

HEAVY-DUTY VEHICLE SELECTION BY USING AHP AND TOPSIS METHODS: THE GREEN LOGISTICS PERSPECTIVE

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ABSTRACT

Environmental sustainability and reduction of carbon emissions have become important and essential in the logistics sector as in many other public and private sectors. Transportation is the most energy consuming activity among all logistics activities. Using less energy-consuming transportation vehicles, reducing carbon emissions and creating energy-efficient facilities are some of the strategies used to alleviate these environmental issues.

The purpose of this research is to develop a decision support model for selection of heavy-duty vehicles (HDVs) and determining the criteria needed for this selection in the scope of green logistics. In the propose Multi Criteria Decision Making (MCDM) model, the selection criteria and their importance were determined by using the Analytic Hierarchy Process (AHP) method. The criteria and their degrees of importance obtained by AHP method were used in Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) method. Selection was made by using TOPSIS method among three types of vehicles which are mono compressed natural gas (Mono-CNG) powered vehicles, CNG-Diesel dual fuel powered vehicles and diesel-powered vehicles. CNG-Diesel dual fuel powered vehicles occurred as most preferable.

Keywords: Sustainability; Carbon Emissions, Green Logistics.

1. Introduction

Transportation costs are increasing every day by increasing oil prices. Nowadays, companies are prioritizing applications that will reduce their carbon foot-prints while selecting their suppliers. In many countries, while carbon emitting activities are regulated for environmental reasons, activities that reduce carbon emissions are encouraged. The use of natural gas as fuel in heavy-duty vehicles reduces transport costs together with carbon and exhaust emissions. However, when selecting vehicles, investment costs, vehicle and fuel supply constraints of natural gas-powered vehicles due to the comparison of diesel-powered vehicles. The rate of increase in natural

gas prices is lower than fuel prices and the cost gap between fuel and natural gas prices are continuously increasing in favour of natural gas. Therefore, first of all, criteria and their weights of selection vehicles need to be determined.

Considering the 2007 survey of the Intergovernmental Panel on Climate Change (IPCC); logistics sector has 13.1% share in total carbon emissions which is one of the main factors causing climate change. According to the World Economic Forum (WEF) calculations in 2009, the impact of the logistics sector on global greenhouse gas emissions is 5.5 % or 2.8 million ton. According to 2014 OECD/IEA data, the share of the transportation sector in world carbon dioxide emissions has increased up to 25% in Figure 2 [14].

Use of CNG and LNG accounts 15–27% reduction in greenhouse gas (GHG) emissions effect per km travel [11]. Thus, it is important to consider ecological in addition to economic criteria involving investment decisions in the logistics sector. Transportation activity has a significant share in logistics operations. Transportation activities within the scope of green logistics have a large scale affected on the environment. Therefore, green transportation is one of the main components of green logistics [17].

Nowadays, the increasing fuel prices increase the interest in the use of more economical alternative fuels. It is known in the world that natural gas provides an advantage over other petroleum product fuels in terms of cost. The fact that natural gas contains less carbon components than other fuel types reduce carbon emissions and exhaust emissions, making natural gas a more environmentally friendly, carbon-emission-reducing and much more economical fuel type.

Reducing the fuel consumption cost with the use of natural gas in vehicles is a sufficient reason to increase the use of Natural Gas Vehicles (NGV's). On the other hand, with the use of natural gas as fuel in vehicles, it is also contributing to the reduction of the carbon emissions in terms of environmental sensitivity and sustainability, which is one of the most important issues in today's world. Other options for reducing fuel consumption costs and associated transportation costs by using natural gas-powered vehicles are the use of OEM mono natural gas-powered vehicles with factory original manufacturer.

It is clear that carbon emission reduction efforts that can be carried out in every field of the logistics sector, which has such a large share in carbon emission, will greatly benefit the total carbon reduction. By determining the criteria and their importance level in heavy-duty vehicles selection, a contribution will be made to the literature on heavy-duty vehicle selection under green logistics concept.

The purpose of this study is to choose among heavy-duty commercial vehicle alternatives with different fuel types, taking into account the reduction of carbon emissions and transportation costs within the scope of green logistics. In this study, three of different type of heavy-duty vehicles powered by CNG, CNG-diesel dual fuel and diesel are compared to each other by considering their carbon emissions and transportation costs under green logistics concept. First, the criteria and their importance level were determined by AHP method. Then, these criteria and their importance level were used as the criteria weights in the TOPSIS method. Finally, selection was made by using the TOPSIS method. AHP pairwise comparisons and TOPSIS forms were filled by eleven experts who work

in logistics, fuel and natural gas distribution, automotive sectors and academia. In addition to expert opinions, sectoral organization reports (as mentioned in 2nd and 3rd part of this study) were used as well.

2. Vehicle Alternatives by Fuel Types

Nowadays, the raise in fuel prices increased the interest in the use of more economical alternative fuels. Cost advantages of natural gas over other petroleum products have been well established. Due to its lower carbon content compared to other fuel types, natural gas is more environmentally, friendly and economical [19].

Natural gas mainly consists of various hydrocarbons, methane (CH_4) and ethane (C_2H_6), is colourless and odourless and slightly lighter than air. Liquefied natural gas (LNG) is the liquid form that can be retained in special insulated tanks at -160°C . Compressed natural gas (CNG) is stored under 250 bar pressure in high pressure tanks [13].

Natural gas has been used as fuel in vehicles for a long time. According to “Natural Gas Vehicle (NGV) Global Reports” on November, 2018, there are 26,455,793 natural gas-powered vehicles in the world. The number of natural gas filling stations and NGV’s distribution by regions are shown in Table 1 [19].

Table 1: Natural Gas Vehicle Distribution by Regions in the World

Regional Growth	NGVs	Stations
Asia-Pacific	18.509.677	18.735
Europe	1.863.167	4.893
North America	205.000	1.930
Latin America	5.621.350	5.480
Africa	5.621.350	208
Total	26.455.793	31.246

Source: [19]

The CNG-Vehicle segment accounted for noticeable share of global NGV Market and is projected to experience significant growth in the near future (Figure 1). Figure 1 is for representative purposes and does not depict actual sale statistics.

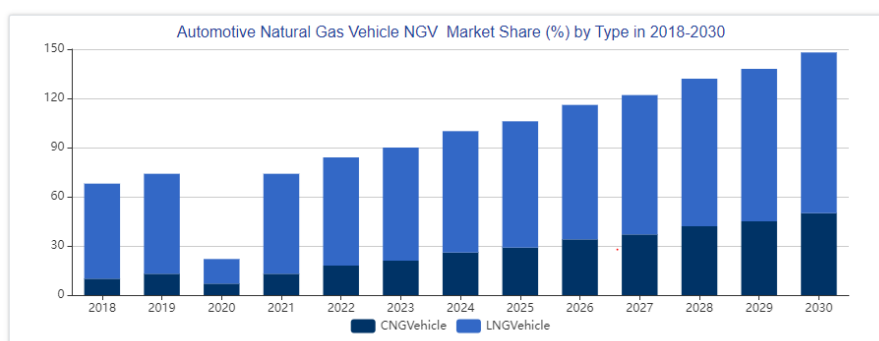


Figure 1: Estimation of CNG and LNG Vehicle Numbers in the World Up To 2030 (Source: [19]).

As the sectors are examined that have a significant impact on carbon dioxide emissions in the world, the transportation sector comes in second place with a share of 25%, as seen in Figure 2.

