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An analysis on energy performance indicator and GWP at Airports; a case study

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ABSTRACT

Airports are very important facilities for global transportation. Energy plays a key role for the comfort needs of passengers and the safe operation of aircraft. In airports with high energy consumption areas, energy management allows the reduction of both costs and environmental impacts. Therefore, the phenomena that affect energy consumption in airports need to be identified. In this study, the factors affecting energy consumption in airport terminal buildings were determined by regression analysis and mathematically modeling. In addition, energy-induced Global Warming Potential (GWP) was determined and its change was explained mathematically. It was seen that with each change in passenger causes a 1.59 kWh energy and 1.44 kg $CO_{2\ eq}$. change. However, each increase in the number of degree days causes a 3468.6kWh energy and 1428 kg $CO_{2eq.}$ increase.

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Introduction

A large part of the global energy requirement is currently provided by fossil fuels. The fact that fossil fuels are the main reason for the global warming problem raises the obligation to use energy more efficiently. Energy management is the most effective way to reduce energy consumption without compromising production quantity and quality in the industrial sector, comfort conditions, and service quality in commercial buildings. The energy-saving potential in Turkey is higher than the amount produced from renewable energy sources. Recovery of this potential can be achieved through effective energy management (Aksoy et al. 2013). Global warming and climate change have made energy efficiency one of the most important issues in recent time for countries (Gülten 2020).

The aviation industry, which constitutes 2.2% of the global energy consumption, is responsible for 2% of the CO_2 emissions. (Turgut, Usanmaz, and Cavcar 2019.). Airports are responsible for 5% of the CO_2 emissions originating from aviation (ACI 2011). There are many factors that affect energy consumption at airports, according to Ortega Alba and Manana (2016): the climate of the region where the airport is located, the features of the terminal building, comfort conditions (thermal, visual and indoor air quality), and the services provided at the airport.

Airports have a significant role in passenger and cargo transportation. When airports are examined in terms of the amounts of energy consumption, they consume almost as much energy as a small city. More than 70% of the energy consumption at airports is used to meet the needs of the terminal building (Costa et al. 2012). In the terminal building, the Heating, Ventilating and Air Conditioning (HVAC) system is the argest consumer of energy (ACI 2014; Akyüz, Altuntaş, and Söğüt 2017). The rapid growth of the aviation industry and the continuous increase in the number of passengers

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traveling has also lead to an increase in energy consumption. The reduction of energy-related costs and environmental impacts introduces the need for energy management at airports.

The most effective way to avoid energy waste is energy management. It is possible to improve energy potential by 40% with existing technology and energy management even in the countries that use energy in the most efficient way (UNIDO 2015). ISO 50001 Energy Management System (EnMS) constitutes the basis of energy management. IS0 50001 EnMS forms the relevant framework and follows the processes of PDCA (plan–do–check–act) as in other management systems (Kanneganti et al. 2017; Ramamoorthy 2012). The energy planning process is the most important stage of energy management practices. In this process, preliminary audits are conducted and the outputs of energy performance are obtained. The most important of these outputs are energy performance indicators (EnPI) (Howell 2014).

In the literature, there are many studies using mathematical modeling on the factors affecting energy consumption in buildings used for different purposes and their mathematical modeling. In Gorucu a multivariable regression analysis was performed to find factors effecting gas demand and to estimate gas consumption (Gorucu 2004). The regression analysis, decision trees, and neural networks were used to estimate electrical energy consumption in Hong Kong. In the study, the variables affecting the electricity consumption in summer and winter seasons were determined and compared by all three methods (Tso and Yau 2007). In the analyzes performed by selecting the factors affecting heating energy consumption as independent variables, a multiple regression model was developed to estimate the heating energy requirement in buildings.: It was observed that their model performed well in future heating energy predictions (Catalina, Virgone, and Blanco 2008). The effect of housing type, size, age, cooling degree day (CDD) and heating degree day (HDD) values on energy consumption were examined by regression analysis. (Kaza 2010). A multiple regression model with high reliability was created to estimate energy consumptions in office buildings in five different climate regions in China. The model was compared with the simulation results and was confirmed to be a powerful model (Lam et al. 2010). A regression model that could estimate heating, cooling and auxiliary energy requirements for different HVAC systems with a high level of accuracy in office buildings was developed by Korolija et al. (2013). A multiple regression model with a simple and broad field of application that could be used to calculate heating energy requirements in buildings was created. The performance of the created model was confirmed by simulations for 17 real buildings. With the verifications made, regression analysis was proven to be an effective method that could be used to make estimates of energy in buildings (Catalina, Iordache, and Caracaleanu 2013). An energy estimation model was developed to be used in the estimation of energy consumption in houses (Jain et al. 2014). 17 design parameters in buildings were used to model the relationship between heating, cooling, and total energy consumption. The coefficient of determination was found to range from 0.94 to 0.95, which means that there was a strong relationship between the 17 variables and annual energy consumption (Asadi, Amiri, and Mottahedi 2014). Energy consumption equations for supermarkets were obtained by regression analysis performed by selecting exterior temperature and relative humidity data as independent variables and energy consumption as a dependent variable. With these equations, future energy consumption estimations were performed for supermarkets (Braun, Altan, and Beck 2014). The change of hourly and daily energy consumption in houses with outdoor temperature and solar radiation was examined using a simple and multiple regression analysis (Fumo and Biswas 2015). Two different regression models were used to obtain the relationship between climate conditions and energy consumption. This relationship has been studied for six energy sources and five different sectors (Shin, Yang, and Kim 2019).

