Energy and Carbon Loss Management in an Electric Bus Factory for Energy Sustainability

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Increasing energy need brings people one step closer to energy saving and alternative sources. The search for reliable and sustainable resources also contributes greatly to technological progress. Thanks to advanced technology, energy use becomes more efficient. However, the concept of sustainability emerges in the field of energy as in other sectors. It is expected that electric vehicles, which have started to increase in interest in recent years, will make a positive contribution to issues such as environmental protection and sustainable energy. In addition, production centers for electric vehicles should also be sustainable and sensitive to carbon emissions. In this study, energy and carbon loss assessment was carried out in an electric bus manufacturing factory. With the help of linear regression analysis, the data of the last 3 years were evaluated. Moreover, as a result of internal audits, energy loss points were determined. As a result of this study, sustainability, carbon loss, and energy management issues in an electric vehicle production factory were evaluated and guiding qualities for today's and future technology companies were revealed.

Keywords: Energy management, carbon loss, sustainability, energy sources, electric bus.

1 Introduction

The increase in energy demand due to the growth in human population all over the world drives people to both find new renewable energy types and decrease the usage of energy. Besides the energy demand, the scarcity of conventional energy sources can play a significant role in energy research. While applying various energy decrease methods, the phenomenon of energy efficiency appears. The phenomenon of energy efficiency can be defined as a decrease in energy usage with unchanged financial positivity, prosperity, and compromise in products [1]. Alternative energy sources that today's research can be sorted as wind, water, solar, natural gas, petroleum, wave, hydrogen, and geothermal. Each of these energy sources produces the electricity that is recent years' favorite energy type. Sustainability, the strong dominator of the 21st century forces several areas such as energy, design, manufacturing, and automotive to be more flexible and innovative. Besides the beneficial results of being sustainable, humanity and a livable environment are strong triggers of this phenomenon. The energy sector looking for new sources that are renewable and sustainable, designers take into account long-live products and also they pay attention to new and sustainable designs, the automotive sector has much know-how on lightweight cases so mass reduction corresponds to less CO2 release which is a more sustainable product. A case study [2] that is focused on the lightweight of a commercial seat is a reliable example of this issue. This weight reduction study benefited from the finite element method and innovative design technics with state-of-art materials. Correlation of different materials and thickness variation was conducted to get light and reliable seats. Results of this study revealed 20 % more light seats. Thus, 20% weight reduction will be achieved in the vehicle in which this seat is mounted, thus reducing overall fuel consumption and reducing carbon emissions in terms of the environment. Another study [3] aimed at light door hinges for the vehicle. This study is also related to lightweight vehicles. Three different aluminum hinges were compared to steel one in finite element analysis. As a result of analyzes carried out without compromising safety standards, 65% weight reduction was achieved with aluminum alloy. The same as the previous example, reduced weight provides more sustainable products.

Energy sources that rely on fossil fuels are the main environmental contaminators and they cannot promise the future. In view of sustainability, renewable energy sources such as wind and water are good candidates for this issue. Electric vehicles are in recent years the most discussed topic. Besides the usage of these vehicles providing sustainable energy consumption, the meeting of the energy demand of these vehicles from renewable sources seems “Yin-Yang” figure. Otherwise, the dream of a clean environment, energy sustainability, and low carbon release cannot come true. In view of sustainability, EPI [4] sorts 180 countries on various performance indicators and releases annual environmental performance reports. These annual reports are like exam papers for countries and are good for the process of taking action for sustainability. While stating sustainability, it is good to mention that climate change is also a significant result of this. United Nations meet for climate change (UNFCCC) [5] and this is called as COP. The last meeting COP 26 was held in England in 2021 so this meeting is the continuation of COP 21 that is the meeting which is the Paris agreement [6] was signed by countries. In this meeting, countries saw their status since Paris agreement was signed.

The aforementioned climate change is associated with carbon emissions. Carbon emission is defined as the diffusion of carbon dioxide that the production of combustion reaction to the atmosphere [7]. Also, it is stated that carbon dioxide emission is associated with financial growth, energy consumption, and population growth [7]. Regardless of its type, energy use is essential in every production process. In general, electricity is the main supporting energy type for production areas. The source of the energy used in production should be the responsibility of the producers. There is also a production history of internal and external manufactured goods. Obtaining the energy used at any stage of this production process has the potential to release carbon to the environment. Monthly or annual audits are a good trigger for carbon emission consciousness in factories.

