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LOGISTICS COST IN THE FOREST INDUSTRY: A CASE STUDY ANALYSIS

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Abstract

The forest products industry occupies a strategic position in the Turkish economy, particularly for its role in generating employment in rural areas and contributing to regional development. The sustainability of this sector depends not only on production capacity but also on the efficiency of logistics processes extending from raw materials to final products. Data from the Turkish Statistical Institute and the General Directorate of Forestry indicate that transportation expenses constitute the largest share of logistics costs. Artvin province, characterized by its mountainous, rugged terrain, stands out as a region where these costs are further amplified by its geography.

The main objective of this study is to examine the logistics cost structure of a forest-industry firm operating in Artvin and to analyze the factors that affect these costs using real-world data. Given the dataset's structure and limitations, a "Cost Structure Analysis" and a "Case Study" approach were adopted. Logistics operational data covering different transport distances from Artvin, capacity utilization rates, empty-return risks, and technological transformation scenarios were analyzed.

The results indicated that approximately 70–80% of total logistics costs are attributable to transportation expenses. Scenario analyses show that when vehicle capacity utilization remains at around 50% by weight, unit costs increased by nearly 100%, highlighting the critical role of volume-weight imbalance as a cost factor. Moreover, projections in which diesel vehicles are replaced by electric vehicles indicate that total logistics costs could be reduced by approximately 20%. The analysis also estimates that the investment payback distance is approximately 480,480 km and that the firm would incur losses if diesel fuel prices exceeded 68 TL per liter. Overall, the study demonstrates that dynamic pricing, backhaul (return load) organization, and a transition toward green logistics are essential to enhance the competitiveness of the Artvin forest industry.

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1. Introduction

Increasing competition, globalization, rapid technological advancements, and shorter product lifecycles are forcing firms to re-evaluate their logistics activities. Achieving a sustainable competitive advantage requires effective management of logistics activities and their associated costs. In this process, improving logistics efficiency depends on information sharing and coordination throughout the supply chain, and, with globalization, the increasing scope and complexity of logistics activities have made logistics costs a strategic management concern for firms (Kıymetli Şen, 2014). While logistics costs vary across sectors, they generally range from 8% to 13% of the product's selling price. Furthermore, it has been determined that businesses that carry out logistics activities in-house incur costs 15-20% higher than those of businesses that obtain these services from specialized logistics firms (Hacıüstemoğlu & Şakrak, 2002).

In production sectors dependent on nature, such as the forestry industry, distance and challenging geographical conditions complicate logistics operations, thereby increasing costs. This situation is highlighted in studies that reveal that long transportation distances constitute a significant logistics challenge both economically and environmentally (Palander et al., 2024).

When the literature is examined, it is observed that transportation costs constitute half or more of the total costs in the forest products industry (especially in timber harvesting) (Dykstra & Heinrich, 1996). The bulky, heavy nature of wood as a raw material, the distance between production areas and markets, and fluctuations in fuel prices are among the main risk factors threatening the sector's financial sustainability (Sessions, 2007). Especially in countries with high fuel costs, prioritizing logistics activities has become a necessity rather than a choice for companies (Kurt, 2010).

Artvin Province, selected as the study area, accounts for 2% of Turkey's forests. Therefore, despite being a province rich in forests (Eminağaoğlu, 2015), Artvin is among the most challenging geographies for logistics activities (Acar, 1998). The region's steep slopes, deep valleys, and low-standard forest road network increase fuel consumption, prolong transportation times, and raise vehicle maintenance and repair costs. These unique topographical conditions lead to a significantly different cost structure for forestry businesses operating in Artvin compared with the Turkish average (Acar, 1998).

This study aims to analyze the logistics costs of a forest industry firm operating in Artvin using a case study approach based on real firm-level data rather than statistical generalizations. By employing a limited yet highly detailed dataset covering transportation operations over different distances, fixed and variable cost components are decomposed, and the firm's unit cost structure is examined comprehensively. In addition, the effects of fuel price fluctuations and operational risks, such as deadheading, on logistics costs are evaluated through scenario analyses.