There are many studies on energy efficiency and environmental sustainability in open literature. In the study conducted at 29 airports in Greece, the energy saving potential and improvement opportunities were evaluated. At the end of the study, it was concluded that the energy saving potential at the airports is between 15% and 35% (Balaras et al. 2003). A roof shading system built on the 3rd Terminal Building of Changi Airport, Singapore, was examined, a new image-based technique was defined in order to measure the effectiveness of lighting devices (Mardaljevic 2004). In the analyzes carried out at three airports in Italy, it was determined that a significant amount of energy savings could be achieved by using the Combined Heating,Cooling and Power (CHCP) system. Thus, it was concluded that operating costs and pollutant emissions at airports can be significantly reduced (Cardona, Piacentino, and Cardona 2006). An optimization model was developed to meet the energy needs of Thessaloniki airport, such as heating, cooling and lighting from renewable energy sources (Koroneos, Xydis, and Polyzakis 2010). A study was carried out at the 52.5 MW cogeneration facility located at Suvarnabhumi Airport in Thailand to improve energy performance. In the study, it was found that the establishment of cogeneration facilities in buildings with high energy use has greater energy efficiency and is therefore better for the environment (Somcharoenwattana et al. 2011). At İzmir Adnan Menderes Airport International Terminal different scenarios, such as using different heating, cooling and ventilation (HVAC) systems with the help of energy simulation and positioning the building in different directions, were evaluated (Ceyhan Zeren 2010). In the study conducted at two airports in Brazil, it was observed that installing a photovoltaic (PV) system on the roofs of airports contributes to reducing the effects of greenhouse gas emissions and is also a good resource for clean and renewable energy (Zomer et al. 2013). A comprehensive analysis has been carried out to reveal the energy performance, energy consumption and related emission effects of terminal buildings. In this context, before the construction of Istanbul's 3rd airport, planned to have an annual capacity of 150 million passengers, the airport's design was examined in terms of environmental sustainability (Kılkış 2014). Kılkış and Kılkış (2016) developed a five-dimensional sustainability ranking index for airports. In addition, it was concluded that the energy produced from renewable energy sources will contribute to reducing the environmental impacts at airports (Kılkış and Kılkış 2016). The establishment of a 2 MWp PV power plant at Raja Bhoj International Airport, India, was evaluated in terms of energy and environmental performance. According to the energy performance and economic-environmental benefit analysis of PV systems, it has been concluded that the initial investment cost will be repaid within 5 years and 59,200 tons of CO_2 could be saved annually (Sukumaran and Sudhakar 2017a). Cochin International Airport, India, provides all of its energy needs from the 12 MWp solar power plant installed on the apron. In this way, 12,134.26 tons of CO_2 emissions are saved each year. It has been observed that it balances the environmental effects caused by the production of the solar panels in 8 months (Sukumaran and Sudhakar 2017b). The application of thermal insulation to the walls and roof of the International Hasan Polatkan Airport, Turkey, terminal building has been evaluated from an economic and environmental aspect (Akyüz, Altuntaş, and Söğüt 2017).

In this study, the variables affecting the energy consumption, in other words, the energy performance indicators (EnPI), of the terminal building of Dalaman International Airport, Turkey, were determined. Moreover, the environmental impacts caused by energy consumption were also calculated by the life cycle assessment (LCA) method. The environmental impacts were evaluated according to global warming potential (GWP) IPCC 100a and expressed as a CO_2 equivalent ($CO_{2eq.}$). The variables affecting GWP are also named as environmental performance indicators (EvPI) in this study. The data related to energy consumption for Dalaman airport's terminal building in 2016, 2017 and 2018 and the countable variables (number of passengers, the total number of flights, degree-day, total freight carried) were obtained from the airport authority. Then, preliminary audits were conducted according to IS0 50001 EnMS standards. EnPI was determined within the scope of the preliminary studies. The energy-related greenhouse gas emission potential ($CO_{2eq.}$) of Dalaman Airport's terminal building was determined using the life cycle assessment method. The total $CO_{2eq.}$ change was also analyzed with countable variables in this study. To the author's knowledge and based on the literature review, there is no research airport-specific EnPIs studies. Another novelty of this study is that it is the first to evaluate energy-related carbon emissions and to analyze and express them mathematically for an airport using LCA. Another important novelty is that the effects of the users on the energy and environmental performance in the buildings were examined for the first time. Using the 2016 and 2017 statistics, the performance indicators for the airport terminal building were determined and expressed mathematically. The energy consumption for 2018 and the energy-related total $CO_{2eq.}$ estimations were made using the mathematical equations obtained and compared to the actual variables recorded for 2018′. These variables are; the number of passengers, heating degree day (HDD), cooling degree day (CDD), number of flights, and total freight carried. Furthermore, the mathematical models obtained by comparing the estimated and actual energy consumption for the year 2018 and the energy-related total $CO_{2eq.}$ were confirmed.

The main purpose of this study is to determine the energy performance indicators at airports using the method described in ISO 50001 EnMS. The effects of these indicators on energy consumption were determined mathematically. In addition, determining the GWP effects with LCA and regression methods and expressing them mathematically is one of the objectives of this study.

Dalaman airport

Dalaman, one of the world's leading tourism centers, has always been one of the world's focal points due to its geographic location, historical value, social structure and economic potential. Dalaman Airport is an internationally important airport that is subject to Turkish civil aviation regulations and is of vital economic, commercial and strategic importance.

Dalaman Airport is located 6 km from the center of Dalaman town. The airport has 2 terminal buildings. Terminal-1 and 2 have indoor areas of 96,500 m^2 and 122,459 m^2 respectively. At the airport, there is one concrete runway with 3,000 x 45 meters size and 57 park positions. Dalaman Airport has the characteristics of an ILS (instrument landing system) CAT II (category 2) airport according to the International Civil Aviation Organization classification. In 2018, Dalaman Airport served 35,471 aircraft. Dalaman Airport, with an annual passenger capacity of 10 million, served approximately 4.5 million passengers in 2018 (Dhmi, 2020).

Method

Obtaining planning outputs is a requirement for ISO 50001. In this study, EnPIs and the expected energy consumption equations were determined by using the past energy consumption data and the variables that were thought to affect energy consumption within the scope of the preliminary energy audits of Dalaman airport's terminal building. Furthermore, the environmental impacts caused by energy consumption and the mathematical equation of these effects were examined.