Electric vehicles generally known, are used since 19th century. Although vehicles with an internal combustion engine in early times took over the electric vehicles by facilities of mass production and financial prons, electric vehicles started to appear again due to sustainable environment worries. Some features such as quietness, user-friendliness, environmentalist, and high efficiency make electric vehicles more attractive when compared to vehicles with internal combustion engines. Commercial vehicles like public transportation vehicles or trucks play a critical role in the transportation of people and goods. Due to their high fuel consumption, their carbon emission and harmfulness to the environment are much higher than passenger cars. From this perspective, electrification of commercial vehicles is more beneficial and effective for both decrease in carbon emission and an increase in energy usage efficiency and sustainability.

In the literature, there are several energy management and efficiency-related study. Özer and Güven [1] studied on energy efficiency of dyeing factories. Evaluation of production and energy consumption by regression analysis was conducted. As a result of the improvement of this study, the efficiency of energy consumption was increased by 49%. Also, it is worth mentioning that production planning show 23% decrease in energy consumption. Katchasuwanmanee, Bateman, and Cheng [8] studied on energy management in an automotive manufacturing plant. For this, they examined temperature in the manufacturing area, evaluated HVAC control system, observed manufacturing information, and simulated smart energy management. By conducting these, it was revealed that simulation of energy management reduced the energy consumption in summer by 15% and in winter by 10%. Öztürk [9] studied on energy consumption in the production of textile goods. He states that electricity, oil, LPG, and coal are energy sources for the textile industry. He highlighted the electricity usage for production, lighting, and HVAC. Results of this study state that increase in electric consumption and heat energy when there is an increase in production. The author states that by these results, an estimation can be provided for any production level and a decrease in production cost for any energy saving. Taner, Sivrioğlu, Topal, Dalkılıç, and Wongwises [10] studied on energy management in sugar production. They generally focused on energy consumption analysis, production quantity, and energy efficiency. To achieve this energy management, they production and energy consumption were controlled, and then energy usage was obtained. A numerical reliability study was conducted. In the results of this study, energy usage and production quantities of the last 3 years was listed and evaluated for finding the relation between energy consumption and sugar production. It has been seen that energy-saving results will be achieved for this study with energy optimization.

Energy consumption graphics constantly hit milestones every year. Turkish Ministry of Energy and Natural Sources [11] declares that electric consumption went up by 8,1% as 331,5 billion kWh in 2021 according to 2020. This consumption will be 370 kWh in 2025 and 591 kWh in 2040 according to a prediction study [11]. Such a significant increase in consumption will bring along the growth in the need for energy production. Thus, both energy production methods should rely on renewable sources, and energy consumption should be taken into account. Therefore, energy consumption and efficiency are the included issues in this study.

In 2011, International Standards Organization (ISO) released the ISO 50001, which describes the features and implementation of the energy management system [12], [13]. ISO 50001 is also referring to other standards such as ISO 9001 and ISO 14001 [12]. This standard was designed regardless of the conditions of the company to be applied and does not impose a set target for the optimization of energy consumption in the company [13]. The company can apply the ISO 50001 standard if it wants to establish a basis for energy management [13]. The energy management standard is created in companies to integrate with production processes and increase energy efficiency. Companies and business partners are expected to reduce energy intensity and carbon emissions in their work environments by using ISO 50001 as a tool [14]. ISO 50001 leads to continuous improvement of consumption efficiency, without specifying an evaluation criterion in terms of energy. at the same time, the specified standard is based on the Plan-Do-Check-Do (PDCA) framework in energy management [15]. This study includes specific energy consumption, specific carbon consumption, and examination of energy–carbon loss in electric bus manufacturer companies. Energy & carbon consumption predictions for 2022 were accomplished by the regression analysis. Carbon reduction studies are very important for electrified commercial vehicles so carbon prediction and sustainability management will be acquired with the help of advanced analysis methods. This study is providing a unique aspect of electric vehicle production with the methods mentioned.

2 Methodology

The automotive industry has been activated in an industrial area at Bursa since 1999. The specified electric bus manufacturing factory is located in a total area of 200.000 m2 and a covered area of 96.000 m2 with approximately 1500 workers. This factory produces electric vehicles with welding, painting, and assembly stages at this location. The capacity of the facility is 30.000 vehicles per year.

