Koc. J. Sci. Eng., 7(2): (2024) 131-136 https://doi.org/10.34088/kojose.1447855

Kocaeli University

Kocaeli Journal of Science and Engineering

http://dergipark.org.tr/kojose

# Well-to-wheel Analysis of Greenhouse Gases Emissions for Dispenser Operation in the Apron of Istanbul Airport: A Comparative Study

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**Article Info**

**Research paper**

*Received* *: March 6, 2024*
*Accepted* *: April 19, 2024*

**Keywords**

*Airport operation*
*Refuelling*
*Dispenser*
*Life cycle assessment*
*GHG emissions*

## Abstract

This study aims to compare greenhouse gas (GHG) emissions of diesel-powered dispenser (DD) and electric-powered dispenser (ED) that are providing refuelling services at Istanbul Airport. The emissions of both dispensers within the framework of the Well-to-Wheel (WTW) system boundary are calculated in kilograms of carbon dioxide equivalents (kg $CO_2$ eq.) according to the Intergovernmental Panel on Climate Change (IPCC) report. The study shows that for a "1 $m^3$ refuelling", the GHG emissions of a DD are approximately 14.1 times higher than those of an ED, with a total of 0.549 kg $CO_2$ eq. ED is found to be dominant in reducing the emissions during refuelling, even in a situation where fossil sources dominate the current electricity generation mix. This shows that switching to electric vehicles (EVs) instead of vehicles using diesel fuel may be an appropriate choice at airports with significant operational potential. However, the environmental impact of the ED should be considered in a broader context with a comprehensive life cycle assessment that includes all phases.

## 1. Introduction

Greenhouse gas (GHG) emissions have created a worldwide environmental concern due to the climate change it causes and the increasing natural disasters associated with it. In recent years, the European Union (EU) and developed countries have made international agreements within the scope of reducing GHG emissions. It is seen that many developing countries are included in these agreements and make reduction commitments.

Transport is one of the most important sources of fossil fuels and accounts for more than a third of carbon dioxide ($CO_2$) emissions from end-use sectors. To achieve Net Zero Emissions by 2050, it is predicted that $CO_2$ emissions from transportation must be reduced by more than 3% per year by 2023 [1]. For this purpose, the use of alternative fuels (hydrogen, biofuel, etc.), the electrification of vehicles, and the use of renewable energy sources in electricity generation are becoming increasingly common all over the world.

In addition to contributing to the world economy, the aviation sector is one of the modes of transportation with intense energy consumption and significant environmental impacts [2]. It accounts for 12% of $CO_2$ emissions from all modes of transport [3]. Between 2% and 5% of aviation emissions come from airport-related emissions [4].

Aviation emissions can be decreased by creating more efficient operations, integrating new technologies and energy options that provide zero emissions and low carbon production. Environmental sustainability studies can indicate which airport operations should be prioritised and whether new designs, activities or the use of renewable energy sources (RES) will be beneficial. For that purpose, it is necessary to understand and examine the effects of both produced and consumed products on the environment.

Life cycle assessment (LCA), as defined by the International Organization for Standardization (ISO) 14040 and 14044, is a methodology used to determine the environmental impacts of a product, process or service throughout its entire life cycle [5]. Previous studies have investigated terminal building operations [6], ground handling and aircraft operations [7], airport pavement

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design alternatives [8], and alternative aviation fuels [9] environmental impacts.

In this study, the GHG emissions of two different dispensers providing jet fuel refuelling services on the apron of Istanbul Airport are evaluated within the Well-to-Wheel (WTW) system boundary.

## 2. Materials and Methods

### 2.1. Study area

Istanbul (41°N, 28°E) is located on the northwest of Türkiye. It is not only most economically and industrially developed megacity, but also a major transport, manufacturing and logistics centre. The city is bounded by the Black Sea to the north and the Sea of Marmara to the south, with the Bosporus straits separating the continents of Europe and Asia. It also has two major international airports, Istanbul Airport and Istanbul Sabiha Gokcen.