1.1. Literature Review

The forest products industry is one sector in which logistics costs constitute the largest share of total product costs. This is mainly due to the long distances between raw material sources, industrial facilities, and consumption centers. The literature shows that this cost structure is strongly associated with geographical constraints, insufficient planning, and technological limitations. Acar and Eroğlu (2001) analyze the effects of forest road planning on transportation costs in mountainous areas such as the Eastern Black Sea Region of Turkey. Troncoso and Garrido (2005) discussed a dynamic mixed integer programming model developed for production and logistics planning in the forest industry. The model aims to solve forest production, plant layout, and load distribution decisions in an integrated manner. Epstein et al. (2007) developed cost-minimization models using linear programming. Seuring and Müller (2008) conducted a systematic review of research on sustainable supply chain management and proposed a framework to structure these studies. Harouff et al. (2008) examined actual transportation costs and route optimization through detailed network analyses to more accurately assess and improve the efficiency of round lumber

deliveries on West Virginia highways. Devlin et al. (2008) demonstrated that GIS-based network analyses, when supported by realistic criteria such as road class, can be used with high accuracy in truck routing and logistics planning. However, they also show that empty return trips significantly increase unit costs. Mobini et al. (2009) addressed the logistics of a forest biomass supply chain to a power plant and examined the economic, operational, and environmental dimensions of biomass supply, transportation, and delivery. For this purpose, a model based on the Integrated Biomass Supply Analysis and Logistics (IBSAL) framework was developed and applied to a proposed 300 MW power plant in Quesnel, British Columbia, Canada. Eker et al. (2010) concluded that the potential ecological impacts of forest roads may become active over time, depending on road density, vehicle traffic, and other factors within the forest ecosystem. Acuna et al. (2012) aimed to achieve cost savings and operational efficiency by optimizing transportation planning for wood-chip production within the Australian forest industry. The study concluded that optimizing transportation efficiency significantly reduced total operating costs. Ghaffariyan et al. (2013) analyzed the operational factors (energy demand, moisture content, interest rate, transportation distance, and truck load capacity) affecting the costs of the forest biomass supply chain in Western Australia using a linear programming-based BIOPLAN model. Abbas et al. (2013) conducted an economic feasibility/cost analysis for the development of the forest products sector in Michigan. The study focused particularly on the harvesting and transportation costs of wood pulp obtained from natural forests. Klvač et al. (2013) showed that transport distance and the type of truck-trailer used significantly affect fuel consumption. Ramamurthi et al. (2014) reported that transportation distance significantly affects logistics costs. Wolfsmayr et al. (2014) and McKinnon (2015) support the integration of green logistics into supply chains. Laitila et al. (2016) investigated the costs associated with transporting wood chips and forest industry by-products by truck. They also aimed to identify the most cost-effective vehicle types for different product groups based on transport distance and supply volume, and to determine the extent to which next-generation, higher-capacity truck-trailers can increase the efficiency of wood-biomass transportation. Svenson and Fjeld (2016) aimed to quantitatively determine the effects of road gradient, road curvature, and road surface roughness on the fuel consumption of a conventional logging truck. It has been determined that the most significant factor affecting fuel consumption is the interaction between vehicle weight and road gradient. Koirala et al. (2017) analyzed the effects of factors such as market location and accessibility, shortage of qualified truck drivers, transportation distances, waiting times, and return of empty trucks on the forest products sector. Malladi and Sowlati (2017) aimed to optimize forest supply chain transportation from a broader, more comprehensive perspective and to provide a roadmap for future research. Fernandez-Lacruz et al. (2020) analyzed the supply costs of wood chips and small timber, processed at roadside storage areas, until delivery to the end user. For this purpose, the operational structure and processes of a theoretical wood-chip supplier operating in Northern Sweden were modeled in ExtendSim® and evaluated through simulation. Akay (2020) attempted to demonstrate with concrete data how effective GIS-based network analysis and optimization is in reducing costs in forest product transportation. It demonstrates that GIS-based route optimization can reduce costs by 34.90% when large trucks are used instead of small ones. Monti et al. (2020) attempted to introduce and implement the Forestry Routing Optimization Model (FRoM), a model based on the classical Vehicle Routing Problem (VRP) in forest transportation logistics. Pichler et al. (2022) tested digital transformation and smart tracking systems in the forestry and timber supply chain, specifically attempting to demonstrate the feasibility and effectiveness of a timber tracking and processing system integrated with RFID technology and smart machinery. Pandur et al. (2022) sought to scientifically demonstrate the determining effect of forest road gradient on fuel consumption and emissions during timber transportation. They find that road gradient directly influences fuel consumption. Gazran et al. (2023) analyzed the effects of integrating truck platooning technology into forest product supply networks on total transportation costs, fuel consumption, and labor requirements, and determined the operational conditions under which this technology yields the greatest efficiency and savings. Small and Ghaffariyan (2023) aimed to identify and evaluate methods to reduce costs and greenhouse gas emissions associated with transporting logs from forests to processing facilities or unloading points during timber harvest. Sedliačiková et al. (2025) reported that current green logistics practices in the wood-processing industry are inadequate, but that businesses' environmental and economic sustainability can be significantly improved by adopting appropriate strategies and systematic approaches. The main objective of the study conducted by Sarı et al. (2025) is to evaluate the operational performance of mechanized log transportation activities in the natural forests of East Kalimantan, Indonesia. In this context, the aim was to quantitatively assess the efficiency, cost, and effectiveness of log transportation operations conducted using a Mercedes-Benz MB 3836 AK logging truck. They report an operational efficiency of 87% in Indonesian natural forests and identify waiting times and load capacity as major cost drivers.