In this study, the energy consumer points have been detected and have been assigned to energy efficiency projects. Also, the relationship between energy consumption and carbon consumption was reviewed by using linear regression analyses and was detailed with the graph as a cumulative summary (CUSUM). Eventually, Specific Energy Consumption (SEC) was used in all scientific data. This section includes subheadings as Energy Management, Linear Regression analysis, and finding Energy Losses, and carbon

Figure 1: *Flow of the methodology.*

Losses respectively. The flow of the methodology can be seen in Figure 1.

2.1 Energy Management

This study comprises that electric consumption evaluation will be conducted that obtained and evaluated between 2019 and 2021 in electric bus manufacturer factory.

In view of usage, two types of sources such as electricity and natural gas were benefited. For this reason, energy values should be calculated for these two different sources separately. In view of energy consumption, SCADA values for the last three years were used with the software of Power Studio. SEC values are an important Key Performance Indicator (KPI) for following the energy consumption of the automotive factory. SEC values can be calculated.

$$SEC = \frac{\text{TotalEnergyConsumption}}{\text{TotalNumberofProduct}} \tag{1}$$

In addition, energy efficiency will be calculated at the end of energy projects energy efficiency can be calculated as;

$$Efficiency(\%) = \frac{\text{consumption}_\text{f} - \text{consumption}_\text{e})}{\text{consumption}_\text{e}} \times 100 \tag{2}$$

2.2 Linear Regression Analysis

Linear regression analysis is a reliable numerical method to see the energy consumption evaluation and prediction. This method is a modeling type that predicts the desired values by handling easily detectable variables. Variables that were wanted to define should be continuously sorted numerically. Also, it is stated that regression analysis is affected by extreme values and distribution properties [16]. Linear regression analysis is a useful tool to indicate the value correlations and future prediction. Since this study aimed the energy management for electric bus manufacturing, the authors focused on energy consumption per year.

The usage of regression analysis for energy predictions has increased with ISO 50001 EnS. In this study, regression analysis was used to determine the Energy Performance Indicator (EnPI) according to the energy consumption over the last 3 years. For calculating regression analysis, the amount of produced vehicle number was selected as the dependent variable, and energy consumption was preferred as the independent variable.

2.3 Finding Energy Losses

This study will be used the loss analysis method in factory dynamics. While creating the loss analysis method 7 energy sub-loss types were determined. They are as;

- Losses due to useless consumption
- Losses due to overconsumption
- Losses due to non-optimization

- Losses due to not using recoverable energy
- Transmission losses
- Transformation losses
- Lack of renewable energy use

A loss collection system was created by Supervisory Control and Data Acquisition (SCADA) and employee cooperation in the factory. Thus, losses and leakages in energy can be prevented immediately.

2.4 Carbon Losses

In this study, the internal methodology of the factory was used for carbon losses as Scope 1 and Scope 2 emissions reduction were followed by associating with energy losses:

$$CO_2 = \sum_{k-1}^{n}(Dak + NCVk + EFk) + (1 - BR)k + OFk) \quad (3)$$

In equation 3, parameters as Da, NCV, EF, BR, and OF correspond to Activity of Data, Calorific Value, Emission Factor, Rate of Biomass, and Oxidation Factor.

3 Results and Discussion

3.1 Energy Management

Energy studies were started with the energy consumption definition including the kind of energy type of the factory. These studies provide the opportunity to the related product and efficiency of energy and carbon emissions. Especially, when the loss analysis and product relationship are determined correctly, energy projects will be prioritized and efficiency will be increased. Thus, the carbon efficiency of electric vehicle producer companies will be increased, and carbon-neutral targets throughout its life cycle will be achieved.

Production mainly depends on two main energy sources that are electricity and natural gas in the factory. Types of energy resources that used in the factory for the last 3 years are given in Figure 2.

Total energy consumption may not always show the correct prediction of the energy performance of the factory. Specific Energy Consumption (SEC) is another preferable supporter for this reason. SEC graphics can be seen in Figures 3 and 4. According to SEC values, the energy and carbon consumption per product are calculated through regression analysis in Figure 4 for energy consumption and Figure 5 for carbon consumption.