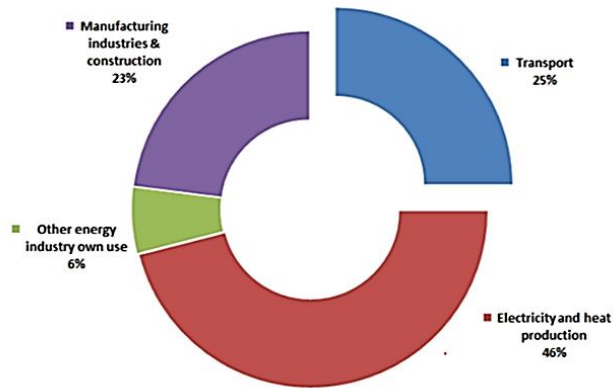


Figure 2: Shares of World CO₂ Emissions Resulting from Fuel Consumption by Sectors (Source: [20])

Petroleum-derived fuels are used in all transportation methods. Combustion of these fuels emits carbon dioxide and other gases into the atmosphere. The most important criterion for being more environmentally and friendly in logistics is to ensure that the engines of the vehicles used in all transportation methods work cleaner and more efficiently and consume less fuel [16].

When the transportation sector is examined within itself in Figure 3, road transportation ranks first in carbon dioxide emissions by a large margin compared to other transportation modes and logistics buildings [35].

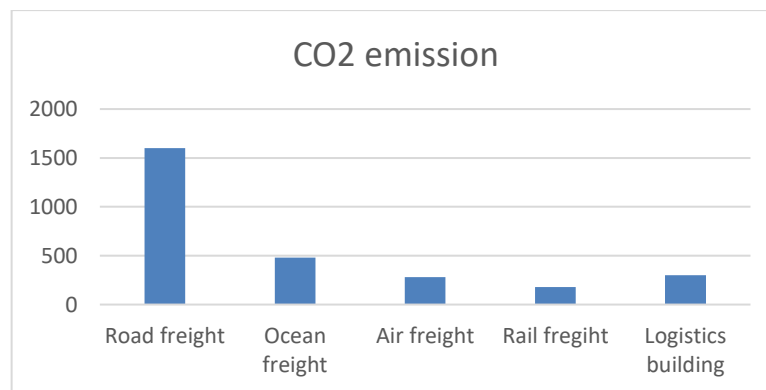


Figure 3: Annual Carbon Dioxide Emissions in the World Logistics Sector – Million Tons (Source: [35])

In this study, diesel, natural gas, natural gas-diesel dual fuel powered vehicles were examined and compared according to fuel types. Since, LPG fuelled vehicles are preferred in passenger cars and electric motor driven vehicles are preferred in both passenger cars and city buses, they are not included in the scope of this study.

2.1. CNG-Diesel Dual Fuel Powered Vehicles

It is an alternative fuel system that vehicle powered by CNG and diesel fuel together in the same engine. Using CNG conversion kits, the amount of diesel consumed in the engine is reduced; CNG and diesel consumed together. Therefore, it is called as “dual fuel system”. Since natural gas fuels are cheaper and have lower exhaust emissions than diesel fuel, vehicles using dual fuel system are more economical and more environmentally.

Advancements in electronic control systems have increased the efficiency of these dual-fuel vehicles. It is expected that the use of dual-fuel systems will become more widespread due to economic and environmental.

Reysaş and many other logistics companies have been using CNG-Diesel dual fuel powered vehicles for years in Turkey. Return on investment period of dual-fuel conversion systems is less than one year as of European average fuel prices November, 2023 (Table 4.).

It is expected that increasing diesel prices will shorten this payback period. CNG and LNG are becoming an expanding market for companies selling natural gas. CNG-Diesel dual fuel powered system working scheme is shown in Figure 4.

Patents regarding the use of natural gas as a dual fuel with diesel in vehicles are given below:

- LNG and Diesel Fuel Mixing System in Vehicles - Patent Number: TR 2009 04854 B [3].
- CNG or LNG Mixing with Diesel as a Dual Fuel Conversion System in Vehicles and Use of CNG Tanks as Additional Storage on Semi-Trailers and Trailers - Patent Number: TR 2013 13251 B [4].

The savings of dual-fuel system provides to users and the vehicle dual fuel conversion cost correspond to a return on investment is approximately one year with today's fuel costs. It is anticipated that this process will become shorter by increasing diesel prices. It is becoming an ever-expanding market for companies selling natural gas as Auto-CNG and Auto-LNG fuel.

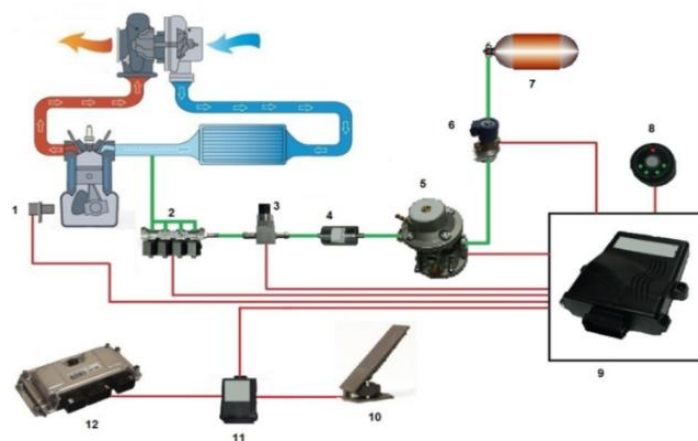


Figure 4: CNG-Diesel Dual Fuelled System Working Diagram (Source: [3] [4])

In Figure 4; 1. Crankshaft Position Sensor; 2. Gas Injectors; 3. Gas Pressure Sensor; 4. Gas Filter; 5. Gas Regulator; 6. Gas Electro Valve; 7. CNG Gas Tank; 8. Fuel Selector Switch; 9. Electronic Control Unit (ECU); 10. Electronic Accelerator Pedal; 11. Accelerator Pedal Simulator; 12. Diesel Control Unit (DCU).

The advantages of CNG-Diesel Dual Fuel powered vehicles are as follows:

- The investment cost of conversion system is cheap and regarding to current fuel costs, the fuel savings amount that the system will provide within one-year equals to conversion cost. That means return on investment period is around one year.
- Since it is dual fuel, it can use both fuels along the way, eliminating the risk of getting stuck on the road and allowing the vehicle to continue operating with diesel when natural gas runs out.
- Compared to a diesel vehicle with the same fuel tank capacity, the vehicle range increases by up to 15% with additional CNG cylinders.
- The fact that the engine can operate with 100% diesel, eliminates the natural gas supply problem and enables the vehicles to be used on every route.
- The dismantling time of the kits, equipment and tubes installed for the conversion from a diesel vehicle to dual fuel vehicle is very short and easy. This allows the vehicles to be sold second-hand as diesel vehicles. Removed kits, equipment and tubes can be installed another vehicle or sold second-hand. All these ensures that the second-hand market for dual-fuel vehicles is high.
- Conversion processes are short. If the vehicle is destroyed or sold due to an accident; it is possible to remove the system and transfer to another vehicle within one day.
- After-sales services, service and spare parts supply processes are the same as the original diesel vehicles, since all original equipment of the vehicles is used without any modification.
- The mileage fuel costs of dual fuel powered vehicles are higher than mono natural gas-powered vehicles and lower than diesel-powered vehicles.
- Carbon emissions and exhaust emission values of dual fuel vehicles are higher than mono NGV's and lower than diesel vehicles.

However; if the vehicle is within the warranty period, it is out of warranty due to conversion. These types of conversions are mostly preferred for vehicles with expired warranty. For vehicles that are within the warranty period, the decision should be made by comparing the savings achieved with the risk cost of being out of warranty.

2.2. Mono-CNG Powered Vehicles

Vehicles that use 100 % CNG fuels in engines are called Mono-CNG-powered vehicles. Mono-CNG powered vehicles are produced by some OEMs; they can also be produced by modifying diesel engines.

The disadvantages of OEM Mono-CNG powered vehicles are as follows:

- Vehicle investment costs are much higher than diesel vehicles and dual-fuel conversion systems, and although fuel savings per kilo-meter are higher, the return-on-investment period exceeds 2 years at today's prices.