Istanbul Airport covers an area of approximately 7650 hectares and is located 35 kilometres from the city centre between the villages of Tayakadın and Akpınar on the Black Sea coast. It has a total of five runways and a terminal with the capacity to handle 90 million passengers a year. With 425,897 flights at Istanbul Airport in 2022 - 109,634 domestic and 316,263 internationals - the airport handled 65.2 million passengers. The study area and the location of the airport are shown in Figure 1.

### 2.2. Refuelling/Operation phase

To establish a sustainable operation at the Istanbul Airport, it was planned to convert the diesel-powered dispenser (DD) to an electric-powered dispenser (ED). The project was the first to have the jet fuel supply vehicles which used on the apron electrically manufactured. The technical specifications of the dispensers were provided by the fuel supplier company (TFS, Turkish Fuel Services) and summarized in Table 1.

The process of refuelling an airplane consists of three steps: (1) the dispenser leaves the charging/diesel station and arrives at the apron; (2) the aircraft refuels; and (3) after the refuelling is finished, the dispenser leaves the apron and drives back to the charging/diesel station.

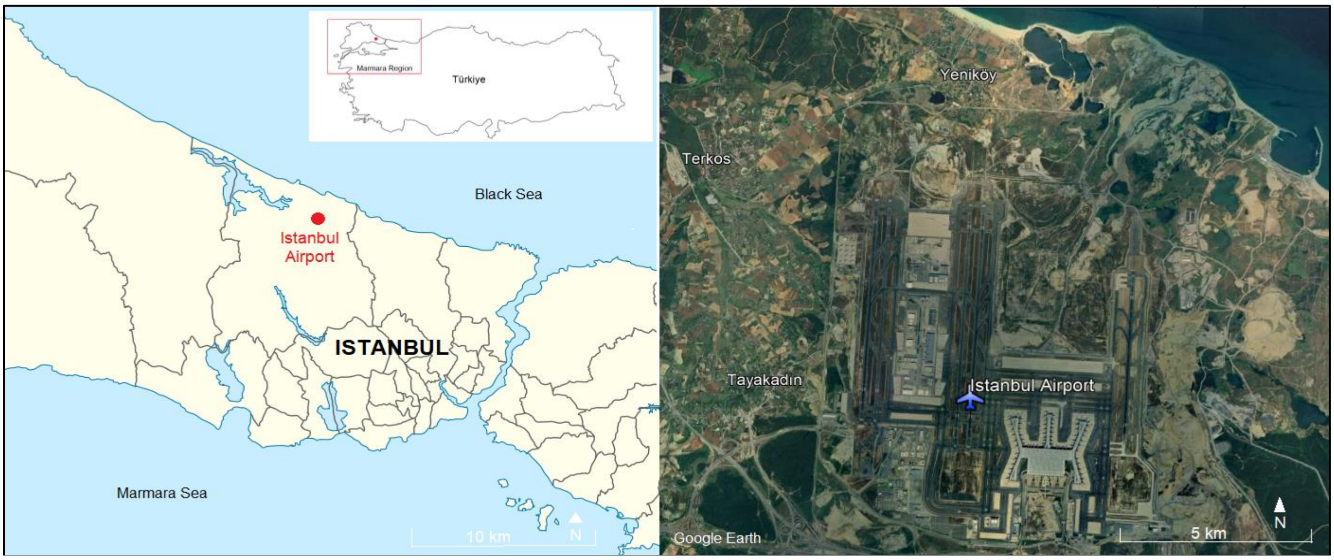


**Figure 1.** Location of Istanbul Airport, Istanbul, Türkiye (41°16'2.74"N, 28°43'38.87"E).

**Table 1.** Technical specifications of dispensers.

| Parameters | Electric-powered dispenser (ED) | Diesel-poweredispenser (DD) |
|---|---|---|
| Total Weight | 3040 kg | 2950 kg |
| Battery type | Lithium-iron Phosphate | - |
| Battery Package Capacity | 53 kWh | - |
| Engine type | Permanent magnet synchronous motor | Common Rail + SCR |
| Electric/diesel consumption per $m^3$ refuelling | 0.06 kWh | 0. 15 L |
| Lifetime (year) | 25 | 25 |

