853.10	43,590.25	18,762,456,271.95	316,930,345.14	2,391,548,440.24

$$b = 0.1137.$$

$$a = 896.56.$$

$$E = 896.56 + 0.1137 \times P.$$

in which R^2 is 0.5535. The maximum energy efficiency increased in November, and the energy efficiency of the factory fell in July.

3.3 Cost of energy and a techno-economic analysis

The cost of energy is energy consumption of the production in energy management. Similar previous studies approached this analysis in different way [2, 3, 6, 14, 68]. Thus, the cost of energy can be found from a techno-economic analysis of the economic feasibility of an energy system. Specific energy consumptions (SEC) can give the cost of

energy. SEC was calculated in several previous studies [8, 13, 14, 17, 25]. The cost of energy was also calculated for the sugar factory. In table 18, the results of the energy consumption were taken from tables from 10, 11 12 and 13.

Thermoeconomic is a technique for analysing the cost of energy through a combination of the 2nd Law of Thermodynamics and economic principles [3, 6, 71–73]. Karaali and Ozturk [73] defined thermoeconomic optimization method, which is a simple and efficient method. This can be viewed as cost analysis and optimization [3, 6, 71, 72]. This definition is the key of thermoeconomic. The unit of energy cost is defined as follows [3, 6, 71, 72]:

Table 14. CUSUM values of the 1st year.

Months	Production [t]	Energy consumption [toe]	Theoretical energy consumption ($a + b \times P$)	Difference value	CUSUM value
January	34,648.00	2,958.21	3,527.05	−568.84	−568.84
February	0	108.90	163.39	−54.49	−623.33
March	0	95.90	163.39	−67.49	−690.82
April	0	105.04	163.39	−58.35	−749.17
May	0	99.69	163.39	−63.70	−812.87
June	0	98.07	163.39	−65.32	−878.19
July	0	106.73	163.39	−56.65	−934.84
August	0	112.15	163.39	−51.24	−986.08
September	10,231.80	1,818.36	1,156.70	661.66	−324.43
October	52,461.64	6,240.14	5,256.42	983.72	659.29
November	58,872.39	4,920.70	5,878.78	−958.07	−298.78
December	59,360.97	6,224.99	5,926.21	298.78	0

Table 15. CUSUM values of the 2nd year.

Months	Production [t]	Energy consumption [toe]	Theoretical energy consumption ($a + b \times P$)	Difference value	CUSUM value
January	53,030.42	8,153.70	7,504.26	649.44	649.44
February	19,092.78	3,864.17	3,178.47	685.70	1,335.14
March	0	435.35	744.84	−309.49	1,025.65
April	0	419.09	744.84	−325.76	699.89
May	0	287.87	744.84	−456.97	242.92
June	0	240.15	744.84	−504.69	−261.78
July	0	220.03	744.84	−524.82	−786.59
August	0	2,551.82	744.84	1,806.98	1,020.38
September	0	457.42	744.84	−287.42	732.96
October	62,384.71	8,338.16	8,696.59	−358.42	374.54
November	66,469.78	8,767.77	9,217.28	−449.51	−74.97
December	62,781.32	8,822.11	8,747.14	74.97	0

Table 16. CUSUM values of the 3rd year.

Months	Production [t]	Energy consumption [toe]	Theoretical energy consumption ($a + b \times P$)	Difference value	CUSUM value
January	56,739.53	7,189.08	8,431.44	−1,242.36	−1,242.36
February	34,885.75	5,223.12	5,261.39	−38.27	−1,280.63
March	0	769.70	200.96	568.74	−711.88
April	0	648.87	200.96	447.91	−263.97
May	0	122.21	200.96	−78.75	−342.72
June	0	−142.54	200.96	−343.50	−686.22
July	0	−5.17	200.96	−206.13	−892.35
August	0	247.90	200.96	46.94	−845.41
September	2,537.50	135.00	569.04	−434.04	−1,279.45
October	56,633.47	9,328.99	8,416.06	912.93	−366.52
November	58,793.79	8,978.66	8,729.42	249.24	−117.28
December	56,028.06	8,445.52	8,328.24	117.28	0

Table 17. CUSUM values of the 4th year.