Energy performance indicators (EnPI) were determined as a result of statistical analyses performed through past energy consumption data and other variables (number of passengers, number of flights, HDD, CDD, freight, etc.) at the airport. Regression analysis is the easiest and most descriptive method that is used to determine the relationship between dependent and independent variables. Therefore, EnPIs can be determined by the equation obtained as a result of linear regression analysis with dependent and predictive variables. The most important issue to consider in linear regression analysis is not only the power of the mathematical model but also its meaning. The most important indicators of analysis outputs are the coefficient of determination (R^2), adjusted R^2 and the p value. R^2 and adjusted R^2 indicate the degree of the mathematical model, for instance, the fact that the adjusted R^2 is found to be 0.9 means that the independent variables explain the dependent variable by 90%. Furthermore, in regression analysis, the p value is important with respect to whether the relationship between independent variables and dependent variable in the selected model is significant. It is desirable for this value to be less than 0.05. The most important objectives in determining performance indicators are to continuously monitor energy and environmental performance to make predictions about the future and to measure their performance.

Regression analysis

Regression analysis is a scientific method that is used to find a mathematical model or equation between independent (predictive) variables and a dependent variable. While analyses performed using only one independent variable are called univariate regression analyses, analyses performed using more than one variable are called multivariate regression analyses (Tso and Yau 2007).

Linear regression analysis

Univariate linear regression analysis is used to model the mathematical relationship between a dependent variable and an independent variable. The equation of a line representing the linear relationship between the dependent and predictive variables is formulated by univariate regression analysis. This equation is expressed by Equation (1) (Fitzmaurice 2016; Fumo and Biswas 2015).

$$Y = \beta_0 + \beta_1 X + \varepsilon \tag{1}$$

Y represents the dependent variable and X represents the independent variable. β_0 and β_1 are regression coefficients, ε is the error between the estimated value and actual value. The estimation model of the regression model in Equation (1) is as in Equation (2).

$$\hat{Y} = \hat{\beta}_0 + \hat{\beta}_1 X_1 \tag{2}$$

$\hat{Y}$ represents the estimated value and $\hat{\beta}$ represents the estimated regression coefficient. The statistical analysis attempting to explain a dependent variable of more than one predictive variable with a linear equation is called multivariate linear regression analysis. Multiple linear regression models with more than one predictive variable are expressed mathematically by Equation (3).

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_p X_P + \varepsilon \tag{3}$$

Y is the dependent variable, X_1, X_2, ..., X_p are the independent variable. β_0, β_1, ..., β_p are regression coefficients, ε is the error between the estimated value and actual value. The estimation model of the regression model in Equation (3) is as in Equation (4).

$$\hat{Y} = \hat{\beta}_0 + \hat{\beta}_1 X_1 + \hat{\beta}_2 X_2 + \ldots + \hat{\beta}_p X_P + \varepsilon \tag{4}$$

$\hat{Y}$ represents the estimated value, $\hat{\beta}_0, \hat{\beta}_1, \hat{\beta}_2and\hat{\beta}_p$ represent the estimated regression coefficients.

Significance of the model

In linear regression, the strength of the relationship between the predictor variables and the dependent variable is determined by the coefficient of determination (R^2). This value ranges from 0 to 1. The coefficient of determination explains the power of the model. In the regression analysis performed with more than one variable, the R^2 value increases. Therefore, the adjusted R^2 (R^2_{adj}) value determines the power of the model in multiple regression analyses. R^2 is calculated by the following equation;

$$R^2 = \left[COR\left(Y, \hat{Y}\right)^2\right] = 1 - \frac{\sum \left(y_i - \hat{y}_i\right)^2}{\sum \left(y_i - \bar{y}\right)^2} \tag{5}$$

$COR\left(Y, \hat{Y}\right)^2$represents the correlation coefficient. R^2_{adj} is calculated by the following equation;

$$R^2_{adj} = 1 - \left(1 - R^2\right) \cdot \frac{n - 1}{n - p - 1} \tag{6}$$

(Fumo and Biswas 2015). k represents the number of regression coefficients (β). As it is understood from Equations (1) and (3), it is $k = p + 1$. n represents the number of observations.

One of the most commonly used methods for determining the amount of energy required for heating and cooling is the Degree – Day method and can be calculated with Equations (7) and (8) by determining an equilibrium temperature. A value that does not require heating and cooling can be selected for the equilibrium temperature. In this study, the equilibrium temperature was selected as 18 °C for heating and 22 °C for cooling temperature, and the degree day value was calculated (Kaynakli 2011).

$$HDD = \sum_{day} (T_b - T_0)^+ \tag{7}$$

$$CDD = \sum_{day} (T_0 - T_b)^+ \tag{8}$$

T_b is the equilibrium temperature, T_o is the mean daily temperature. The degree – day values were calculated with the data obtained from the meteorological station at Dalaman Airport.

Life cycle assessment (LCA)

LCA analysis is a method that evaluates all environmental aspects of a product or process starting from the extraction of the raw material from nature and returning it to nature as waste (from cradle to grave). Life cycle stages include all stages consisting of obtaining the raw materials, its processing, conversion into products or services, transportation and distribution, use by the consumer, and waste or recycling (Khasreen, Banfill, and Menzies 2009). LCA method consists of purpose and scope, inventory analysis, impact assessment and interpretation stages (ISO 2006; Rodríguez Ramos et al. 2018).

The aim of this study is the determination and mathematical modeling of energy consumption and the environmental impacts causing energy consumption. In this study, the environmental impacts caused by energy sources, (natural gas, fuel oil, and electricity), used in Dalaman airport's terminal building were obtained by the LCA method and mathematically modeled. The functional unit was selected as 1 kWh energy and the system boundary is presented in Figure 1. The data used in the LCA analysis were examined in two categories, being foreground and background data. Foreground data were obtained from technical reports and literature. Background data were obtained from the ecoinvent database existing in SimaPro software.