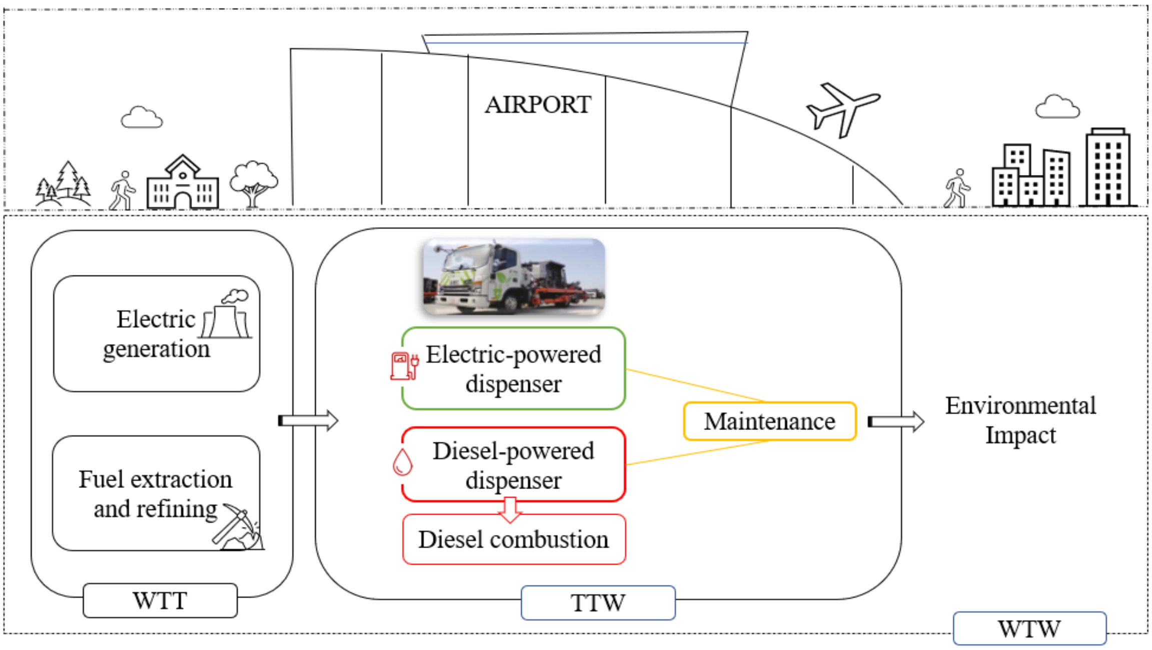


**Figure 2.** The framework of system boundary in this study.

## 2.3. WTW analysis

LCA has been conducted by ISO 14040 and ISO 14044 [10-11] standards, in the following main steps: 1) Goal and scope definition, 2) Life cycle inventory, 3) Life cycle impact assessment and 4) Interpretation.

WTW analysis is a simplified LCA application that consists of two stages: Well-to-Tank (WTT) and Tank-to-Wheels (TTW) and can be used for transportation policy [12-13]. The WTW estimates GHG emissions of the vehicles covering the extraction of the energy (fuel or electric etc) source, production, distribution (WTT), and energy conversion or consumption in the vehicle (TTW) [14-17]. In this study, the evaluation of electric and diesel-powered dispensers included the fuel cycle within the system boundary of WTW (Figure 2).

## 2.4. Inventory for WTW system boundary of dispensers

The WTT stage of the DD included fuel extraction and refining, transportation, and distribution of fuels. In the TTW phase, the exhaust emissions caused by the combustion of the fuel and the maintenance of the dispenser are discussed. As seen in Table 1, the fuel consumption of the DD, which has a total mass of 2950 kg, was 0.15 L per 1 $m^3$ of refuelling. The WTT and TTW phases of the DD were modelled using the Ecoinvent database. It is one of the widely used databases and is used as the source of background data for transportation vehicles literature [16, 18-21]. The background data are generally representative of global and European averages.