2. Materials and Methods

2.1. Material

The main data set of this study comprises logistics operational data for 2025 obtained from a firm operating in the forest industry sector in Artvin province. As the study area, the cities of Kayseri, Diyarbakır, Rize, İzmir, and Samsun, located in different geographical regions of Türkiye and characterized by high trade volumes, were selected as destinations for Artvin. The dataset is based on primary sources obtained directly from the firm.

The data used in the analysis are grouped as follows:

Trip Data: Route distances (km), trip durations (days), and transported cargo volumes (tons).

Vehicle and Performance Data: Type of vehicle used (truck/semi-trailer), average fuel consumption (L/100 km), and vehicle capacity utilization rates.

Cost Data: Fuel unit prices, driver allowances and wages, annual fixed costs (insurance, taxes, casco insurance, depreciation, maintenance, and repairs), and operational costs (storage and handling).

2.2. Method

In this study, given the structure of the available dataset ($n = 5$) and the data's deterministic nature, the "Cost Structure Analysis" and "Case Study" methods were adopted. This method allows for in-depth analysis with a limited number of data points and enables the separation of company-specific cost dynamics on a "unit cost" basis. The analysis process was carried out in three main stages: (1) Classification of Cost Items, (2) Creation of a Unit Cost Calculation Model, (3) Scenario-Based Sensitivity Analysis.

2.2.1. Classification of Cost Items

To accurately calculate logistics costs, expense items have been grouped into two main categories, "Fixed" and "Variable," based on their sensitivity to activity volume.

Fixed Costs: These are time-invariant expenses incurred regardless of whether the vehicle is in transit. In this study, annual depreciation, motor vehicle tax (MTV), traffic insurance, comprehensive insurance, and annual periodic maintenance expenses are included in the scope. The total annual fixed cost was divided by the number of active working days of the business to obtain the "Daily Fixed Cost Coefficient."

Variable Costs: Expenses that vary directly with trip distance and operational volume. Fuel consumption, tire wear allowance, and distance-based maintenance expenses are in this group.

Operational Expenses: Driver wages (daily pay), storage, and handling (loading and unloading) costs are modeled as trip-based expenses.

2.2.2. Unit Cost Calculation Model

In calculating the Total Logistics Cost (TC), the following equation was created based on the "Total Cost of Ownership" (TCO) approach:

$$TC_i = (FC_{day} * t_i) + (Y_i * P_{fuel}) + (S_{day} * t_i) + D_i + E_i \quad (1)$$

Here: TC_i : Total Trip Cost for route i (TL); FC_{day} : Daily Fixed Cost (Annual Fixed Costs / 250 Days*); t_i : Trip duration (Days); Y_i : Total fuel consumption (Liters); P_{fuel} : Fuel unit price (TL/Liter); S_{day} : Driver's daily cost (TL/Day); D_i : Storage cost (TL/Trip); E_i : Handling (Loading/Unloading) cost (TL/Trip).

The company's annual active operating time was hypothetically assumed to be 250 days (in logistics, active trip days are generally considered to be 250-260).

The total costs obtained from this model were divided by the trip distance (km) and cargo volume (tons) to calculate the "Unit Transportation Cost" performance indicators (TL/km and TL/ton).