Months	Production [t]	Energy consumption [toe]	Theoretical energy consumption ($a + b \times P$)	Difference value	CUSUM value
January	48,833.14	8,336.76	6,447.02	1,889.74	1,889.74
February	21,879.04	3,523.45	3,383.37	140.08	2,029.82
March	0	820.71	896.56	-75.85	1,953.97
April	0	699.75	896.56	-196.80	1,757.17
May	0	505.22	896.56	-391.34	1,365.83
June	0	915.29	896.56	18.74	1,384.57
July	0	1,611.94	896.56	715.38	2,099.95
August	0	623.08	896.56	-273.48	1,826.47
September	0	317.37	896.56	-579.19	1,247.28
October	67,962.89	8,912.23	8,621.34	290.88	1,538.17
November	73,782.47	8,366.95	9,282.81	-915.86	622.31
December	76,395.56	8,957.51	9,579.82	-622.31	0

Figure 2. CUSUM chart of the 1st year.

$$\dot{C}_{En}[\$/toe] = \frac{C_{cost}[\$]}{E_e[toe]} \quad (9)$$

where $\dot{C}_{En}$ is the unit of energy cost. C_{cost} is the total investment cost (the capital cost, depreciation cost, operating and maintenance cost, and energy-power cost). The total investment cost was taken as 30,000,000 [\$] according to the factory accounting department. E_e is the total energy consumption as shown in table 18.

$$SEC \left[\frac{toe}{t} \right] = \frac{E_e[toe]}{P[t]}, \quad (10)$$

where SEC is the specific energy consumption which was 0.1062 [toe/t] for the first year. The unit of energy cost was 688.22 [\$/toe] for the last year. From these results, it can be

observed that the 4th year is the best among them. Therefore, the optimisation of the factory was reached in the 4th year. The factory increased the power plant's energy and took several energy precautions.

The CUSUM charts of the last four years were compared with respect to their energy consumption and energy efficiencies in figure 6. The 3rd year of the factory's energy efficiency was found as the best among them. Therefore, the energy plant of the factory's power was increased in the 3rd year. Additionally, the 4th year of factory's energy consumption increased more than the other years. The 4th year of the factory's energy performance was found to be the worst among them. So, these results showed that Energy Efficiency of Turkish Law and Directives [74, 75] required factories to have an energy manager.

Figure 3. CUSUM chart of the 2nd year.

Figure 4. CUSUM chart of the 3rd year.

4. Conclusions

In conclusion, the factory's management made a decision to decrease the power plant's energy production. Thus, the production of sugar beets decreased in this year, and they could not increase the production of energy.

In this study, the data accuracy was investigated by SPSS statistical software, as documented in the Appendix. The results of the CUSUM energy values were used to obtain a

mathematical relation for the last four years using SPSS 17.0. The results proved the relation between the production data (independent variable) and the energy consumption data (dependent variable). The Appendix section includes a detailed step by step method. The statistical techniques ensured data accuracy for this study.

The unit of energy cost was 688.22 [\$/toe] for the last year. The obtained results are found to be compatible with previous studies. Finally, it was seen that the factory can

Figure 5. CUSUM chart of the 4th year.

Table 18. Cost of energy from the total production — consumption of energy values for the last year and the optimisation year.

Year	P total of sugar production amount [t]	P _{pr} , total sale price ^a [\$]	E _p , total energy production [toe]	E _e , total energy consumption [toe]	E _{cost} , cost of energy consumption ^b [\$]	SEC, specific consumption energy [toe/t]	$\dot{C}_{En}$, The unit of energy cost (\$/toe)
1 st	215,574	250,713,492.4	3,192.11	22,888.88	2,288,888	0.1062	1,310.68
2 nd	263,759	306,751,717.0	9,724.02	42,557.63	4,255,763	0.1613	704.92
3 rd	265,618	308,913,734.0	5,233.71	40,941.35	4,094,135	0.1541	732.75
4 th	288,853	335,936,155.3	4,877.27	43,590.25	4,359,025	0.1509	688.22

^aPrice of sugar taken from the Official of Turkish Sugar Factory Incorporeal [69] was 1.163 [\$/kg].

^bEnergy consumption price was taken from the International Energy Agency [70] publication from the table of average prices and taxes in Turkish liras. A heavy fuel oil for electricity generation price was 2456 Turkish liras per tonne, which converted to approximately 100 [\$/t]. In addition, 100 [\$/t] is equivalent to 100 [\$/toe]. This equivalent was taken from the General Directorate of Renewable Energy [68].