When the existing studies in the literature on the determination of environmental impacts due to power generation in Turkey were reviewed, all processes between obtaining the raw material of each source from nature, establishing the electricity generation facility, and completing the operational life of the generation facility were included in the determined system boundary (Atilgan and Azapagic 2016; Günkaya et al. 2016). In the environmental impact analysis of electrical generation, the functional unit was selected as 1 kWh, as in other studies. The impact values were obtained from the ecoinvent database v3.

LCA studies in the literature were examined and LCA methodology was created. In this context, the LCA study conducted in our study is similar to the previous studies in the literature. Unlike LCA studies in current scientific literature, however, the interpretation phase of this study is unique. When the open scientific literature is examined, it is clear that this is the first study in which the GWP effect at airports is expressed mathematically by a regression method.

Impact assessment

The life cycle impact assessment, or briefly, the impact assessment, is the stage in which the size and significance of potential impacts are determined and assessed in an LCA study with a defined system boundary (Curran 2012). In this study, the LCA analysis was performed for the determined system boundary, and global warming potential (GWP) was examined.

IPCC 2013 is the updated version of IPCC 2007, developed by the International Panel on Climate Change (IPCC). With this method, the effects of the climate change factor can be calculated for 20, 100

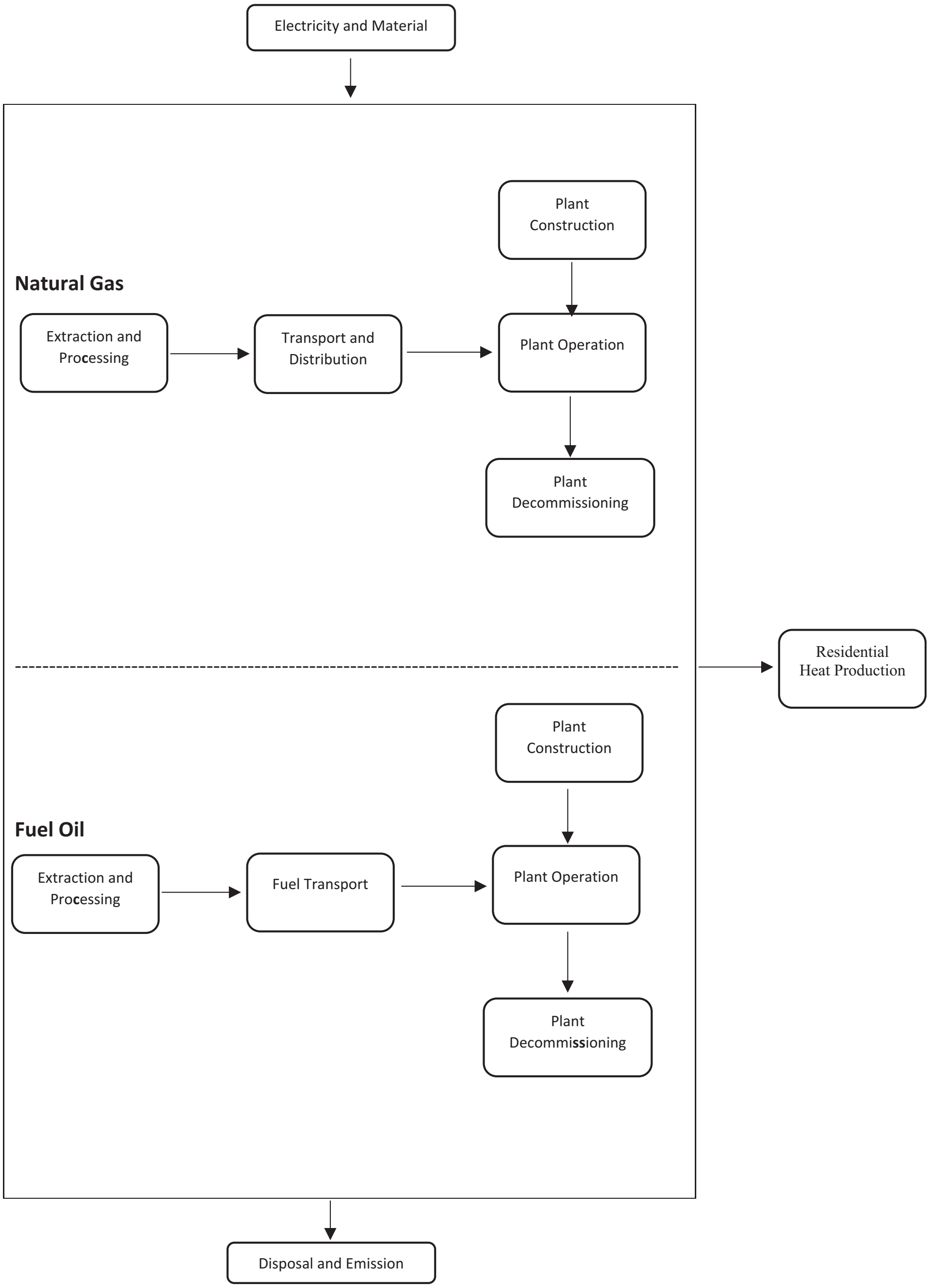

Figure 1. System boundary of LCA study.

and 500 year periods. In this study, the effects of the global warming potential (GWP) were calculated for a 100 year period. (Goedkoop et al. 2009; Lamnatou and Chemisana 2015). LCA analyses were performed using SimaPro 9.0.0.35 software. The data used in the model were obtained from the existing ecoinvent database v3 in SimaPro 9.0.0.35 software.