2.2.3. Sensitivity (Scenario) Analysis

This study employs a "Sensitivity Analysis" method to measure the impact of critical variables (fuel price, occupancy rate, inflation, etc.) affecting total costs in forestry logistics. Six different scenarios were designed to assess operational risks and future investment opportunities for the business. The scenarios were constructed assuming all other variables remained constant, and in each scenario, only the relevant independent variable was changed to analyze its impact on unit cost (TL/km and TL/ton). The scenarios designed within the scope of this study are defined below:

Scenario 1 (Fuel Price Sensitivity): This study examines the impact of potential fluctuations in fuel (diesel) prices, the largest component of logistics costs, on total costs. The extent to which increases and decreases in the price per liter of diesel change the cost of each trip has been calculated.

Scenario 2 (Return Load Risk): The problem of "one-way transportation," frequently encountered in the transportation of forest products, has been addressed. By comparing the situation in which the vehicle cannot find a return load after unloading (returning empty) with the situation in which it finds a return load and returns at full capacity, the "invisible cost" of the empty return journey is revealed.

Scenario 3 (Vehicle Load Capacity Analysis): The impact of situations where the vehicle's carrying capacity is not fully utilized on unit costs is simulated. By comparing 100% load capacity with utilization rates of 75% and 50%, the multiplier effect of underloading on unit costs is investigated.

Scenario 4 (Inflationary Pressure and Operational Cost Shock): The impact of sudden changes in the economic conjuncture on total logistics costs, especially shock increases (30%, 50%, etc.) in operational cost items such as tires, maintenance and repair, personnel costs, and insurance, is analyzed.

Scenario 5 (Empty Return Probability Analysis (Expected Cost Value)): In situations where the risk of an empty return is uncertain, a probabilistic approach has been followed to make decisions under uncertainty. The "Expected Cost Value" for a 50% probability of finding a return load has been calculated.

Scenario 6 (Electric Vehicle (EV) Conversion Projection): Within the scope of green logistics and technological transformation, the replacement of existing diesel vehicles with electric trucks (EVs) has been modelled. Considering the initial capital expenditure (CAPEX), charging costs, and maintenance advantages of electric vehicles, projections of savings and return on investment (ROI) relative to diesel operations have been performed.

2.3. Data Collection and Preparation Process

The data were compiled from the company's 2025 records. The 5 different destinations included in the analysis (Kayseri, Diyarbakır, Rize, İzmir, Samsun) were selected to represent both short-distance (150 km) and long-distance (1560 km) transportation. Data sets for each trip are given below:

Rize Trip: 150 km distance, 1 day duration, 52 liters of fuel consumption.

Diyarbakır Trip: 500 km distance, 1.5 days duration, 185 liters of fuel consumption.

Samsun Trip: 550 km distance, 1 day duration, 180 liters of fuel consumption.

Kayseri Trip: 800 km distance, 2 days duration, 275 liters of fuel consumption.

İzmir Trip: 1560 km distance, 3 days duration, 546 liters of fuel consumption.

Fixed expenses were calculated based on company data; Annual Maintenance (50,000 TL), Tires/Spare Parts (70,000 TL), Depreciation (30,000 TL), Insurance (25,000 TL), and Taxes (21,048 TL) were added together to derive the daily fixed cost share. The analyses were performed using cost tables created in Microsoft Excel.

3. Results and Discussion

3.1. Allocation of Fixed Costs (Daily Cost Factor)

In logistics cost analysis, considering only fuel and driver costs underestimates the actual cost. Therefore, the company's annual fixed costs have been calculated and allocated to each trip according to trip duration (days). The annual fixed costs obtained from the company's records are as follows:

Maintenance and Repair: 50,000 TL/Year

Tires and Spare Parts: 70,000 TL/Year

Depreciation: 30,000 TL/Year

Taxes (Motor Vehicle Tax) and Insurance: 46,048 TL/Year (21,048 TL Tax + 25,000 TL Insurance)

Total Annual Fixed Cost: 196,048 TL

Daily Fixed Cost Share (DST): Assuming the company operates actively for an average of 250 days a year; $FC_{day} = 196,048/250 \approx 784.19$ /day

This amount is the daily cost to the business, even if the vehicle's ignition is not switched on, and in the analyses, it was multiplied by the trip duration and added to the total cost.

3.2. Trip-Based Cost Structure Analysis

The Total Logistics Cost (TC) for each destination was obtained by summing the following components:

1. Variable Costs: Fuel cost.

2. Personnel Costs: Driver wage (1,618 TL per day $\times$ Trip duration).

3. Operational Costs: Storage (1,666 TL per day) and Handling (525 TL).
 4. Fixed Cost Share: (784.19 TL × Trip duration).