The power mix of Türkiye is considered to determine the impact of the WTT stage of ED. Türkiye generated 326.2 TWh of electrical energy in 2022, a 2.5% decline from the year before. The contributions of various sources to the nation's total electricity mix can be seen in Figure 3. In 2022, 34.6% of electricity was produced from coal, 22.2% from natural gas, 20.6% from hydropower, 10.8% from wind, 4.7% from solar power, 3.3% from geothermal energy, and 3.7% from other sources [22].

The electricity consumed by ED, which has a total mass of 3040 kg, was 0.06 kWh per 1 $m^3$ (Table 1). Since the ED does not directly cause emissions during refuelling, only its maintenance was considered. The data used for the evaluation of electricity generation was taken from the Ecoinvent database. The transmission, distribution and charging losses were also included in the analysis.

Fuel and electric consumption data was provided by the company that carries out the aircraft supply service on the apron. There is no data on the maintenance phase of dispensers considered in this study in the literature and databases. For this reason, the estimated data of a passenger car for the maintenance phases was used for calculations [23-25].

During the aircraft refuelling, the dispensers run at idle until the end of refuelling. Because of this, the non-exhaust emissions sourced from tire, wheel, and road wear were neglected. In this study, “1 $m^3$ refuelling” was used as functional unit to make comparison of GHG emissions between dispensers.

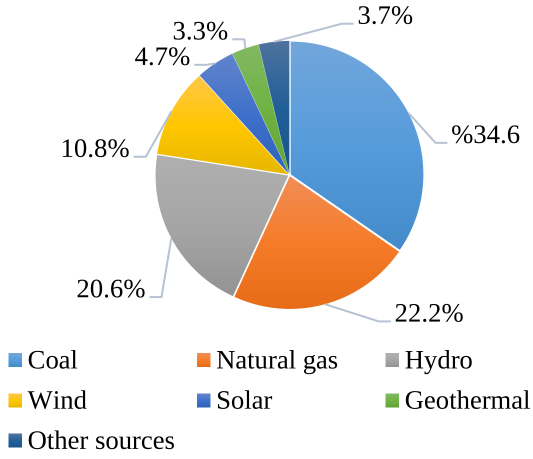


**Figure 3.** Distribution of Türkiye's electricity generation by resources in 2022.

### 2.6. Assessment method

The GHG emissions of the dispensers are calculated in kilograms of carbon dioxide equivalents (kg $CO_2$ eq.) using the 100-years global warming potential (GWP) based on the Intergovernmental Panel on Climate Change.

## 3. Results and Discussion

Figure 4 illustrates the percentage contributions of each phase that forms the WTW system boundary to the GHG emissions for dispensers. With 87.6% of the total GHG emissions, exhaust emissions from the diesel-powered dispenser during refuelling were the main contributor. The contribution of the fuel extraction and refining and maintenance phases to GHG emissions was approximately 11% and 1.42%, respectively (Figure 4a). It has been observed that 83.3% of the emissions of ED originate from the WTT phase and 16.7% from maintenance, which represents the TTW phase (Figure 4b). The total GHG emissions from the ED were calculated to be 0.0390 kg $CO_2$ eq. For 'refuelling 1 $m^3$', the GHG emissions of a DD are approximately 14.1 times higher than those of an ED, with a total of 0.549 kg $CO_2$ eq. GHG emissions from the diesel combustion phase are dominant in the TTW. It shows that the emissions generated by the DD running at idle during refuelling significantly affect the results. In the TTW phase, as almost zero exhaust emissions are produced by ED, the most significant impact comes from electricity generation.

Studies show that the environmental performance of the use phase of electric vehicles (EVs) depends mainly on the electricity mix used to provide energy to the vehicles and that integrating RES into electricity generation improves environmental impacts [16, 19, 24, 26-27]. Athanasopoulou et al. showed that the lowest $CO_2$ emissions of EVs were observed in countries with higher ratios of renewable and nuclear energy [28]. Shafique et al. (2022) showed that the operation phase of the electric vehicle in 2050 will cause 85.91% lower GHG emissions compared to the current year, and the reason for this is the increase in the share of RES in electricity generation according to base on the Hong Kong electricity mix [25].