Result and discussion

Prediction of terminal building energy consumption

In this study, the energy consumption at airports and GWP effects caused by energy were examined specifically for Dalaman Airport's terminal building. The equations obtained in the regression analysis, which were used to determine the EnPIs required by ISO 50001, are very useful equations that can be used to make future energy consumption predictions. Furthermore, these equations can also be used to evaluate the performance of energy investments to be made (structural changes, more efficient energy systems, etc.). The change of total energy consumption in Dalaman Airport's terminal building in 2016 and 2017, on a monthly basis, with HDD, CDD, number of passengers, number of flights and the amount of freight carried was analyzed by regression analysis, and the significant results are given respectively. In the regression analysis, it was observed that the total energy consumption at the airport varied only with the number of passengers and degree day (DD). HDD and CDD values were calculated by considering operating parameters of the boilers and cooling system used in the airport terminal building. The equation of total energy consumption (E.C.) in the airport terminal building was found as the following and its unit was kWh.:

$$E.C.(kWh) = 141971 + 3468.6\, x\, DD + 1.59\, x\, Pass \tag{9}$$

As it is understood from Equation (9), the energy consumption changed by 3,468.6 kWh with 1 unit change of DD. Furthermore, the energy consumption changed by 1.59 kWh with each change of passenger in the airport. The R^2_{adj} value of the regression analysis was found to be 0.92, which means that there was a very strong positive correlation between energy consumption and the independent variables (DD and the number of passengers). In other words, the change in the number of DD and number of passengers accounted for energy consumption by 92%. The relationship between estimated energy consumption calculated by Equation (9) and actual energy consumption is shown in Figure 2. As is understood from Figure 2, the equation obtained is a powerful equation that can be used for future energy consumption predictions in the airport terminal building.

The energy consumption of the terminal building of Dalaman Airport was estimated by Equation (9) obtained using the 2016 and 2017 data and and compared to the actual variables recorded for 2018. . Subsequently, the relationship between the estimated value and the actual energy consumption in 2018 was examined. In other words, the power of the equation obtained (the prediction) was validated. As is understood from Figure 3, there is a strong relationship (91.6%) between the actual energy consumption and the energy consumption predicated by Equation (9) for 2018. The strong relationship between estimated and actual energy consumption for 2018 confirms the impact of EnPIs on energy consumption. It also shows that estimation equations are important equations that can be used to evaluate future energy performance.

The mathematical relationship between the change in the number of passengers and energy consumption is shown in Equation (10).

$$E.C. = 710248 + 1.3\, x\, Pass. \tag{10}$$

The linear relationship between total energy consumption and the number of passengers is presented in Figure 4. The R^2 value obtained here was 0.62. Only the number of passengers is weak in explaining the energy consumption in the airport terminal building. Climate conditions play an important role in this impact.

The relationship between energy consumption predictions based on the number of passengers in 2018 and the actual energy consumption in 2018 is presented in Figure 5. As it is understood from Figures 3 and 5, degree day significantly affected the energy consumption of the terminal building.

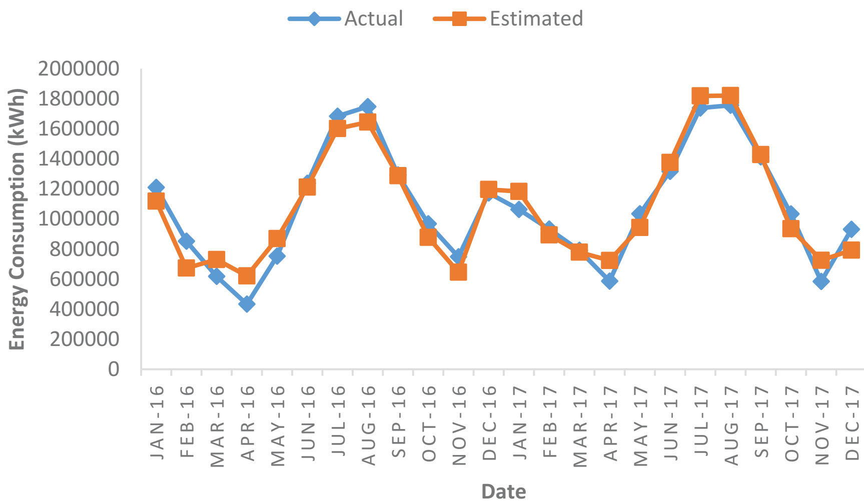

Figure 2. Actual and estimated energy consumption in 2016 and 2017.

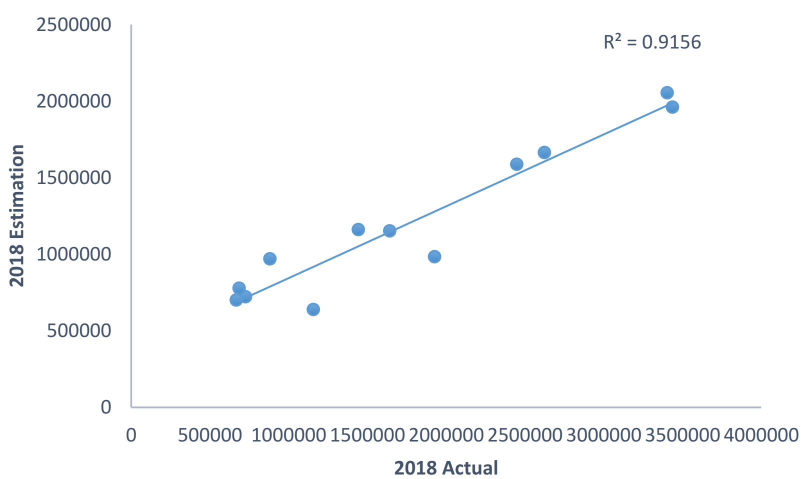

Figure 3. Relationship between actual and estimated energy consumption in 2018.