Table 1: Trip-based total logistics cost results

Destination	Distance (km)	Duration (day)	Fuel (TL)	Personnel expenses (TL)	Storage or handling (TL)	Fixed cost share (TL)	Total cost (TL)
Rize	150	1	2,964	1,618	2,191	784.19	7,557.19
Diyarbakır	500	1.5	10,545	2,427	2,191	1,176.23	16,339.23
Samsun	550	1	10,260	1,618	2,191	784.19	14,853.19
Kayseri	800	2	15,675	3,236	2,191	1,568.38	22,670.38
İzmir	1,560	3	31,122	4,854	2,191	2,352.57	40,519.57

When Table 1 is examined, the weights of the cost items can be interpreted as follows:

Dominance of Fuel Costs: While fuel accounts for 39% of total costs on the shortest route (the Rize trip), this share increases to 76.8% on the longest route (the İzmir trip). As distance increases, the marginal effect of other operational expenses (storage and handling) declines, and fuel costs become dominant.

Personnel and Time Relationship: Due to Artvin's geographical characteristics, the average speed is low (mountainous roads), increasing trip times and, consequently, personnel costs. For example, because the İzmir trip lasts 3 days, personnel costs total 4,854 TL, accounting for 12% of the total.

3.3. Unit Cost Analysis

The "Cost Per Kilometer" and "Transportation Cost Per Ton" data, the most basic indicators of logistics efficiency, have been calculated. The total cargo transported across all trips has been set at 20 tons.

Table 2: Unit cost comparison results

Destination	Distance (km)	Total cost (TL)	Cost unit (TL/km)	Cost per ton (TL/ton)
Rize	150	7,557.19	50.38 TL	377.86 TL
Diyarbakır	500	16,339.23	32.68 TL	816.96 TL
Samsun	550	14,853.19	27.01 TL	742.66 TL
Kayseri	800	22,670.38	28.34 TL	1,133.52 TL
İzmir	1560	40,519.57	25.97 TL	2,025.98 TL

As shown in Table 2, the unit cost per kilometer decreases with increasing transportation distance. The cost per kilometer on the Rize route is very high at 50.38 TL. The main reason for this is that fixed costs (storage, handling, insurance, etc.) are reflected in the unit cost at a much higher rate over short distances. On the İzmir route, however, despite a tenfold increase in distance, the cost per kilometer decreased to 25.97 TL. This situation is evidence of economies of scale in logistics, specifically in Artvin. However, the total freight cost (2,025.98 TL per ton) is at a level that makes competitiveness challenging.

3.4. Scenario (Sensitivity) Analyses

Different scenario analyses were conducted to measure the resilience of the current cost structure to external economic factors and operational risks.

3.4.1. Scenario 1: Changes in Fuel Prices

The average fuel price during the analysis period was assumed to be 57 TL/Liter. The impact of a potential 10% increase in energy market prices (62.7 TL/Liter) on total costs has been calculated.

İzmir Trip (Long Distance): Fuel costs will increase from 31,122 TL to 34,234 TL, resulting in a total cost increase of 3,112 TL. This represents approximately a 7.7% increase in total cost.

Rize Trip (Short Distance): Fuel costs will increase from 2,964 TL to 3,260 TL, resulting in a total cost increase of only 296 TL. This represents a 4% impact on total cost.

Conclusion: Long-distance transportation is twice as sensitive to fuel price fluctuations as short-distance transportation. Profit margins on shipments from Artvin to the western provinces are at risk of rapid erosion due to rising fuel prices.

3.4.2. Scenario 2: Deadhead Risk Analysis

The current analysis assumes that the company provides another logistics service on the return journey, thus eliminating (absorbing) the return cost. However, finding return loads may not always be possible in the sector. When analyzing the worst-case scenario ("Empty Return") where the vehicle returns empty to Artvin after unloading:

- Even if fuel consumption decreases by approximately 20% due to the vehicle being empty, additional fuel costs will still be incurred for the return journey.
- Izmir Example: The return fuel cost will be approximately 24,897 TL (80% of the outward cost).
- Total Cost: 40,519 TL (Outbound) + 24,897 TL (Return Fuel) = 65,416 TL.

Conclusion: If the return load cannot be found, transportation costs increase by 61.4%. This is the biggest threat to the competitiveness of Artvin's forestry industry. Logistical planning for shipments without guaranteed return loads is not financially sustainable.