- The risk of being stranded on the road when it runs out of fuel is high. Its range varies depending on the number of cylinders on the vehicle. As the number of cylinders increases, the carrying capacity of the vehicle decreases due to the weight and space occupation of the cylinders.
- They cannot be used on every route due to fuel supply problems.
- Usage routes depend on the network of supply stations.
- Its use is becoming widespread in "round-trip" buses operating at certain distances on certain routes, such as city buses.
- Since they cannot be used in every route and region, their second-hand market value is low.
- Since vehicle production is much less than diesel vehicles, vehicle delivery times are longer and sales prices are higher than diesel vehicles.
- Transferring the engine and equipment to another vehicle in case of destruction in accidents or sale is not preferred due to the high cost and long procedures.
- In terms of after-sales services, the fact that service and spare parts supply has not become widespread yet increases repair and maintenance processes and costs.

Despite all these disadvantages, mileage fuel costs are lower than both CNG-Diesel dual fuel powered vehicles and diesel-powered vehicles. Carbon emissions and exhaust emission values are also lower than both diesel and CNG-Diesel dual fuel powered vehicles [9].

In general, the benefits and advantages of using natural gas as fuel in vehicles are as follows:

- Natural gas is a safe because it is lighter than air and needs a higher air mixing ratio to be ignited.
- There is no leakage during the filling and usage.
- Since natural gas is lighter than air, it is released up in the air.
- Due to its high self-ignition temperature and low combustion range, natural gas is a less risky fuel in case of an accident compared to other liquid fuels.
- Due to its low carbon content, natural gas causes the least contamination in oil, filter, injector, valve, combustion chamber and exhaust systems. As a result of this, need for maintenance is decreased, engine life is increased, and operation costs are reduced.
- The number of natural gas stations is increasing day by day.
- Tanks where natural gas is stored in the form of CNG under high pressure are reliable tanks resistant to very high pressures with international certifications.

For these reasons; the safety aspects of NGV's are at similar levels to vehicles using other fuels. The use of NGV's reduces the theft of diesel fuel by drivers, which is a frequently encountered problem in the transportation sector.

2.3. Diesel-Powered Vehicles

Since the inception of diesel engines, diesel fuel has become the preferred type of fuel for light and heavy-duty vehicles due to their high efficiency and lower operation costs. The main disadvantages of diesel-powered vehicles are higher mileage fuel cost and more harmful exhaust emissions compared to natural gas-powered vehicles.

The advantages of Diesel-powered vehicles are as follows:

- Vehicle investment costs are lower.
- They can be used on every route due to the ease of refuelling
- Areas of use and routes are not limited to the network of supply stations.
- Delivery times are shorter as production quantities are high.
- After sales services and spare parts supply are more common and less costly.
- Their second-hand values are high.

The disadvantages of Diesel-powered vehicles are as follows:

- Transferring the engine and equipment to another vehicle in case of destruction in accidents or sale is not preferred due to high cost and long procedures.
- Carbon emissions and exhaust emission values are higher than both CNG-Diesel dual fuel and Mono Natural Gas-powered vehicles.
- The mileage fuel costs of diesel-powered vehicles are higher than both Mono-CNG and CNG-Diesel dual fuel powered vehicles.

2.4. Electric Powered Vehicles (EV)

Today, the use of electric-powered vehicles and hybrid electric powered vehicles is common in passenger cars. Depending on range and charging possibilities, electric powered city buses can be used on limited routes. There are constraints for electrical storage and range due to high power requirement in heavy-duty electric powered vehicles. However, with the advancement and cost reduction of electrical energy storage technologies it is expected that heavy-duty EVs will be more common in the near future [2].

The claim that carbon emissions are zero during the use of electric vehicles is also unrealistic. Namely, the carbon emissions that occur in the production of electricity required when charging an electric vehicle varies depending on the variety of electricity generation sources used by each country. Since they are not widely used yet, they are not included in this study.

2.5. Liquefied Petroleum Gas (LPG) Powered Vehicles

LPG fuel is not included either in this study because it is widely used only in passenger cars and not in heavy commercial vehicles. In Table 2, it is demonstrated the comparison table of advantages and disadvantages of Diesel, CNG-Diesel dual fuel and Mono CNG powered vehicles.

Table 2: Comparison Table of Advantages and Disadvantages of Diesel, CNG-Diesel Dual Fuel and Mono CNG Powered Vehicles

	Diesel Powered Vehicle (Dpv)	Cng-Diesel Dual Fuel Powered Vehicle (Dfv)	Hydrogen Powered Vehicle (Hdpv)
Conversion Or Investment Cost	Low	Lower Than "Hdpv"	High

Return On Investment (Roi) Period	Long	Short	Long
Trip Range	High	High	Low
Refueling Station Availability	High	High	Low
Second Hand Sale Value	High	High	Low
Ease Of Conversion	-	High	Low
Availability Of After Sales Service	High	High	Low
Drivability Or Ease	High	Low	Low
Fuel Consumption Cost (\$/Km)	High	Lower Than "Dpv" Higher Than "Hdpv"	Low
Carbon Emission Values	High	Lower Than "Dpv" Higher Than "Hdpv"	Low
Delivery Period	Short	Short	Long
Safety Status	Good	Middle	Middle
Leasage And Operation Loss	Low	Middle	Long
Maintenance And Service Period	Short	Middle	Long
Fuel Efficiency	High	Lower Than "Dpv"	High

Source: [3] [4] [5]

2.6. Vehicle Fuel Types and Features

Due to its low CO₂ emissions, CNG is the least environmentally harmful fuel compared to diesel and gasoline. Unlike diesel, natural gas does not produce dirt and sediment and because of this natural gas engines require less maintenance and longer engine life compared to diesel engines [1]. Chemical features of fuels used in vehicles are shown in Table 3.

Table 3: Chemical Features of Fuels Used in Vehicles

Properties	Natural Gas (CNG)	Diesel	Gasoline	LPG
Combustion Efficiency (%)	92	90	90	90
Octane Number	120 - 125	25	95 - 100	80
Self Ignition Temperatures c	600	225	440	48
Combustion Range - Air Ratio (%)	5 - 15	0,8 - 1,0	0,3 - 7,6	2 - 8,7
Thermal Values (Kcal/Kg)	10.800	10.200	7.870	10.000
Kilograms of \$CO ₂ Emitted per Million British	53,07	73,16	71,5	63,07
Thermal Units (Btu) of Energy				

Source: [12] [30]

The annual change in energy price inflation of countries is shown in Figure 5. The rate of increase in natural gas prices is lower than the rate and frequency of increase in other fuel prices, and the cost gap between other fuel prices and natural gas prices is constantly widening in favour of natural gas [18].

Year-on-year change in energy price inflation, October 2022

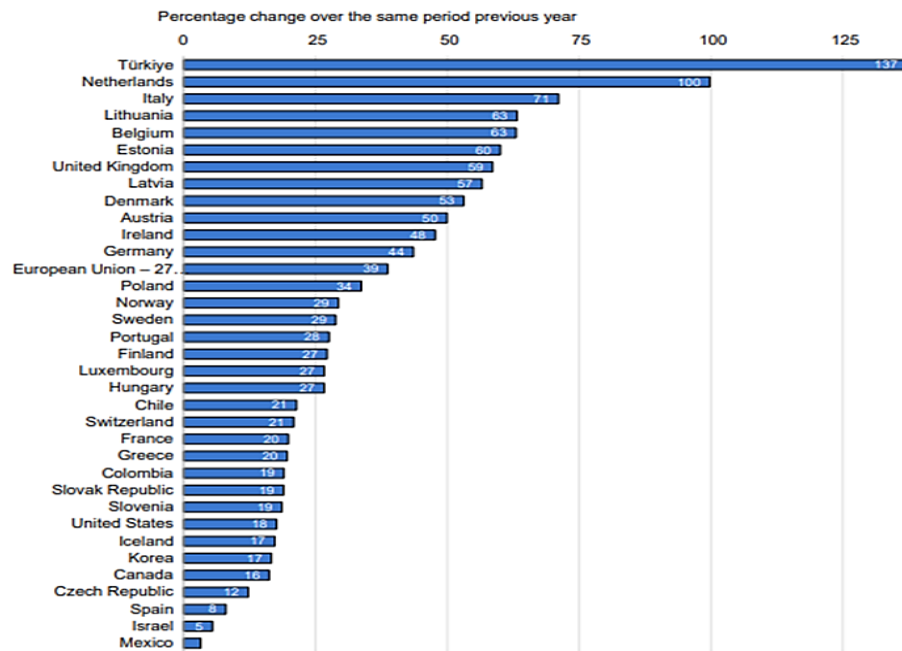


Figure 5: Annual Change in Energy Price Inflation of Countries According to the OECD Consumer Price Indices Database Published by the International Energy Agency (Source [15]).