Figure 6. CUSUM Chart's comparison of the last four years.

decrease the unit of energy by optimisation. In conclusion, this study proved that the sugar factory should employ an energy manager to comply with the Energy Efficiency of Turkish Law and Legislation. Regrettably, it was understood that it dispended energy consumption of 43,590.25 [toe] for the last year. If factories have an energy consumption greater than 1,000 toes, they must include an energy manager for their factory. Although the unit of energy cost is more feasible than in the other years, specific energy consumption is not as good as the other years. According to the proposal, the unit of energy cost can be taken over 688.22 [\$/toe] when energy management is completed by all departments of the factory, immediately. Consequently, the specific consumption of energy can be decreased by energy management.

Appendix

In this study, SPSS Statistic Method was used for data accuracy and prediction, which was previously proved for this method. All years were investigated for accuracy. In this study, regression analysis was performed in SPSS Statistic 17.0 package. The figures and results show the energy consumption and production relationship, which was significant for each year. The Multi Linear Regression Model was used in this study. The model output is given in the Appendix, which also provides comments on the statistical technique for these outputs. This study used methods similar to previous studies. Kalayci [38] used SPSS to apply multivariate statistical techniques, including regression analysis. In the Appendix, these results were fitted according to the previous studies [41–45].

The 1st, 2nd, 3rd and 4th years are the same in figure 7. Entered variable is uretim^a (production). a means that all requested variables were entered, and b means that the dependent variable is tuketim (energy consumption). Variables Entered/Removed^b used the Enter Method in figure 7.

Model Summary^b gave the model summary of the energy consumption and production in table 19. R² indicates the percentage of the dependent variable explained by the independent variables. In these results, the R² value was 0.961 for the 1st year, 0.966 for the 2nd year, 0.981 for the 3rd year and 0.962 for the 4th year. The R² value indicated the accuracy of the data to be close to 1.

ANOVA^b is the analysis of variance of the energy consumption and production in table 20. The ANOVA Table presents the entire model to detect the significance of the test. In these results, the F-test value was 244.882 for the 1st year, 283.630 for the 2nd year, 527.780 for the 3rd year and 253.373 for the 4th year. All Sig. Values are 0.000. These results showed that the models are significant for each year.

In table 21, Coefficients^a (Parameter Prediction) shows the prediction values that relate to the t values. When the unit of product increases, the consumption of energy increases. The results of the model's prediction equation for all years are as follows:

The equation of the 1st year was $y = 163.384 + 0.097x$,

the equation of the 2nd year was $y = 744.845 + 0.127x$,

the equation of the 3rd year was $y = 200.959 + 0.145x$,

and the equation of the 4th year was $y = 896.556 + 0.114x$.

where y shows the energy consumption, and x shows the production. This appendix presented the data accuracy. All of the year's data were accurate.

The Residuals Statistics^a results are shown in table 22. The Mean of Predicted Values was 1,907.41 for the 1st year, 3,546.47 for the 2nd year, 3,411.78 for the 3rd year and 3,632.52 for the 4th year. The Standard Deviation of Residuals Values was 501.02 for the 1st year, 708.18 for the 2nd year, 550.67 for the 3rd year and 739.87 for the 4th year. The Standard Predicted Value was 1.00 for all years. The Standard Residual values were 0.95 for all years.

Figure 7. Variables Entered/Removed^b input from the SPSS package programme.

Table 19. Model Summary^b output of energy consumption and production relationship from the SPSS package

Year	Model	R	R square	Adjusted R square	Standard error of the estimate	Change statistics				
						R square change	F change	df1	df2	Sig.F change
1 st	1	0.980 ^a	0.961	0.957	525.47	0.961	244.882	1	10	0.000
2 nd	1	0.983 ^a	0.966	0.963	742.75	0.981	283.630	1	10	0.000
3 rd	1	0.991 ^a	0.981	0.980	577.55	0.981	527.780	1	10	0.000
4 th	1	0.981 ^a	0.962	0.958	775.98	0.962	253.373	1	10	0.000

^aPredictor, which is production (constant).^bDependent variable, which is energy consumption.**Table 20.** ANOVA^b output of the energy consumption and production relationship from the SPSS package.

Year	Model 1	Sum of squares	df	Mean square	F	Sig
1 st	Regression	6.762×10^7	1	6.762×10^7	244.882	0.000 ^a
	Residual	2,761,185.964	10	276,118.596		
	Total	7.038×10^7	11			
2 nd	Regression	1.565×10^8	1	1.565×10^8	283.630	0.000 ^a
	Residual	5,516,759.021	10	551,675.902		
	Total	1.620×10^8	11			
3 rd	Regression	1.760×10^8	1	1.760×10^8	527.780	0.000 ^a
	Residual	3,335,614.798	10	333,561.480		
	Total	1.794×10^8	11			
4 th	Regression	1.526×10^8	1	1.526×10^8	253.373	0.000 ^a
	Residual	6,021,412.467	10	602,141.247		
	Total	1.586×10^8	11			

^aPredictors i.e., production (constant).^bDependent variable that is energy consumption.**Table 21.** Coefficients^a output of energy consumption and production relationship from the SPSS package.