3.4.3. Scenario 3: Vehicle Load Factor (Capacity Utilization) Analysis

In forest product transportation, vehicles may not always reach their maximum tonnage (20 tons) due to the density and geometric structure of the raw material (e.g., log diameters). In this scenario, the change in "Unit Costs" was analyzed while the total trip cost remained constant; however, the vehicle load factor decreased to 75% (15 tons) and 50% (10 tons).

Table 3: Unit cost variation based on occupancy rate

Occupancy Rate	Load Quantity (Tons)	Total Trip Cost (TL)	Unit Cost (TL/Ton)	Cost Increase Rate
100%	20 tons	40,519.57 TL	2,025.98 TL	-
75%	15 tons	40,519.57 TL	2,701.30 TL	33%
50%	10 tons	40,519.57 TL	4,051.96 TL	100%

The analysis results in Table 3 highlight the importance of economies of scale in logistics. Even when the vehicle is fully loaded at 50% capacity (10 tons), the transportation cost per ton doubles, rising from 2,025.98 TL to 4,051.96 TL. This indicates that forestry operations should aim not only to "fill the vehicle" but also to "reach the maximum tonnage" when planning loads. Freight rates for transporting low-density products should be revised to account for this inefficiency coefficient.

3.4.4. Scenario 4: Inflationary Pressure and Operational Cost Shock

Not only fuel prices but also personnel and spare parts costs fluctuate with macroeconomic conditions. In this scenario, fuel prices are kept constant; however, it is assumed that driver wages increase by 30% due to minimum wage increases, and fixed costs (maintenance/spare parts) indexed to the exchange rate increase by 50%.

Analysis (Izmir Trip – 1,560 km / 3 Days):

- Current Personnel Cost: 4,854 TL - New Cost (+30%): 6,310 TL
- Current Fixed Cost Share: 2,352 TL - New Cost (+50%): 3,528 TL
- Fuel and Operational Cost: 33,313 TL (Keeping Constant)

Conclusion: Total trip cost increased from 40,519 TL to 43,151 TL. Even if fuel prices did not increase, these increases in personnel and maintenance costs alone would raise total costs by 6.5%. This finding demonstrates that focusing solely on the pump (fuel) in cost management is insufficient; broader inflationary effects should also be allocated a 5-10% "Risk Margin" in budgeting.

3.4.5. Scenario 5: Empty Return Probability Analysis (Expected Cost Value)

Previous analyses examined "Fully Loaded Return" (Optimistic) and "Fully Empty Return" (Pessimistic) scenarios. However, uncertainty prevails in real life. This analysis calculates the "Expected

Unit Cost," which is the financial equivalent of a more realistic scenario in which the probability that the business finds a return load is 50% (i.e., an empty return on 1 out of every 2 trips).

- Case A (Full Return): Cost Per Ton = 2,025 TL
- Case B (Empty Return): Cost Per Ton = 3,270 TL
- Probability: 50%

Formula:

$$\text{Expected Cost} = (\text{Cost}_{\text{full}} \times 0.5) + (\text{Cost}_{\text{empty}} \times 0.5)$$

$$\text{Expected Cost} = (2,025 \times 0.5) + (3,270 \times 0.5) = 2,647.5 \text{ TL/ton}$$

Conclusion: In a system in which the company cannot guarantee the return load and relies on chance (50% probability), it should budget not according to 2,025 TL per ton, but according to the risk-weighted cost of 2,647.5 TL. This means that the invisible cost is approximately 622.5 TL per ton.

3.4.6. Scenario 6: Electric Vehicle (EV) Conversion Projection

In line with the European Green Deal and sustainable logistics goals, the cost structure resulting from replacing diesel vehicles with electric trucks was simulated. Assumptions:

1. Energy Consumption: It is assumed that a fully loaded electric truck consumes an average of 1.4 kWh/km in the Artvin region.
2. Energy Price: It is assumed that 30% of the charging is done at the company's depot (Industrial electricity: ~5 TL/kWh) and 70% at public stations (Fast charging: ~12 TL/kWh), with an average unit price of 10 TL/kWh.
3. Other Expenses: It is assumed that the maintenance costs of electric vehicles are 40% lower than those of diesel vehicles, but fixed costs increase by 50% due to the initial investment cost (depreciation).