In Figure 6, it is observed that the range in natural gas and oil prices has widened in favour of natural gas in the last decade [10].

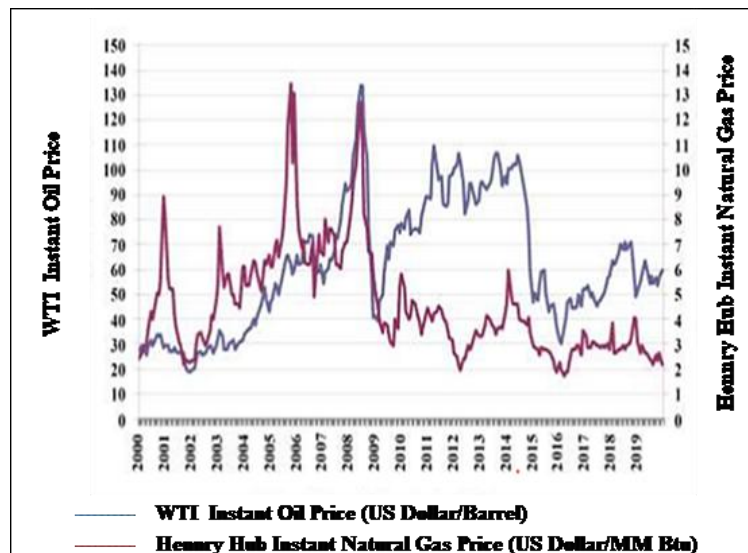


Figure 6: Henry Hub Instant Natural Gas Market Price and WTI Oil Instant Market Price Comparison Over the Years (Source: [12]).

Since alternative fuel vehicles are high-tech products that offer many advantages, their purchasing costs are generally more expensive. The lower operating and maintenance costs of NGV's make them more preferable in

the long run. However, this needs to be ensured, as government subsidies will significantly affect the market shares of alternative fuel vehicles in the early stages [25].

When the amounts of carbon monoxide (CO), non-methane hydro-carbons (NMHC), nitrogen oxide (Nox), sulphur oxide (Sox) and exhaust particles (PM) that create air pollution are compared per unit kilo-meter according to the fuel types used in vehicles, it is seen that natural gas is much lower than diesel and gasoline in Figure 7[11].

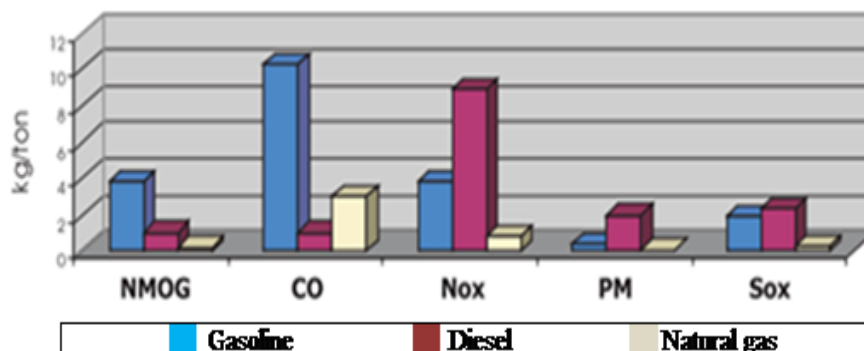


Figure 7: Air Pollutant Emission Values Per kilo-meter According to Fuel Types (Source: [11]).

The emission values reduced by new generation NGV's compared to gasoline and diesel vehicles are as follows [13]:

- 77 – 80% reduction in Nox
- 76% reduction in CO
- Over 97% reduction in benzene
- Approximately 90% reduction in ozone-harming hydrocarbons
- A reduction of 99% or more in particulate matter (PM)
- 20% Decrease in greenhouse gases

Natural gas is one of the cleanest fuels compared to other fossil fuels as it does not produce toxic, corrosive products that affect the environment and causes less carbon emissions. When carbon dioxide emissions per kilometer are compared according to fuel types, it is seen that natural gas in the form of CNG and LNG used as vehicle fuel is much lower than diesel and gasoline (Figure 8.).

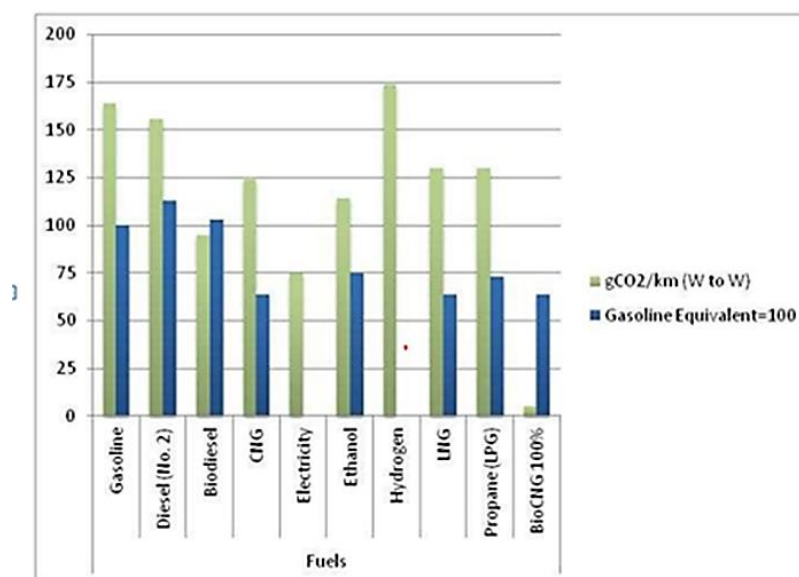


Figure 8: Carbon Dioxide Emissions Per kilometer by Fuel Types (Source: [23]).

The benefits of NGV's are as follows [4] [5]:

- Natural gas is a safer fuel due to its characteristic features.
- The emission rate of a natural gas engine, which causes greenhouse gases and toxic substances, is much lower than that of gasoline and diesel engine vehicles.
- Evaporation of natural gas during filling and use does not spread into the environment and cause environmental pollution and risk.
- CO₂ emission rate of NGV's decreases by more than 20% compared to other vehicle fuel types.

The transportation of natural gas via pipelines creates lower transportation risks and costs compared to fuel oil and LPG transported to stations by road, and does not cause environmental pollution.

Since natural gas is lighter than air, it does not precipitate into the environment and mixes with the atmosphere if released. It does not accumulate and have an explosive effect like LPG, and it is a less dangerous fuel.

- According to research conducted in many cities in USA, diesel exhaust gases have been held responsible for the formation of some very fine particles that increase the risk of respiratory diseases. However, NGV's exhaust particulates contain only much smaller amounts of these particles.
- Due to its high auto-ignition temperature and low combustion range, natural gas is a less risky fuel in case of an accident compared to other liquid fuels.
- High rates of pollutants in other fuels such as carbon monoxide (CO), organic gases other than methane (NMOG), nitrogen oxide (Nox), sulphur oxide (Sox) and exhaust particles (PM) are the ones that cause the most pollution and abrasion in engines. Due to the low rates in natural gas, contamination in oil, filter, injector, valve, combustion chamber and exhaust systems decreases and maintenance periods are extended, thus operating costs are reduced and engine life is extended.