3.2 Linear Regression Analysis

The aforementioned regression analysis study results were illustrated in Figures 6 and 7

In Figure 7, it is seen that R2 values for Scope 1 and Scope 2 emissions are quite low (3% and 13% respectively). This shows that direct and indirect carbon emissions in electric bus production are not directly related to the production of the vehicle. For this reason, a carbon loss system has been created. In the carbon loss analysis, it is expected that 'Type 1 – Useless Consumption' and 'Type 7 – Lack of Renewable Energy Use' will be high and these losses are expected to be intervened. Thus, the study was focused on non-production energy and carbon loss projects.

3.3 Energy and Carbon Loss Analysis

When the loss structure for automotive companies is analyzed, energy losses are among the top 10 losses. Energy and carbon losses per product are given in Figure 8.

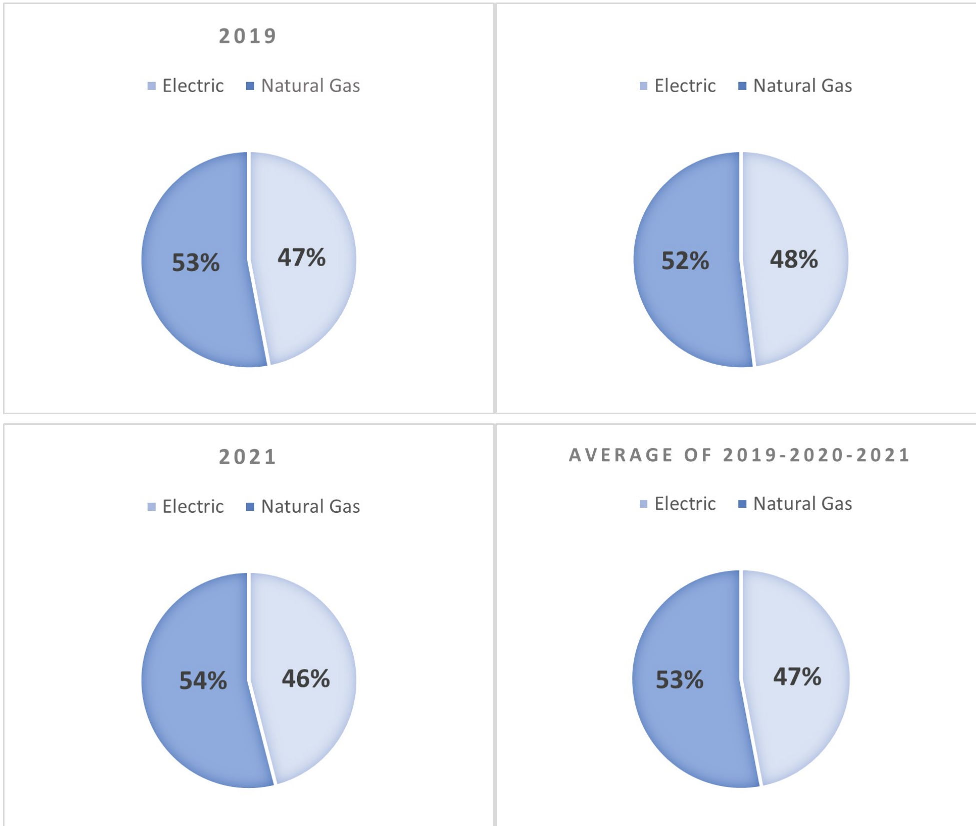

Figure 2: *Energy consumption rates between 2019 and 2021.*

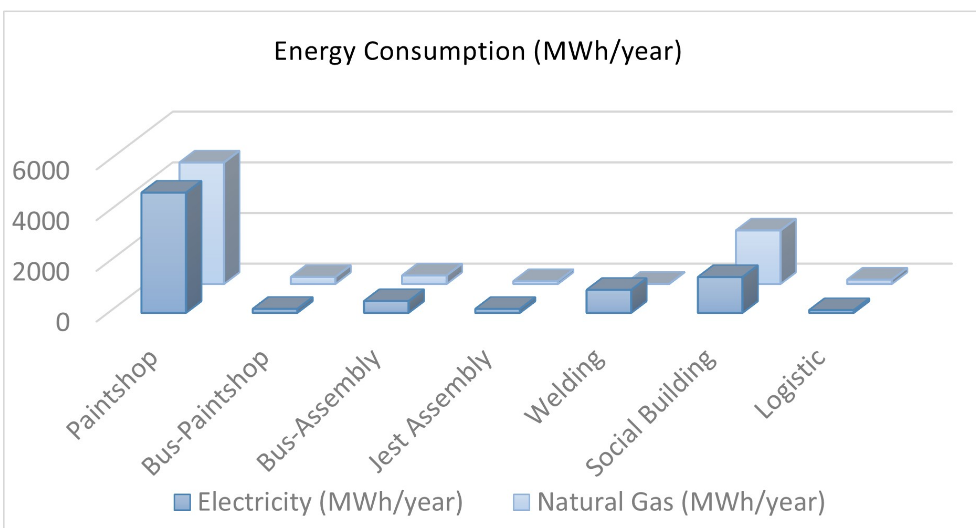

Figure 3: *Energy consumption according to units (MWh/year).*

Considering the directions about sustainability, electric vehicle producers should consider carbon tax and other carbon costs. For this reason, in this study, the carbon costs of the energy projects determined

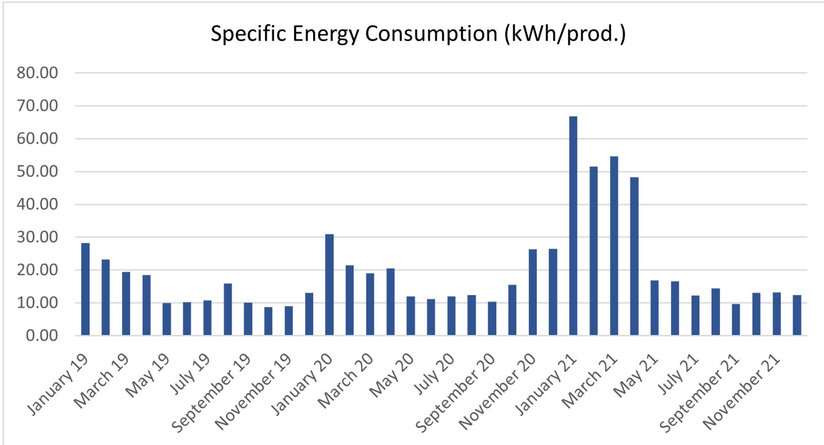

Figure 4: *Specific energy consumption (2019 to 2021).*

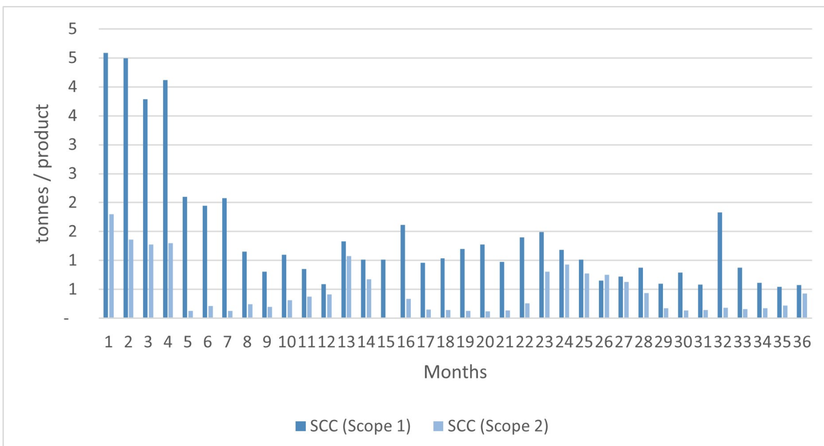

Figure 5: *Specific carbon consumption for scope 1 and scope 2 emissions (2019 to 2021).*