Year	Model 1	Unstandardized coefficients		Standardized Coefficients			95.0% Confidence Interval for B	
		B	Std. Error	Beta	t	Sig.	Lower bound	Upper bound
1 st	(Constant)	163.384	188.230		0.868	0.406	-256.019	582.787
	Uretim	0.097	0.006	0.980	15.649	0.000	0.083	0.111
2 nd	(Constant)	744.845	271.379		2.745	0.021	140.174	1,349.515
	Uretim	0.127	0.008	0.983	16.841	0.000	0.111	0.144
3 rd	(Constant)	200.959	217.555		0.924	0.377	-283.784	685.702
	Uretim	0.145	0.006	0.991	22.973	0.000	0.131	0.159
4 th	(Constant)	896.556	282.351		3.175	0.010	267.440	1,525.673
	Uretim	0.114	0.007	0.981	15.918	0.000	0.098	0.130

^aDependent variable, i.e., energy consumption.

Uretim means production (constant).

In this study, Reliability Analysis (Scale Alpha) was investigated with the SPSS package. Table 23 shows the reliability data for the last four years. In this

Table, Cronbach's Alpha Based on the Standardized Items was nearly 0.99 for all years. These results indicate strong data reliability because the results are

Table 22. Residuals statistics^a output of the energy consumption and production relationship from the SPSS package.

		Residuals statistics ^a				
Year		Minimum	Maximum	Mean	Standard deviation	N
1 st	Predicted value	163.38	5,926.22	1,907.41	2,479.31	12
	Residual	−958.05	983.68	0.00	501.02	12
	Standard predicted value	−0.70	1.62	0.00	1.00	12
	Standard residual	−1.82	1.87	0.00	0.95	12
2 nd	Predicted value	744.84	9,217.28	3,546.47	3,771.57	12
	Residual	−524.82	1,806.98	0.00	708.18	12
	Standard predicted value	−0.743	1.50	0.00	1.00	12
	Standard residual	−0.707	2.43	0.00	0.95	12
3 rd	Predicted value	200.9588	8,729.42	3,411.78	4,000.54	12
	Residual	−1,242.36	912.94	0.00	550.67	12
	Standard predicted value	−0.80	1.33	0.00	1.00	12
	Standard residual	−2.15	1.58	0.00	0.95	12
4 th	Predicted value	896.56	9,579.82	3,632.52	3,724.20	12
	Residual	−915.86	1,889.74	0.00	739.87	12
	Standard predicted value	−0.735	1.59	0.00	1.00	12
	Standard residual	−1.180	2.44	0.00	0.95	12

^aDependent variable: energy consumption (tuketim).**Table 23.** Reliability analysis (Scale Alpha) output of the energy consumption and production relationship from the SPSS package.

		Reliability statistics	
Year	Cronbach's alpha	Cronbach's alpha based on standardized items	Number of items
1 st	0.323	0.990	2
2 nd	0.401	0.991	2
3 rd	0.442	0.995	2
4 th	0.366	0.990	2

very near 1. Statistics scale alpha gives the data reliability [38].

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List of symbols

$\dot{C}_{En}$ the unit of energy cost, \$/toe
 E_e total energy consumption, toe
 a slide in the horizontal axis

b slope of the line in the horizontal axis
 C_{cost} total investment cost, \$
 CS_i sum of CUSUM value
 D_i difference value
 E energy consumption, Gcal; toe
 E_j consumption of energy amount, toe
 E_p total energy production, toe
 i, j notation
 P material production, tonnes
 P_i specific variable of material production amounts, tonnes
 P_{pr} total sale price, \$
 R^2 R Squared (Linear regression analysis symbol)
 t tonnes

Abbreviations

ANOVA analysis of variance
 CUSUM cumulative sum
 CUSUMSQ cumulative sum of squares
 DE differential evolution
 GA genetic algorithm
 HVAC heating, ventilating and air conditioning
 PASW predictive analytics software
 PDS public distribution system
 PSO particle swarm optimization
 SEC specific energy consumptions, toe/t
 SPSS statistical package for the social sciences

Greek symbols

Σ Sum

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