- Tanks where natural gas is stored in CNG form under high pressure and LNG form at very low temperatures such as -160 centigrade are durable and reliable tanks with international certifications.
- On the other hand, fuel theft, which is frequently encountered in diesel vehicles due to malicious approaches of drivers, is also greatly reduced.
- The supply problem reduces the widespread use of natural gas as a fuel in vehicles. This problem has been resolved with a natural gas-diesel dual fuel system.

The safety aspects of NGV's are at similar levels to vehicles using other fuels.

3. Sample Application and Findings

Some of the findings described in 2nd and 3rd part of this study were obtained from Reysaş Logistics company which is one of the biggest logistics companies in Turkey. It was obtained from the field applications in the projects described below, developed together by the company and patent holder [3] [4] [5]. Data and findings were obtained by traveling more than 25 million kilo-meters with dozens of vehicles of the company. Vehicles converted to Mono-CNG and CNG-Diesel Dual Fuel powered vehicles were compared with existing diesel vehicles. While a diesel truck with a 600 Liters capacity fuel tank can travel 1,765 kilo-meters with a diesel fuel tank, a 2,032 km distance can be covered with additional CNG cylinders with a capacity of 470 Liters (115 sm³ x 4 ea.) added to the 600 Liters diesel tank. With the dual fuel system, vehicle range increases by 15%.

As shown in Table 2., CNG-Diesel dual fuel and OEM Mono-CNG powered vehicles have some advantages and disadvantages compared to each other. According to fuel saving and investment costs criteria, the compression of diesel, CNG - diesel dual fuel and mono CNG powered vehicles is shown in Table 4. prepared by adding November 2023 European average CNG and Diesel prices, vehicle sales prices and CNG-Diesel Dual Fuel vehicle conversion cost to the investment cost of the diesel vehicle. Results from fuel consumption data of three types of vehicles were included in the calculations. When the conversion costs of CNG-Diesel Dual Fuel vehicles are compared to the fuel savings, they provide a return-on-investment period of 9 months. When the investment cost difference between mono CNG and diesel-powered vehicles is divided by fuel consumption savings of mono CNG powered vehicles, there is a return-on-investment period of 22 months.

Table 4: Comparison of Savings and Investment Return Periods

	Diesel Powered Vehicle	Cng-Diesel Dual Fuel Powered Vehicle	Mono Cng Powered Vehicle
Vehicle Investment Cost €	80.000 €	88.000 €	125.000 €
Fuel Consumption Cost €/Km	0,63	0,54	0,42
Saving By Diesel €/Km		0,089	0,209
Saving For 120,000 Km Milage Per Year			
Saving Per Year €		10.680	25.080
Return On Investment - RoI			
In Months		9	22
Average Fuel Price In Europe, November 2023			
Diesel Price (€/Lt)	1,85		
Cng Price (€/Sm ³)	1,05		

(Source: [5])

According to Vehicle in Use Europe Report of ACEA (European Automobile Manufacturers Association) in January 2021, there are 55,044,006 of commercial vehicles and buses in use in European Union, EFTA (Norway and Switzerland) and Europe (Russia, Turkey and United Kingdom).

If only 20% of total commercial vehicles and buses in Europe were to switch from diesel-powered vehicle to natural gas-powered vehicle, the reduction in total amount of carbon dioxide and nitrogen oxides would be over 5,400,000 ton per year. That means also fuel cost saving would be over 70 billion euros per year.

4. Methodology

A total of eleven experts were included in AHP and TOPSIS survey. These consist of executives and managers in the auto-CNG fuel sales sector, two technical managers in the companies that make conversion proses to natural gas from diesel engine in the vehicles, one director in the logistic company using these kind of vehicles, two academicians and one sales manager in a company that sells diesel and natural NGV's. In addition, data and reports belong to Turkish Statistical Institute (TUİK), Turkey Energy Market Regulatory Authority (EPDK), Auto-Natural Gas Association (ODİDER), Turkey Mechanical Engineers Association (TMMOB) and NGV Reports were used [19] [21]. Stevenson (1996) explained the basic process followed in evaluating alternative decision points and selection criteria as follows [31]:

- Determination of the criteria affecting on selection
- Determination of the weights of the criteria affecting on selection
- Determination of alternatives that are suitable for the criteria affecting on selection
- Evaluation of proper alternatives that meet the criteria affecting on selection

MCDM is one of the scientific methods used when choosing among alternatives. TOPSIS method is also one of the MCDM method used in logistics for selection of warehouse location, transportation models, vehicles etc. Choudhary and Shankar (2012), in their location determination studies for the thermal power plant, determined the weights of the criteria using by the AHP method and then selected the best of the alternative locations using by the TOPSIS method [12]. Considering the economic, environmental and social sustainability criteria, there are significant effects on the selection of the type of transport vehicle. However, there is a lack of the literature regarding on sustainable transportation in the green logistics perspective [32].

In this study, initially, AHP for determining the criteria and their importance levels, then TOPSIS for selection among the alternatives.

AHP and Analytic Networking Process (ANP) methods can be used not only in the selection of decision alternatives, but also in determining the priority order of the criteria affecting a decision. Therefore, in some cases, alternatives are not available and only problems of priority order of the criteria can be solved with AHP and ANP methods [7] [24] [34].

AHP is a general measurement theory with a multi-level hierarchical structure that derives judgment priorities based on the evaluations and judgments of individuals and groups. The major advantage of the hierarchical structure of AHP is that it allows the basic components of the general problem and their interdependencies to be structured and systematically decomposed with great flexibility and in detail. In the literature, AHP method appears to be one of the most used methodologies for dealing with selection problems related to multi- criteria decision making. Compared to other multi-criteria decision-making methods, the main advantages of the AHP method are listed below:

- The AHP method is widely applied in multi-criteria decision-making problems, resource allocation, planning and many other areas.
- The AHP method provides a hierarchical representation of the problem that aids in analytical decision making.
- The AHP method can address both tangible and intangible qualities and features.

Based on the information received from the experts and literature and AHP model was determined according to four main criteria and nineteen sub-criteria. The priority order of the criteria was determined by AHP method and these values were used as weights of criteria in decision matrix of TOPSIS and selection was made by TOPSIS method.

In this study, the TOPSIS method, which is a MCDM approach that allows the determination of decision alternatives that are closest to the positive ideal solution and furthest from the negative ideal solution was used. The proposed form of TOPSIS method calculates the distance of decision alternatives to positive and negative ideal solutions using the Euclidean distance formula [36].

4.1. Steps of AHP Method

The steps used in the AHP method created by Saaty (1990-2008) are listed below [28] [39]: [26] [33]

Step 1. Decision-making problem is defined by determining criteria. AHP model is shown in Figure 9.

Step 2. A cross-criteria comparison matrix is created.

Step 3. Percentage distribution of criteria importance is determined

B_i The column vector is shown as n-pieces and n-component vector.

In the comparison matrix, the importance levels of the criteria relative to each other are shown in a logical structure. Column vectors that form the comparison matrix are used to determine the weights (percentage importance distributions) of all criteria (1).

$$B_i = \begin{bmatrix} b_{11} \\ b_{21} \\ \vdots \\ \vdots \\ b_{n1} \end{bmatrix} \quad b_{ij} = \frac{a_{ij}}{\sum_{i=1}^n a_{ij}} \quad (1)$$

Step 4. The consistency of pairwise comparison of criteria is measured.

AHP bases the essence of Consistency Ratio **CR** calculation on the comparison of the number of criteria and a coefficient λ called the Eigen Value. To calculate Eigen Value λ (2), first column vector **D** is obtained from the matrix multiplication of the comparison matrix **A** and the priority vector **W** [33].

$$E_i = \frac{d_i}{w_i} (i = 1, 2, \dots, n) \quad \lambda = \frac{\sum_{i=1}^n E_i}{n} \quad (2)$$

The Consistency Indicator **CI** is divided by the standard correction table value called the Random Indicator **RI** to obtain the Consistency Ratio **CR** (3) using following formulas [33].

$$CI = \frac{\lambda - N}{n - 1} \quad CR = \frac{CI}{RI} \quad (3)$$

The calculated **CR** value is less than 0.10 which indicates that the comparisons made by the decision-maker are consistent. If the **CR** value is greater than 0.10, it indicates a calculation error in AHP or the inconsistency of the decision maker in comparison. While the consistency ratios are accepted up to the limit of 0.10, some researchers state that the 0.20 limit is also acceptable [27]. If all the matrices are consistent, the next step is taken; if not, the pairwise comparison with the corresponding matrices should be repeated until to be consistent.