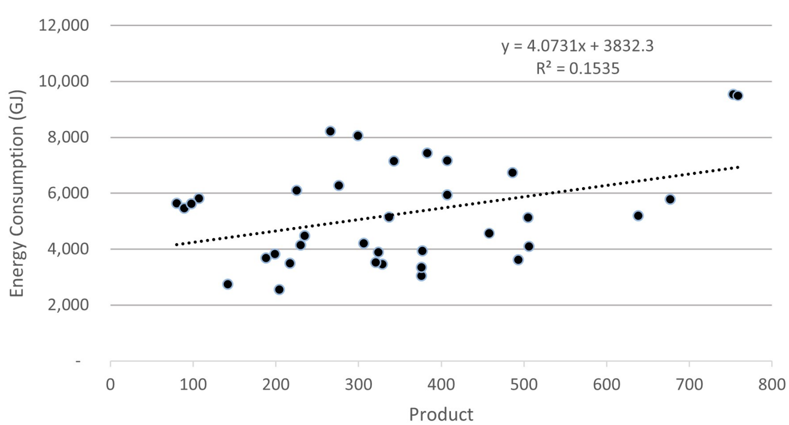

Figure 6: *Regression analysis for energy consumption.*

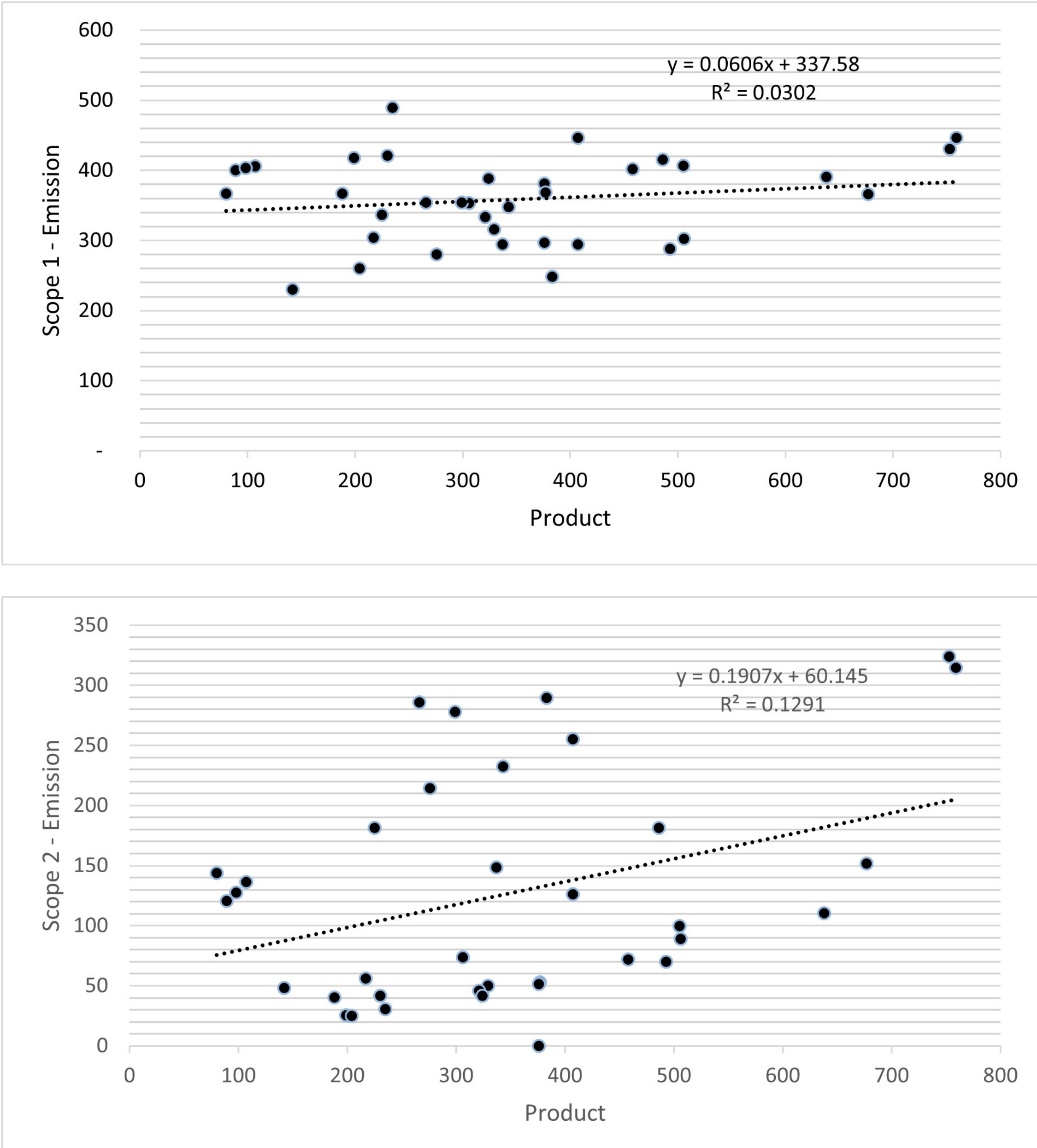

Figure 7: *Regression Analysis for Scope 1 Emissions (above) and Scope 2 Emissions (below).*

for feasibility are included. İdentified carbon costs can be listed as;