Summer season

In this study, the analyses were performed separately in the months during which heating and cooling were needed in the terminal building. Due to its location and climate region, the terminal building was heated between November and April and cooled between May and October. The relationship between total actual energy consumption in May – October 2016 and 2017 and the other variables (CDD, number of passengers, the total number of flights, freight carried) was examined. In the regression analysis performed for the summer season, the relationship between energy consumption and the predictive variables was found in Equation (11).

$$E.C. = 308454.2 + 4570.3xCDD + 1.04\,x\,Pass. \tag{11}$$

For this model, the R^2_{adj} value was obtained as 0.95. This value indicated that there was a strong relationship between energy consumption and variables (CDD and number of passengers) in the summer season. The power of this relationship is also understood from Figure 6. As is understood

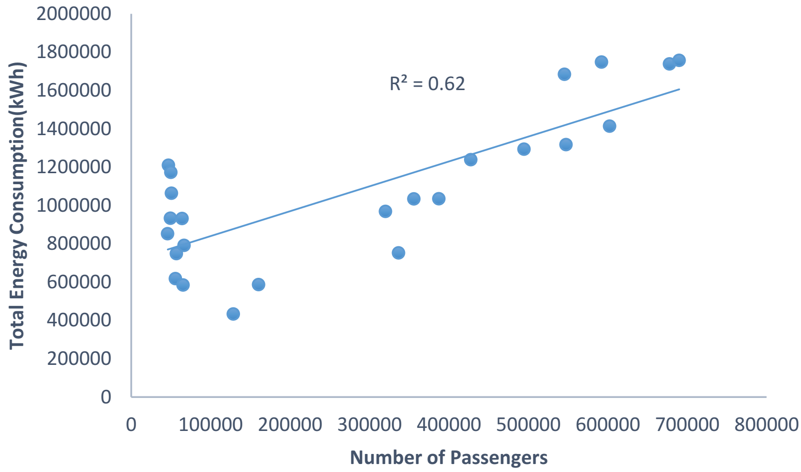

Figure 4. Relationship between total energy consumption and the number of passengers.

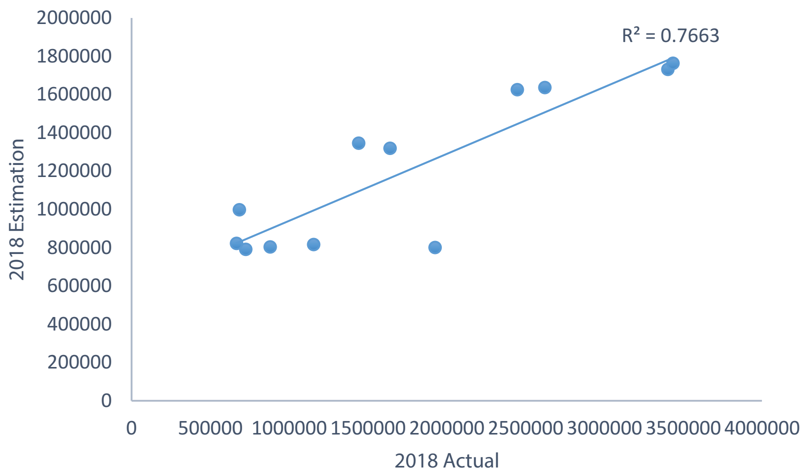

Figure 5. The relationship between actual and estimated total energy consumption based on the number of passengers in 2018.

from Equation (11), each change in the CDD and the number of passengers led to an energy change of 4,570.3 kWh and 1.04 kWh, respectively.

Winter season

Dalaman Airport's terminal building was heated between November and April. HDD was calculated by considering the heating parameters of the heating system, and the change in total energy consumption was examined. As a result of the regression analysis, it was determined that the energy consumption in the winter season was only related to the HDD. Although the R^2_{adj} value was found to be high in the regression analysis performed with all combinations of other predictive variables, it was observed that the p values were greater than 0.05. The mathematical relationship between total energy consumption and HDD is presented in Equation (12).

$$E.C. = 279812 + 3235.6\,x\,HDD \tag{12}$$

As it is also understood from the equation, each change of HDD led to a change of 3,225.6 kWh in energy consumption. In this model, HDD explained 82% of energy consumption, as can be seen in Figure 7.

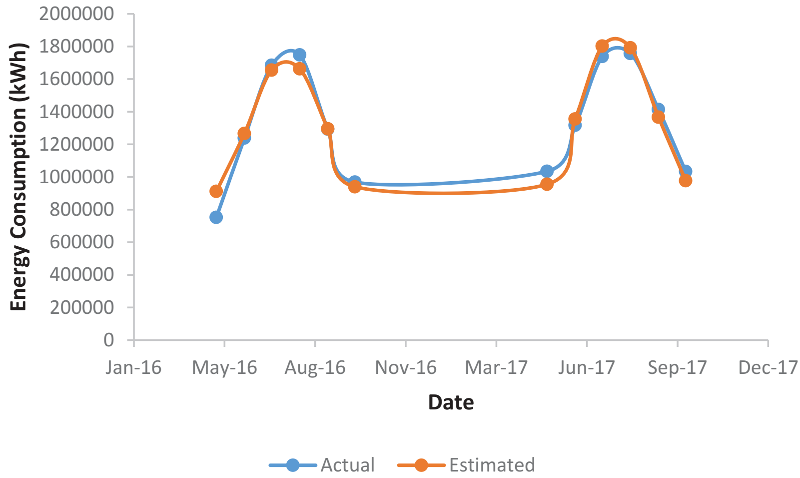

Figure 6. Actual and estimated energy consumption in the 2016–2017 summer season.

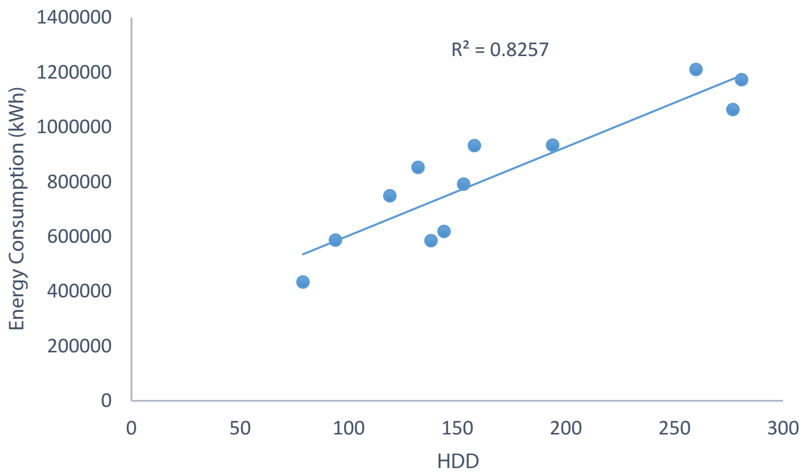

Figure 7. Relationship between total energy and HDD in the winter season.