Step 5: The percent distribution of importance at the **m** decision point is determined for each criterion.

Step 6: Distribution of results on decision points is determined.

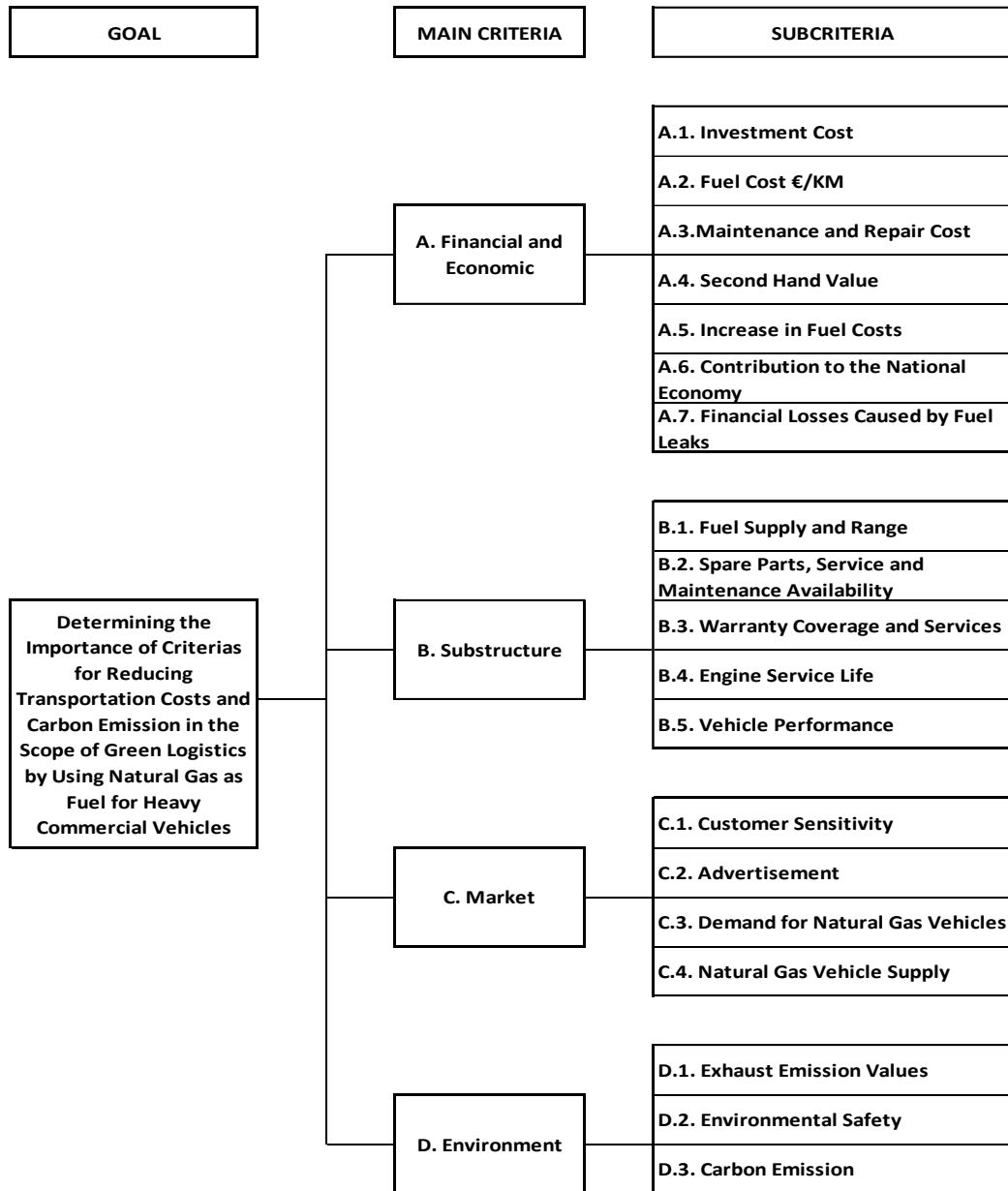


Figure 9: Goal, Main and Sub-Criteria for AHP Model

AHP and ANP methods can be used not only in the selection of one of the decision alternatives, but also in determining the priority order of the criteria affecting a decision. Therefore, in some cases there are no alternatives and problems can be solved by AHP and ANP methods to determine criteria priorities. At the end of the evaluation process, the questionnaires with a consistency ratio of less than 0,10 were evaluated. The normalized matrices and AHP results for each main criteria can be seen on Table 5, Table 6., Table 7., Table 8. Table 5 demonstrates the AHP results for main criteria A (Financial and economic). The consistency ratio for all AHP results is lower than the desired level of 0,10. In Table 5 In the last column the weights of the each criteria and the weights of the main criteria can be seen. For instance, the weight of criteria A1 is 0,092 and the weight of main criteria A is 0,498.

Table 5: AHP Results for Main Criteria A

	A1	A2	A3	A4	A5	A6	A7	Weights of Subcriteria
A1	0,176	0,158	0,216	0,175	0,180	0,187	0,198	0,092
A2	0,352	0,315	0,256	0,383	0,280	0,196	0,406	0,156
A3	0,032	0,048	0,039	0,023	0,044	0,113	0,035	0,024
A4	0,071	0,058	0,120	0,071	0,085	0,124	0,053	0,041
A5	0,275	0,316	0,252	0,233	0,280	0,230	0,217	0,128
A6	0,027	0,046	0,010	0,016	0,035	0,029	0,018	0,013
A7	0,066	0,058	0,107	0,099	0,096	0,121	0,074	0,044
$\sum A_i$	1,000	1,000	1,000	1,000	1,000	1,000	1,000	Total= 0,498
$\Lambda_{max}= 7,358$			CI= 0,060			RI= 1,320		CR= 0,045

Table 6. demonstrates the AHP results for main criteria B.

Table 6: AHP Results for Main Criteria B

	B1	B2	B3	B4	B5	Weights of Subcriteria	
B1	0,487	0,555	0,501	0,502	0,400		0,135
B2	0,076	0,087	0,093	0,124	0,084		0,026
B3	0,085	0,082	0,088	0,085	0,100		0,024
B4	0,190	0,138	0,201	0,196	0,282		0,056
B5	0,162	0,138	0,117	0,093	0,133		0,035
ΣAi	1,000	1,000	1,000	1,000	1,000	Total=	0,276
Λmax=	5,062		CI=	0,016		RI= 1,120	CR= 0,014

Table 7. demonstrates the AHP results for main criteria C (Market). The weight of main criteria C is 0,168.

Table 7: AHP Results for Main Criteria C

	C1	C2	C3	C4	Weights of Subcriteria			
C1	0,333	0,300	0,327	0,351		0,055		
C2	0,155	0,139	0,132	0,129		0,023		
C3	0,179	0,184	0,176	0,169		0,030		
C4	0,333	0,377	0,365	0,351		0,060		
ΣAi	1,000	1,000	1,000	1,000	Total=	0,168		
Λmax=	4,005		CI=	0,02	RI=	0,900	CR=	0,02

Table 8. demonstrates the AHP results for main criteria D (Environment). The weight of main criteria D is 0,057.

Table 8: AHP Results for Main Criteria D

	D1	D2	D3	Weights of Subcriteria
D1	0,320	0,320	0,320	0,018
D2	0,307	0,307	0,307	0,018
D3	0,374	0,374	0,374	0,021
$\sum A_i$	1,000	1,000	1,000	Total= 0,057
$\Lambda_{max}=$	4,116		CI= 0,00	RI= 0,580 CR= 0,021

Weights of sub and main criteria as are shown in Table 9. The most important criteria is A.2. fuel consumption and cost.