Table 4: Comparative analysis of the Izmir trip

Cost Item	Current status (Diesel)	Future scenario (Electric)
Energy/fuel cost	31,122 TL (546 Liters of Diesel Fuel)	21,840 TL (2,184 kWh x 10 TL)
Personnel cost	4,854 TL	4,854 TL
Fixed costs (including depreciation)	2,352 TL	3,528 TL (The effect of high vehicle prices)
Operational costs	2,191 TL	2,191 TL
Total cost	40,519 TL	32,413 TL
Cost per ton	2,025 TL	1,620 TL

Conclusion and Forecasting: Despite high upfront investment costs, the transition to electric vehicle technology has the potential to reduce total costs by 20% on long-distance routes such as those in Izmir. This dramatic reduction in energy costs could enhance the competitiveness of Artvin's forestry industry internationally. However, the current charging infrastructure and range limitations may prolong operational times. Therefore, this scenario should be considered a medium- to long-term strategic objective.

3.5. General Assessment of the Findings

The results of this study reveal that total transportation costs and per-ton costs in road freight vary systematically with distance, capacity utilization rate, operational efficiency, and external economic shocks.

Table 5: Comparing the cost impacts of all scenarios on cities

Cities	Scenario Name	Total Trip Cost (TL)	Change (%)	Cost Per Ton (TL)	Change (%)
Rize (150 km)	Current Situation (Control)	7,557 TL	-	378 TL	-
	Scenario 1: Fuel Price Increase (10%)	7,853 TL	3.90%	393 TL	3.90%
	Scenario 2: Deadheaded Trip	9,928 TL	31.40%	496 TL	31.40%
	Scenario 3: 50% Capacity Utilization	7,557 TL	0%	756 TL	100%
	Scenario 4: Inflationary Shock	8,441 TL	11.70%	422 TL	11.70%
	Scenario 6: Electric Vehicle (EV)	7,085 TL	-6.20%	354 TL	-6.20%
Diyarbakır (500 km)	Current Situation (Control)	16,339 TL	-	817 TL	-
	Scenario 1: Fuel Price Increase (10%)	17,394 TL	6.50%	870 TL	6.50%
	Scenario 2: Deadheaded Trip	24,775 TL	51.60%	1,239 TL	51.60%
	Scenario 3: 50% Capacity Utilization	16,339 TL	0%	1,634 TL	100%
	Scenario 4: Inflationary Shock	17,915 TL	9.60%	896 TL	9.60%
	Scenario 6: Electric Vehicle (EV)	13,382 TL	-18.10%	669 TL	-18.10%
Samsun (550 km)	Current Situation (Control)	14,853 TL	-	743 TL	-
	Scenario 1: Fuel Price Increase (10%)	15,879 TL	6.90%	794 TL	6.90%
	Scenario 2: Deadheaded Trip	23,061 TL	55.30%	1,153 TL	55.30%
	Scenario 3: 50% Capacity Utilization	14,853 TL	0%	1,486 TL	100%
	Scenario 4: Inflationary Shock	16,028 TL	7.90%	801 TL	7.90%
	Scenario 6: Electric Vehicle (EV)	12,685 TL	-14.60%	634 TL	-14.60%
Kayseri (800 km)	Current Situation (Control)	22,670 TL	-	1,134 TL	-
	Scenario 1: Fuel Price Increase (10%)	24,238 TL	6.90%	1,212 TL	6.90%
	Scenario 2: Deadheaded Trip	35,210 TL	55.30%	1,761 TL	55.30%
	Scenario 3: 50% Capacity Utilization	22,670 TL	0%	2,268 TL	100%
	Scenario 4: Inflationary Shock	24,630 TL	8.60%	1,232 TL	8.60%
	Scenario 6: Electric Vehicle (EV)	18,979 TL	-16.30%	949 TL	-16.30%
İzmir (1560 km)	Current Situation (Control)	40,519 TL	-	2,025 TL	-
	Scenario 1: Fuel Price Increase (10%)	43,631 TL	7.7%	2,181 TL	7.7%
	Scenario 2: Deadheaded Trip	65,416 TL	61.4%	3,270 TL	61.4%
	Scenario 3: 50% Capacity Utilization	40,519 TL	0%	4,051 TL	100%
	Scenario 4: Inflationary Shock	43,151 TL	6.5%	2,157 TL	6.5%
	Scenario 6: Electric Vehicle (EV)	32,413 TL	-20%	1,620 TL	-20%

When Table 5 is analyzed, it is observed that the total trip cost increases strongly, but not linearly, with distance under the control scenario. While the total cost for Rize is 7,557 TL, it increases to 40,519 TL for İzmir. Similarly, costs per ton increase with distance, from 378 TL/ton to 2,025 TL/ton. This indicates that the cumulative effects of fuel, depreciation, labor, and time costs become more pronounced in long-distance transportation. The control scenario provides a solid reference point for comparing the effects of other scenarios.