Prediction of terminal building energy-related $CO_{2eq.}$

In this study, the system boundary of $CO_{2eq.}$ value, which is a measure of GWP, was calculated by considering all the processes presented in Figure 1. The effects of GWP were calculated for a 100 year period. Furthermore, the mathematical relationship with other quantifiable variables (HDD, CDD, number of passengers, load carried, the total number of flights) were analyzed. Kg $CO_{2eq.}$ value calculated as a result of the production of 1 kWh heating energy from natural gas and fuel oil was calculated at the system boundary specified in Figure 1. The values obtained were calculated with Equations (1)–(4). The following equations were obtained by calculating the environmental effects (kg $CO_{2eq.}$) caused by 1kWh energy in the LCA study. The amount of greenhouse gases from energy consumption is given as CO_2 equivalent ($CO_{2eq.}$). As is seen in Equation (13), $CO_{2eq.}$ changed by 1.44 kg and 1,428 kg, respectively, with each change in the number of passengers and DD,

$$CO_{2eq.} = 92990 + 1428xDD + 1.44\,x\,pass. \tag{13}$$

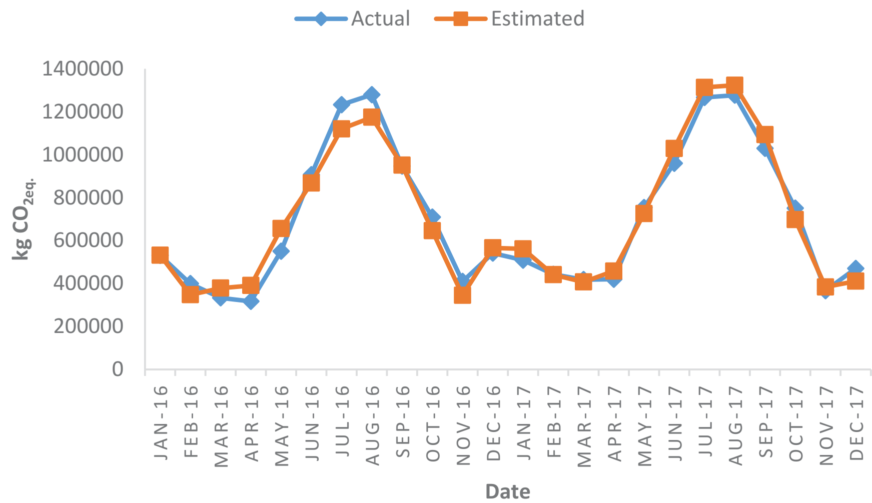

Figure 8. Actual and estimated kg $CO_{2eq.}$ in 2016–2017.

In this equation, the R^2_{adj} value was calculated as 0.965, which means that the amount of greenhouse gas from energy consumption was strongly related to external climate conditions and the number of passengers. Nevertheless, the relationship between total kg $CO_{2eq.}$ caused by energy consumption and the estimated value using Equation (13) is presented in Figure 8.

The estimation was made with the number of passengers and DD values for 2018 using Equation (13). Figure 9 shows the relationship between the actual and estimated value for 2018. A very strong relationship was found between the estimated and actual values. The power of the equation was verified by comparing it with the actual values.

The energy consumption-induced kg $CO_{2eq.}$ for the summer (May – October) and winter (November – April) seasons were analyzed separately to demonstrate the effects of CDD and HDD. The relationship between $CO_{2eq.}$ amount and variables (number of passengers and CCD) in the summer season is shown in Equation (14).

$$CO_{2eq.} = 208549 + 3777.5xCDD + 0.68\,x\,Pass. \tag{14}$$

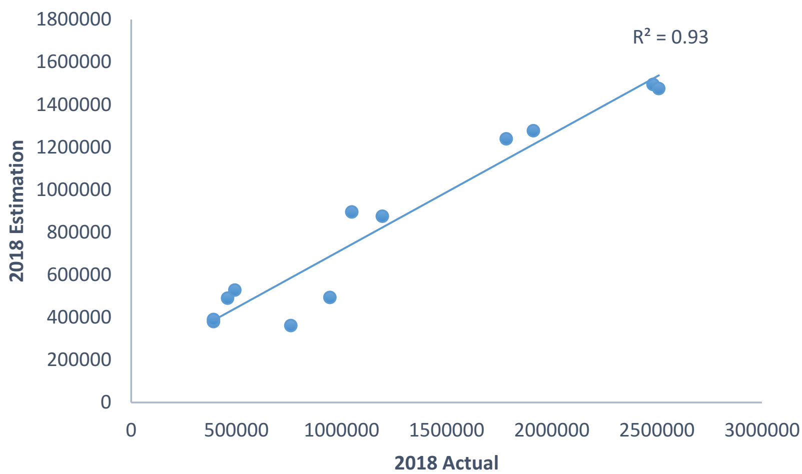

Figure 9. Relationship between the actual and estimated kg $CO_{2eq.}$ in 2018.