- Unnecessary Consumption
- Overconsumption
- Lack of Optimization
- Lack of Recoverable Energy Use
- Transmission Losses

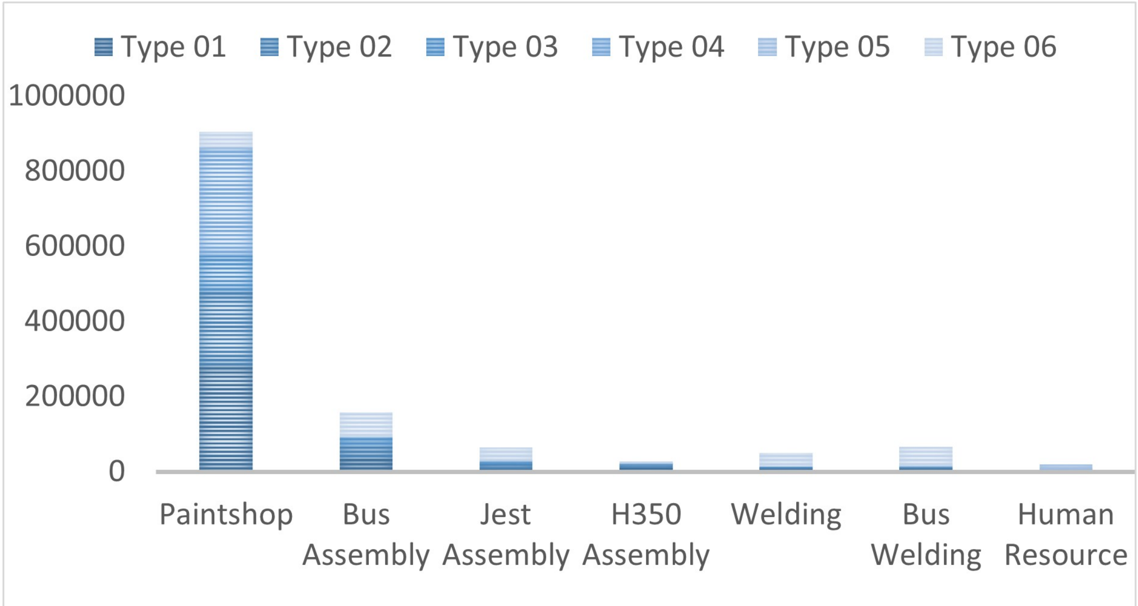

Figure 8: *Energy and carbon losses per unit (Average).*

- Transformation Losses
- Lack of Sustainable Energy Use

Energy loss identification and Significant Energy User (SEU) are followed by energy project creation. In this context, energy-saving improvements include;

- Pump/motors
- Compressors
- Lightning
- Cabins and drying ovens

Cabins and drying ovens are stated as the most used and lost energy in the automotive industry. Therefore, it is significant to priority according to energy consumption. These projects include prevention of energy consumption due to air leaks, recovery of waste heat, boiler efficiency, transformation to less consumer lighting technologies, and efficient operation at the pump or/and motor systems.

The numerical values determined according to the aforementioned equations are shown in the following sub-headings, near the values are indicated in parentheses from which equation they are obtained.

Unnecessary Consumption
The losses are related to unnecessary consumption. In the cataphoresis tank, unnecessary consumption was determined as 86.3 kWh with help of SCADA. Wrong-designed equipment is defined as the root cause of this loss. Energy loss due to useless consumption was prevented and 384.312 kWh energy saving was achieved (eq.2) by adding an inverter. Finally, 191 tonnes of carbon saving was achieved as scope 2 emissions (eq.3).