The impact of the 10% increase in fuel prices on costs is distance sensitive. While the cost increase is limited to 3.9% for short distances (Rize), it rises to 7.7% for long distances (İzmir). This finding reveals that the share of fuel costs in total costs increases with distance. The fact that the observed increases in per-ton costs directly correlate with total costs indicates that fuel price shocks have a proportional effect across scales.

The highest cost increase among all cities is observed in this scenario. The total trip cost increase is 31.4% in Rize, compared with 61.4% in İzmir. Similarly dramatic increases are observed in per-ton costs. This finding clearly demonstrates the critical importance of the load factor in transportation efficiency.

Empty return trips lead to increased non-revenue mileage, thereby significantly increasing total and unit costs. The results confirm that return trip optimization is indispensable for cost control in logistics planning.

In the 50% capacity utilization scenario, it is noteworthy that although the total trip cost remains unchanged, the cost per ton increases by 100% in all cities. This can be explained by the per-unit concentration of fixed costs as the amount of cargo transported decreases.

The inflationary shock scenario led to cost increases of 6.5%-11.7%. The highest increase was observed on the short-distance Rize line. This result stems from the fact that fixed and semi-fixed costs account for a larger share of total costs in short-haul operations. Inflationary pressures can affect not only long-distance operations but especially short-distance operations relatively more severely.

The electric vehicle scenario has had a cost-reducing effect in all cities. The rate of decrease is 6.2% in Rize, while it reaches 20% in Izmir. This result shows that electric vehicles provide a greater economic advantage over long distances.

4. Conclusion

This study examines the logistics cost structure of a forestry industry enterprise operating in Artvin Province, using a case study based on real operational data for 2025. The findings reveal that logistics costs in Artvin are significantly higher than the Turkish average, attributable to the mountainous topography and the distance between production centers and consumption centers. In the analyzed trips, 70-80% of total logistics costs were transportation expenses (fuel and personnel). The study quantitatively demonstrates that distance is not the only determinant of logistics costs; return load organization, tonnage utilization rate, and operational organization have a much more critical impact on costs. In particular, the fact that per-ton costs increase by more than 60% when vehicles return empty makes the "empty return" risk a structural competitive disadvantage. Similarly, using a vehicle that is volumetrically full but has low weight capacity can double unit costs. Scenario analyses of fuel prices have shown that total costs are highly sensitive to energy prices. A 10% increase in diesel fuel prices increases total logistics costs by an average of 7.7%, particularly on long-distance routes. Electric vehicle (EV) scenarios indicate that total trip costs can be reduced by approximately 20%, particularly on long-distance routes. Despite the high initial investment, the cost can be amortized over the vehicle's lifespan due to the energy and maintenance savings of electric vehicles. However, given Artvin's geographical and climatic conditions, factors such as battery life, range, and charging infrastructure have been identified as critical constraints to this transformation.

Based on the findings, the following strategic recommendations have been developed to reduce logistics costs and increase competitiveness in the Artvin forestry industry:

- Long-distance shipments should not be planned without guaranteeing return loads. Businesses should adopt bidirectional shipment planning via digital freight platforms and regional logistics collaborations.
- In logistics planning, the target should be "weight-based full capacity" instead of "volume," and light and heavy products should be transported using the mixed loading method.
- The shared use of vehicle fleets by small and medium-sized enterprises in Artvin through logistics cooperatives will significantly reduce empty return rates.
- Fuel price index pricing and risk premium clauses should be added to freight contracts to counter fluctuations in fuel prices.
- Electric vehicle investments should be initiated with pilot applications, especially on long-distance routes and shared industrial charging stations, and public support should be evaluated to reduce charging infrastructure costs.
- In short-haul transportation, the focus should shift from fuel to time, and process management and operational efficiency should be increased through GPS, vehicle tracking, and inventory management systems.
- Rehabilitation of forest roads, establishment of regional logistics centers, and fuel or green logistics incentives for the sector should be prioritized in terms of public policies.
- Simulation-based risk analyses with broader datasets, regional comparative studies, and cost-benefit analyses of green logistics applications will make significant contributions to the literature.

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Disclosure Statement

No potential conflict of interest was reported by the authors.

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