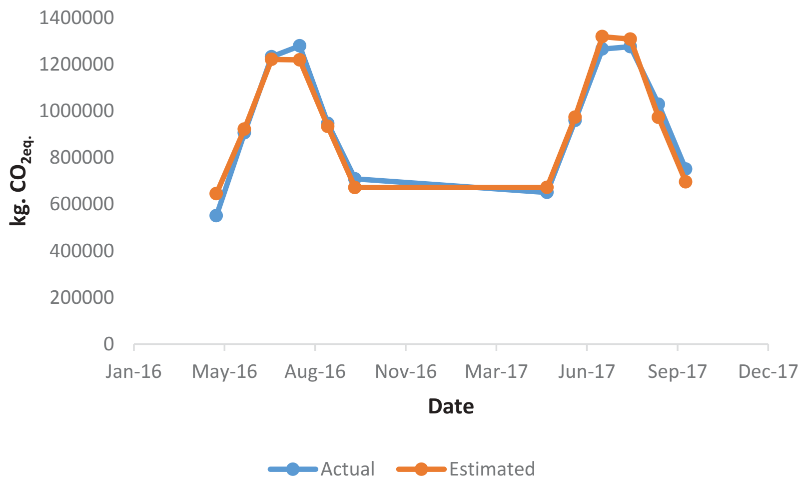

Figure 10. Actual and estimated kg $CO_{2eq.}$ in 2016–2017 summer.

As is understood from Equation (14), each increase in the CDD and passengers in the summer season led to 3,777.5 and 0.68 kg $CO_{2eq.}$ increase, respectively. In the analysis performed for the summer season, the R^2_{adj} value was found to be 0.96, representing that there was a very strong relationship. The relationship between total energy consumption related to the total kg $CO_{2eq.}$ in the summer season and the value estimated using Equation (14) is presented in Figure 10.

In the analyses performed for the winter season, kg $CO_{2eq.}$ value had a significant relationship only with HDD, as in the prediction of energy consumption between November – April. The mathematical relation between kg $CO_{2eq.}$ and HDD was obtained as in Equation (15).

$$CO_{2eq.} = 276729 + 897 \text{ x HDD} \tag{15}$$

In this equation, the R^2 value was found to be 0.78 as shown in Figure 11, which means that the total amount of kg $CO_{2eq.}$ was explained by HDD by 78%.

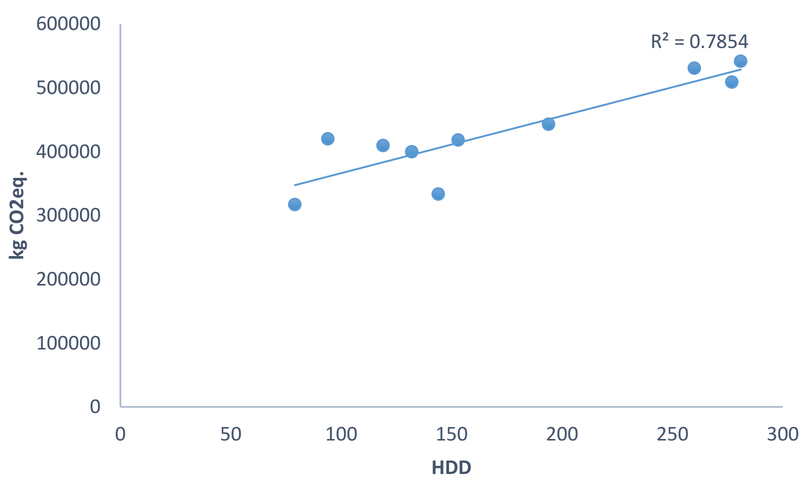

Figure 11. Relationship between kg $CO_{2eq.}$ and HDD in 2016–2017 winter.

Conclusion

It is known that there are many parameters that affect energy consumption in airports. However, how these factors affect energy consumption can be determined by regression analysis performed as specified in ISO 50001 EnMS. ISO 50001 requires the determination of EnPIs regardless of the scope, size, or type of organization (public or private). Regression analysis is the most commonly used method for determining the relationship between variables. EnPIs can be determined for the airports with significant results obtained from such analyses. In this study, EnPI and EvPIs were determined for Dalaman airport's terminal building. In the analyses, the effect of the number of passengers and external climate conditions (DD) on energy consumption was expressed mathematically and the power of this relationship was given. Moreover, the energy-related environmental impact assessment was expressed mathematically by LCA method, and the power of the relationship was determined. The analyses were performed using 2016 and 2017 (24 months) data. It was observed that energy consumption varied with the number of passengers using the airport and DD, which is a measure of exterior temperature, and these variables explained energy consumption by 92%. In this study, the variables affecting energy consumption were separately determined and modeled for the seasons during which the airport terminal building was heated (winter) and cooled (summer). For the summer season, it was observed that CDD and the number of passengers explained energy consumption by 95%. In the analyses performed for the winter season, energy consumption was found to be associated only with HDD. The amount of $CO_{2eq.}$ caused by energy consumption was obtained by LCA analysis to determine EvPIs. EvPIs were determined using energy-related $CO_{2eq.}$value and the countable variables of the airport (HDD, CDD, number of passengers, number of flights, freight carried). In the analyses performed using 24 months of data, it was observed that the number of passengers and DD explained the amount of $CO_{2eq.}$ caused by energy consumption by 96.5%. This value also indicated that the equation was very close to the correct equation. The amount of $CO_{2eq.}$ was also analyzed separately for summer and winter. It was found that the GWP effect in the summer season could be explained with CDD and the number of passengers by 96%. In the winter season, it was observed that the amount of $CO_{2eq.}$ changed only by HDD.

Estimation equations were obtained by using the 2016 and 2017 data. Energy consumption and kg $CO_{2eq.}$ estimates were made for 2018 with the obtained equations. The estimated values were compared with the actual values for 2018 and it was determined that there was a strong relationship between the estimated and actual energy consumption for 2018 and kg $CO_{2eq.}$ In other words, the equations obtained were verified. In all analyses, EnPI and EvPIs were determined as passenger numbers and DD values for the airport terminal building. With this study, EvPIs were determined and mathematically expressed at the airports for the first time based on the LCA method. With the equations obtained, estimations can be made for the future of Dalaman airport's terminal building. Moreover, the performance of energy efficiency investments can also be determined by using these equations. The following topics are suggested for future studies.

- Determination of energy improvement opportunities by carrying out detailed audits
- Evaluation of renewable energy potential and comparison with current situation
- Examining the effects of passenger behavior on energy consumption

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