Table 9: Weights of Sub and Main Criteria

SUB-CRITERIA	WEIGHTS
A.2. Fuel Consumption Cost €/KM	15,6%
B.1. Fuel Supply and Range	13,5%
A.5. Increase in Fuel Costs	12,8%
A.1. Investment Cost	9,2%
C.4. Natural Gas Vehicle Supply	6,0%
B.4. Engine Service Life	5,6%
C.1. Customer Sensitivity	5,5%
A.7. Financial Losses Caused by Fuel Leaks	4,4%
A.4. Second Hand Value	4,1%
B.5. Vehicle Performance	3,5%
C.3. Demand for Natural Gas Vehicles	3,0%
B.2. Spare Parts, Service and Maintenance Availability	2,6%
B.3. Warranty Coverage and Services	2,4%
A.3. Maintenance and Repair Cost	2,4%
C.2. Advertisement	2,3%
D.3. Carbon Emission	2,1%
D.1. Exhaust Emission Values	1,8%
D.2. Environmental Safety	1,8%
A.6. Contribution to the National Economy	1,3%
MAIN CRITERIA	WEIGHTS
A. Financial and Economic	49,8%
B. Substructure	27,6%
C. Market	16,8%
D. Environment	5,7%

4.2. Steps of TOPSIS Method

TOPSIS method was developed by Yoon and Hwang (1980) [44]. The TOPSIS method, which is one of the multi-criteria decision-making methods, can be applied directly on data without a qualitative conversion [6] [8] [26]. The algorithmic steps of TOPSIS [28] and its use in the case study are as follows:

Step 1. Formation of Decision Matrix A_{ij}

Decision Matrix A is the starting matrix created by the decision maker. In the A_{ij} matrix, i is the number of decision points and j is the number of evaluation factors.

Step 2. Compute The Standard Decision Matrix R_{ij} which is Normalized Matrix.

The Standard Decision Matrix is calculated using the elements of matrix A_{ij} with the following formula. The matrix R_{ij} (4) is obtained as shown below.

$$r_{ij} = \frac{a_{ij}}{\sqrt{\sum_{k=1}^m a_{kj}^2}} \quad (4)$$

The decision matrix demonstrated in Table 10. The normalized matrix is shown in Table 11. In Table 10 and Table 11 the values in the cells are rounded to integer, and the calculations are done as a decimal number.

Table 10: Decision Matrix

CRITERIA	A1	A2	A3	A4	A5	A6	A7	B1	B2	B3	B4	B5	C1	C2	C3	C4	D1	D2	D3
Diesel Vehicle	5	1	5	5	1	1,4	1,2	5	5	4,8	4,5	5	1,3	1,3	4,5	5	1	3,7	1,2
Cng-Diesel Dual Fuel Vehicle	4	3	4	5	3	3,7	3,3	3,8	3,3	2,5	4	3,5	3,2	3,8	3,1	2,9	3	3,4	3,1
Mono Cng Vehicle	1	5	3	1,1	5	4,7	5	1	2,1	3	4,1	3,5	4,1	4,1	1,4	1	5	3,7	5

Table11: Normalized Matrix

CRITERIA	A1	A2	A3	A4	A5	A6	A7	B1	B2	B3	B4	B5	C1	C2	C3	C4	D1	D2	D3
Diesel Vehicle	0,8	0,2	0,7	0,7	0,2	0,2	0,2	0,8	0,8	0,8	0,6	0,7	0,2	0,2	0,8	0,8	0,2	0,5	0,2
Cng-Diesel Dual Fuel Vehicle	0,6	0,5	0,6	0,7	0,5	0,6	0,5	0,6	0,5	0,5	0,5	0,5	0,6	0,6	0,5	0,5	0,5	0,6	0,5
Mono Cng Vehicle	0,2	0,8	0,4	0,1	0,8	0,8	0,8	0,1	0,1	0,3	0,5	0,6	0,8	0,8	0,2	0,2	0,8	0,6	0,8

Step 3. Compute The Weighted Normalized Decision Matrix V_{ij} ; $\sum_{i=1}^n w_i = 1$

The weighted normalized matrix obtained using the criteria weights determined by the AHP method is shown in Table 12. The entire table was not demonstrated as it does not fit.

Table 12: Weighted Normalized Matrix

CRITERIA	A1	A2	...	B1	B2	...	C1	C2	...	D1	D2	...
Diesel Vehicle	0,071	0,026	...	0,106	0,020	...	0,013	0,005	...	0,003	0,009	...
Cng-Diesel Dual Fuel Vehicle	0,057	0,079	...	0,081	0,013	...	0,033	0,014	...	0,009	0,010	...
Mono Cng Vehicle	0,014	0,132	...	0,021	0,009	...	0,042	0,018	...	0,016	0,011	...

Step 4. Compute Ideal A^+ and Negative-Ideal A^- Solutions

In order to create the ideal solution A^+ (5), set, the weighted evaluation factors in the V_{ij} matrix, that is the largest of the column values (if the evaluation factor towards to minimization, the smallest values in each column are selected) are selected.

$$A^+ = \left\{ \left(\max_i v_{ij} \mid j \in J \right), \left(\min_i v_{ij} \mid j \in J' \right) \right\} \quad (5)$$

$$A^+ = \{v_1^+, v_2^+, \dots, v_n^+\}$$

The negative-ideal solution set A^- (6) is formed by selecting the smallest of the weighted evaluation factors, that is, the smallest column values (if the evaluation factor towards to the maximization, the largest values in each column are selected) in the V_{ij} matrix.

$$A^- = \left\{ \left(\min_i v_{ij} \mid j \in J \right), \left(\max_i v_{ij} \mid j \in J' \right) \right\} \quad (6)$$

$$A^- = \{v_1^-, v_2^-, \dots, v_n^-\}$$

In the formulas shown above; if the criteria are benefit-oriented, J shows the maximization in the positive ideal solution set and J' shows the minimization in the negative-ideal solution set. Similarly, if the criterion is cost-oriented, J shows the minimization in positive ideal solution set and j shows the maximization in negative-ideal solution set. Ideal Solution Values are shown in Table 13.

Table 13. Ideal Solution Values (A*) and Negative-Ideal Solution Values (A-)

Ideal Solution Values (A*)	Negative-Ideal Solution Values (A-)
0,071	0,014
0,132	0,026
0,017	0,01
0,029	0,006
0,108	0,022
0,01	0,003
0,036	0,009
0,106	0,021
0,02	0,009
0,019	0,01
0,034	0,03
0,025	0,018
0,042	0,013
0,018	0,005
0,024	0,007
0,051	0,01
0,016	0,003
0,011	0,009
0,018	0,004

Step 5: Compute the Discrimination Scales

In the TOPSIS method, “Euclidean Distance Approach” is used to find deviations from the ideal and negative-ideal solution set for each decision point. The deviation values of the decision points are called as Ideal Discrimination S_i^* and Negative-Ideal Discrimination S_i^- scales (7).

$$S_i^- = \sqrt{\sum_{j=1}^n (v_{ij} - v_j^-)^2} \quad S_i^* = \sqrt{\sum_{j=1}^n (v_{ij} - v_j^*)^2} \quad (7)$$

S_i^* and S_i^- values for each alternative are shown in Table 14.