According to Turkey's 2022 electricity generation mix, which is used as a basis for evaluating the current situation, natural gas and coal are the main sources of electricity production (56.8%). Despite fossil resources being dominant, ED had less GHG emissions. This was because ED does not need to run during refuelling and the amount of electricity required for only the display of devices was very low (0.06 kWh). According to the Turkish National Energy Plan, it is estimated that nuclear energy will be included in the electricity generation mix in the future years and will have a share of 11.1% in 2035 [22]. To this purpose, the construction of the Akkuyu Nuclear Power Plant (NGP) is currently ongoing. The first reactor is aimed to be put into operation in 2024. Also, the share of wind and solar energy will reach a total share of 35% in 2035. By increasing the proportion of RES in the electricity used by EVs for charging, there can be a significant reduction in GHG emissions for the use phase [24].

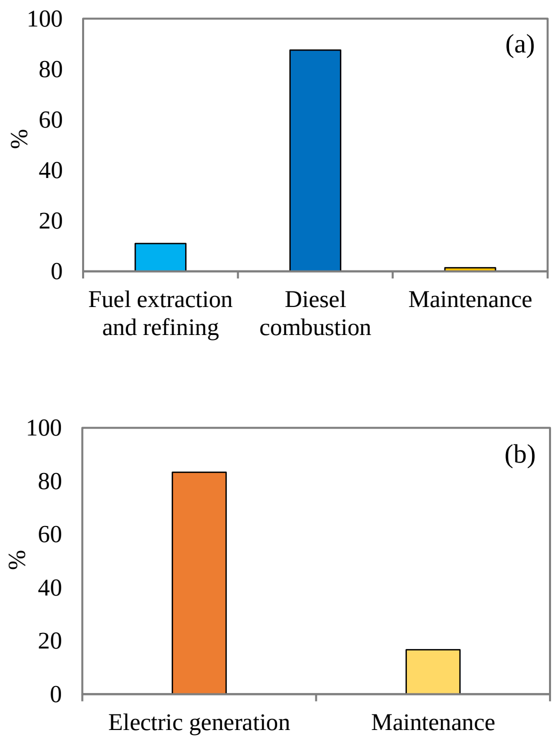


**Figure** 4. Characterization results for GHG emissions; (a) Diesel-powered dispenser (b) Electric-powered dispenser.

## 4. Conclusions

The GHG emissions of refuelling/operation phase of the diesel-powered and electric-powered dispensers used for refuelling at Istanbul Airport were evaluated within the framework of the WTW system boundary.

ED is found to be dominant in reducing the GHG emissions during 1 $m^3$ jet fuel refuelling, even in a situation where fossil sources dominate the current electricity generation mix. The refuelling/operation phase of ED caused 92.9% less GHG emissions than DD. Electricity generation has been the main influencing factor for results, as there are almost zero exhaust emissions produced in the case of the TTW phase of EDs. However, ED created less GHG emissions because it was not idle during refuelling and the amount of electricity it consumed was low.

This shows that switching to EVs instead of vehicles using diesel fuel may be an appropriate choice at airports with a significant operational potential. In addition to expanding the use of EVs at airports, options for adapting a cleaner energy option to airport operations for future transport electrification should be considered and encouraged.

## Limitations

It can be said that the use of ED for refuelling at airports has an advantage in improving the effects on the environment. However, this study is a preliminary study focusing only on the effects of dispensers within the WTW system boundary. It does not cover the production phase and end-of-life phases of dispensers.

The environmental impact of the ED should be considered in a broader context with a comprehensive life cycle assessment that includes all phase. This will contribute to the identification of hot spots of other phase of the vehicles at included in the operating fleet and future improvement study.

## Declaration of Ethical Standards

The author(s) of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

## Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Acknowledgements

This study was funded by Scientific Research Projects Coordination Unit of Istanbul University-Cerrahpasa. Project number FDK-2021-35905.

We are thankful to the Turkish Fuel Service (TFS) for providing the data during the study.

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