Over Consumption
The overconsumption creates a loss. 80 kWh energy overconsumption was determined in the air preparation unit of the heating system with the help of SCADA. Lack of system knowledge was defined as the root cause. It was defined from SCADA data that there is still consumption for the levels of upper 22 OC. Also,

it is possible to use outside air by adding a valve system. 70.400 kWh/year (eq.2) and 14 tonnes carbon saving as Scope 1 (eq.3) was gained.

Lack of Optimization
The losses are related to also deficiency of optimization. Lack of optimization was revealed with the evaluation of the pump and 19 kWh energy consumption was saved by increasing the efficiency of pumps. Lack of equipment was defined as the root cause. By changing pumps with brand new, 98.000 kWh/year (eq.2) and 49 tonnes/year carbon saving as Scope 2 (eq.3) were achieved.

Lack of Renewable Energy Use
The losses are also related to the lack of recoverable energy using in the compressor units. 181 kWh energy recovery was detected with an analysis. Lack of technology was defined as the root cause. The addition of heat recovery unit to the output of compressors resulted in the factory saving 452.500 kWh/year (eq.2) and 84 tonnes/year of carbon as Scope 1 (eq.3).

Transmission Losses
Cooling chiller overload brings about loss. This loss was detected with the help of SCADA as 47 kWh energy consumption for the cooling chiller. Lack of knowledge is the root cause of this loss as well. By changing the water transmission line instead of the cooling unit and it was a disabled cooling unit in summer. This modification made the factory save 48.465 kWh/year (eq.2) and 24 Tonnes/year as Scope 2 (eq.3).

Transformation Losses
Energy consumption during the time of rest is a significant loss. It was detected with the help of theoretical calculation and 40 kWh energy consumption in the lighting system. 36.000 kWh/year (eq.2) and 18 tonnes carbon emissions as scope 2 (eq.3) gained by adding a field scanner sensor that reduces the magnitude of lighting automatically when area usage is reduced.

Lack of Sustainable Energy Use
Renewable energy technology usage affects the loss. It was detected as 7.000 MWh/year with the help of a feasibility report. The root cause is lack of technology in this scenario. This project is not yet completed and at the end of this process, 7,000 MWh/year (eq.2) will be used from renewable energy. Also, it will be a carbon-neutral factory for Scope 2 emissions. Total carbon and energy gained are given in Table 1 below.

Table 1: Energy and Carbon Savings in Types of Losses

Losses	**Electric (kWh/year)**	**Natural Gas (kWh/year)**	**Scope 1 (tonnes/year)**	**Scope 2 (tonnes/year)**
Unnecessary Cons.	384.312	-	-	191
Over Cons.	-	70.400	14	-
Lack of Optimization	98.000	-	-	49
Lack of Renewable Energy Use	-	452.500	84	-
Transmission Losses	48.465	-	-	24
Transformation Losses	36.000	-	-	18
Lack of Sustainable Energy Use	7.000.000	-	-	3.481
Total	7.566.777	522.900	98	3.763

4 Conclusions

In this study, studies on energy management and carbon loss in the electric vehicle production factory were carried out and the findings were evaluated. In addition, the energy consumption values between 2019 and

2021 were gained and illustrated. Regression analysis for energy consumption per product number showed increase in product number corresponding to an increase in energy consumption as expected. With this issue, some fluctuation was observed on graphics. Environmental status has an effect on the production process thus consumption values were varied. For instance, while the number of 677 vehicles produced in figure 1 required approximately 6590 GJ, the real amount was revealed as 5782 GJ. This is because the variable environmental conditions such as weather, internal temperature, and mental state of employees. Electric and natural gas consumption between 2019 and 2021 averaged 53% and 47% for electric and natural gas respectively. Electricity consumption is dominant at this rate, and therefore, the use of sustainable energy sources will have a significant impact on the financial budget of the factories. In view of resource usage per unit, while the welding unit was expected as the most consumer, the PaintShop was seen on the top of the list among the other specified units. It was thought that compressors are critical equipment for energy consumption in this unit. Moreover, the internal temperature is important by qualified production. Paintshop was followed by social building. For sustainable and quality production, it is necessary for employees to have sufficient rest time. Making necessary improvements without sacrificing social units will provide financial savings. When the revealed energy loss points are evaluated, it has been revealed that the lack of information about the equipment used or the system has a significant effect on the energy loss issue. In this context, providing training on hardware knowledge and process mastery throughout the company and increasing energy consumption awareness will provide significant advantages on an annual basis.

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