Table 14. Calculation of Discrimination Scales

Ideal Discrimination S_i^*				Negative-Ideal Discrimination S_i^-			
Criteria	Diesel Vehicle	Cng-Diesel Dual Fuel Vehicle	Mono Cng Vehicle	Criteria	Diesel Vehicle	Cng-Diesel Dual Fuel Vehicle	Mono Cng Vehicle
A1	0	0,0002	0,0032	A1	0,0032	0,0018	0
A2	0,0111	0,0028	0	A2	0	0,0028	0,0111
A3	0	0	0	A3	0	0	0
A4	0	0	0,0005	A4	0,0005	0,0005	0
A5	0,0075	0,0019	0	A5	0	0,0019	0,0075
A6	0	0	0	A6	0	0	0
A7	0,0008	0,0002	0	A7	0	0,0002	0,0008
B1	0	0,0006	0,0072	B1	0,0072	0,0035	0
B2	0	0	0,0001	B2	0,0001	0	0
B3	0	0,0001	0,0001	B3	0,0001	0	0
B4	0	0	0	B4	0	0	0
B5	0	0,0001	0,0001	B5	0,0001	0	0
C1	0,0008	0,0001	0	C1	0	0,0004	0,0008
C2	0,0002	0	0	C2	0	0,0001	0,0002
C3	0	0,0001	0,0003	C3	0,0003	0,0001	0
C4	0	0,0004	0,0017	C4	0,0017	0,0004	0
D1	0,0002	0	0	D1	0	0	0,0002
D2	0	0	0	D2	0	0	0
D3	0,0002	0	0	D3	0	0	0,0002
Total Value				Total Value			
S_i^*	0,144	0,0809	0,1147	S_i^-	0,1149	0,1088	0,1441

Step 6: The Relative Proximity to Ideal Solution

Ideal and negative-ideal discrimination scales are used to calculate the relative closeness of each decision point to the ideal solution C_i^* (8). The scale used here is the share of the negative-ideal discrimination measure within the total discrimination measure. The formula for calculating the relative closeness value to the ideal solution is as follows:

$$C_i^* = \frac{S_i^-}{S_i^- + S_i^*} \quad i = 1, 2, m \text{ and } 0 \leq C_i^* \leq 1 \quad (8)$$

Wherein $C_i^+ = 1$ shows the absolute closeness of the relevant decision point to the ideal solution and $C_i^- = 0$ shows the relevant decision point to the negative-ideal solution [36]. Using the ideal and negative-ideal solution values, the ranking values are obtained by calculating the relative approach to the ideal solution as shown in Table 15.

Table 15: Relative Approach to Ideal Solution and Ranking

	S_i^+	S_i^-	C_i^+	Ranking
Diesel Vehicle	0,1440	0,1149	0,4437	3
Cng-Diesel Dual Fuel Vehicle	0,0809	0,1088	0,5735	1
Mono Cng Vehicle	0,1147	0,1441	0,5567	2

5. Conclusions and Suggestions

The importance rating of the criteria found by the AHP method are summarized in Table 9. The main criterion “Financial and Economic” weighted with 49.8 % has the highest importance as expected. The “Environment” criterion has a weight of 5.7% among the four main criteria.

The top five criteria “Fuel Cost €/KM”, “Fuel Supply and Range”, “Increase in Fuel Costs” “Investment Cost”, “Natural Gas Vehicle Supply” have a weight of 57%. It is noteworthy that the criteria of “Fuel Supply and Range” and “NGV’s Supply” which are not related to cost, are among the top five criteria.

The most significant impact on transportation costs is the “A2 Fuel Cost € / KM” criterion which has the highest importance with a weight of 15.6%. According to this criterion, the experts who made evaluations placed the mono CNG powered vehicles and the CNG-diesel dual fuel powered vehicles in the first and second places respectively. Diesel-powered vehicles are the least preferred option for all experts.

It is important that “B1 Fuel Supply and Range” criterion with a weight of 13.5%, has the second place right after the “A2 Fuel Cost € / KM” criterion. In addition, “B1. Fuel Supply and Range” criterion is in the top five criteria for all experts’ surveys and it shows that the availability of fuel supply is extremely important for such NGV’s.

According to “B1 Fuel Supply and Range” criterion, which weights 13.5%, all experts gave the lowest score for mono NGV’s. It shows that the “Fuel Supply and Range” criterion for mono NGV’s poses serious risk unless the number of natural gas supply stations reaches a sufficient level. Mono CNG powered vehicles unlike dual-fuel powered vehicles, cannot operate when they run out of fuel and cannot reach refuelling stations. Although they are more costly to operate, dual-fuel powered vehicles are preferred over mono CNG powered vehicles due to the risk of not having refuelling stations on routes.

According to the “A1 Investment Cost” criterion, which ranks fourth with a weight of 9.2%, although mono-CNG powered vehicles have the lowest fuel costs, they rank second due to highest investment costs. In terms of both investment and fuel consumption cost, return on investment (ROI) period of mono-CNG powered vehicles takes twice as long as that of dual fuel powered vehicles. This shows that OEM mono CNG vehicles are still priced too high.

“C4. NGV’s Supply” criterion ranks fifth with a weight of 6%. Since the production volumes of OEM mono CNG powered vehicles are much less than diesel-powered vehicles, their delivery times are longer. On the other hand, diesel-powered vehicles can be converted to dual-fuelled powered vehicles within one day.

In terms of the weighted 4.1% “A4. Second Hand Value” criterion, mono CNG powered vehicles are preferred in presence of limited route depending on CNG supply. In case of CNG fuel supply shortage, dual-fuelled vehicles can continue to run on diesel alone, unlike mono CNG vehicles. This is an advantage in terms of second-hand value in dual fuel powered vehicles as well as in diesel-powered vehicles.

Dual fuel vehicles can run on diesel fuel when CNG is not available. This is one of the reasons why dual-fuel powered vehicles preferred over mono CNG powered vehicles. The CNG-Diesel dual-fuel powered vehicles can be converted back into diesel vehicles with very low labour cost and short time. In addition, dual fuel powered vehicles were preferred because the CNG equipment’s could be transferred to other vehicles and continue to be used again. This situation provides an advantage for CNG-Diesel dual-fuel powered vehicles in terms of second-hand value.

Considering the operating expenses such as maintenance, repair and after sales services (B2, B3 and A3) which have a total weight of 7.4%, diesel vehicles are more preferred.

Since natural gas contains less carbon than diesel, the consumables such as oil and filters can be less contaminated and can be used for a longer time.

When the investment costs and fuel savings are compared to diesel vehicles, it is seen that the return on investment of CNG-Diesel dual fuel powered vehicles is less than one year and Mono CNG powered vehicles are more two years.

According to the weight of the criteria taken by the AHP method and the selection order determined by the TOPSIS method, CNG-Diesel dual fuel powered vehicles have the highest-ranking value with 0.57. Mono CNG powered vehicles ranked second with 0.55 and Diesel-powered vehicles ranked third with 0.44.

Dual fuel powered vehicles are preferred over mono-CNG powered vehicles for the following reasons:

Supply shortage is the biggest obstacle to the widespread use of natural gas. This problem can be solved by using dual-fuel systems. As natural gas-powered vehicles become more common, the number of natural gas stations will also increase.

Dual fuel vehicles do not cause problems in terms of range and refuelling, their investment value is lower, the system is easy to install and transfer to other vehicles when necessary, and second-hand value and demand are higher.

Until the number of natural gas refuelling stations sufficient level, natural gas - diesel dual fuel powered vehicles are seen as the most suitable vehicles in terms of reducing carbon emissions and reducing transportation costs.

Nowadays, the increasing fuel prices increase the interest in the use of more economical alternative fuels. It is known in the world that natural gas provides an advantage over other petroleum product fuels in terms of cost. The fact that natural gas contains less carbon components than other fuel types reduce carbon emissions and exhaust emissions, making natural gas a more environmentally friendly, carbon-emission-reducing and much more economical fuel type.

Especially in countries that are dependent on foreign fuel products, all kind of cost-reducing practice provide added value to the country's economy. From this perspective, as the use of natural gas in the logistics sector becomes more widespread, its contribution to the country's economy will increase and it will also contribute to reducing carbon emissions. Among the efforts to use energy more efficiently, natural gas appears to be most important energy source to replace oil in especially in the transportation sector. In recent years, governments have encouraged the use of natural gas and focused heavily on natural gas investments.

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