Charging Forward: Evaluating the Total Ownership Costs of EVs Versus ICE Vehicles in Thailand's Commercial Trucking Industry
พลังงานปริวรรต: การประเมินต้นทุนรวมระหว่างรถบรรทุกไฟฟ้า และเครื่องยนต์สันดาปในอุตสาหกรรมรถบรรทุกเพื่อการพาณิชย์

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Abstract

The escalating urgency of global warming has accelerated the shift toward environmental consciousness. To address this, the European Union aims to phase out Internal Combustion Engines (ICE) by 2030 in favor of environmentally pleasant vehicles, like electric trucks. In contrast, Thailand's principal transport network still largely depends on diesel vehicles, exacerbating pollution and financial strain from crude oil imports. This study evaluates the feasibility of transitioning to electric commercial trucks by assessing the Total Ownership Cost (TCO) of fossil fuel (Diesel), CNG, and EV trucks. Crucial factors such as Capital Expenditure (CAPEX) and Operational Expenditure (OPEX) are considered in the context of last-mile delivery. From data collected over six months, from January to June 2023, a total of 423 containers were analyzed from five service providers. The transportation route documented was from the Dry Port (ICD Lat Krabang) to the Laem Chabang Port.

This analysis aims to provide insights into the dynamics of container transportation within this specific route for the given timeframe. The key inquiry is whether the transition from fossil fuels to electricity and its potential effect on commodity prices is financially viable. The results indicate that vehicles powered by natural gas, electricity, and diesel have TCO per kilometer of 15.33, 17.33, and 22.52 baht, respectively. This reflects the inability of service providers to immediately reduce freight charges due to the higher initial purchase cost of electric vehicles compared to the other two types. Considering that exports contributed to approximately 58.6% of Thailand's economy in 2021 (World Bank, 2023), strategic adjustments in supply chain management, backed by national tax policies, are imperative. Such initiatives not only promote green transportation but also drive the country towards achieving its goal of net-zero greenhouse gas emissions.

Keywords: EV truck, Total Ownership Cost (TCO), CNG, Internal Combustion Engine, Comparative analysis cost, Fossil fuel

<div align="center">**บทคัดย่อ**</div>

      สภาวะโลกร้อนที่ส่งผลกระทบการเปลี่ยนแปลงสภาพภูมิอากาศอย่างเร่งด่วน ณ ปัจจุบัน สหภาพยุโรปมุ่งหวังที่จะยุติการใช้เครื่องยนต์สันดาป ภายในปี พ.ศ. 2573 โดยเลือกใช้ยานพาหนะที่เป็นมิตรกับสิ่งแวดล้อม เช่น รถบรรทุกไฟฟ้า ในทางตรงกันข้าม ระบบขนส่งที่สำคัญของประเทศไทยยังขึ้นอยู่กับรถยนต์ที่ใช้ดีเซลเป็นส่วนมาก ซึ่งส่งผลทำให้เกิดปัญหามลพิษและผลกระทบทางด้านการเงินของประเทศจากการนำเข้าน้ำมันดิบ การศึกษานี้มุ่งเน้นที่จะประเมินความเป็นไปได้ในการเปลี่ยนชนิดของรถบรรทุกพาหนะด้วยการประเมินต้นทุนรวมในการเป็นเจ้าของ ของรถยนต์ที่ใช้เชื้อเพลิงฟอสซิล เชื้อเพลิงก๊าซธรรมชาติ และรถบรรทุกไฟฟ้า ปัจจัยที่สำคัญ เช่น ค่าใช้จ่ายด้านการลงทุน และค่าใช้จ่ายด้านการดำเนินงาน ถูกพิจารณาในบริบทของการจัดส่งสินค้าช่วงสุดท้าย จากการเก็บข้อมูลจากบริษัทที่ให้บริการตู้ส่งออก เป็นระยะเวลาหกเดือน ตั้งแต่เดือนมกราคม ถึง มิถุนายน พ.ศ. 2566 จากจำนวนรวม 423 ตู้ จากผู้ให้บริการห้า ราย เส้นทางที่เก็บข้อมูลคือ Dry port (ICD ลาดกระบัง) ไปยังท่าเรือแหลมฉบัง คำถามสำคัญคือการเปลี่ยนจากเชื้อเพลิงฟอสซิลเป็นไฟฟ้าจะมีความคุ้มค่าทางการเงินหรือไม่ และมีผลกระทบต่อราคาสินค้าหรือไม่ ผลที่ได้คือรถที่ใช้เชื้อเพลิงก๊าซธรรมชาติ ไฟฟ้า และ ดีเซล มีต้นทุนรวมบาทต่อกิโลเมตร เท่ากับ 15.33, 17.33, และ 22.52 ตามลำดับ ซึ่งสะท้อนถึงการผู้ให้บริการไม่สามารถลดค่าบรรทุกสินค้าได้ทันที เนื่องจากต้นทุนการซื้อรถไฟฟ้าที่สูงกว่าอีกสองประเภท เมื่อพิจารณาว่าสินค้าส่งออกมีส่วนร่วมในสัดส่วนของเศรษฐกิจของประเทศไทยประมาณร้อยละ 58.6 ในปี พ.ศ. 2564 (World Bank, 2023) การเปลี่ยนแปลงในการจัดการโซ่อุปทานอย่างมีกลยุทธ์ โดยการสนับสนุนจากนโยบายภาษีจากภาครัฐ จึงเป็นสิ่งที่จำเป็นในการส่งเสริมการขนส่งสีเขียวและสามารถบรรลุเป้าหมายของการลดปริมาณการปล่อยก๊าซเรือนกระจกเป็นศูนย์

คำสำคัญ: รถบรรทุกไฟฟ้า, ต้นทุนรวมในการเป็นเจ้าของ, เชื้อเพลิงก๊าซธรรมชาติ, เครื่องยนต์สันดาป, เปรียบเทียบต้นทุน, เชื้อเพลิงฟอสซิล

Introduction

      As the world grapples with the escalating effects of global warming, a collective and decisive response has become crucial. At the heart of this environmental crisis is the excessive use of fossil fuels, which has led to unprecedented levels of carbon dioxide emissions, subsequently driving global temperatures upwards. This situation has compelled nations worldwide to reconsider their energy sources and consumption, particularly within the transportation sector, a significant contributor to global carbon emissions (Johnsson et al., 2019, Nadeau et al., 2022)

      One such compelling instance is the decision of the European Union (EU) countries to phase out the Internal Combustion Engine (ICE) by 2035 (Kottasova, 2023) in favor of renewable energy vehicles. This transformation echoes a global shift towards green energy, underscoring the importance of sustainability. Thailand, heavily reliant on diesel-powered transportation for inland logistics, where over 80% of its shipments are facilitated, is now on the brink of its transition.

      This research paper evaluates the potential shift from ICE to Electric Vehicles (EVs) in Thailand's commercial trucking sector. It will delve into the comparative analysis of the Total Ownership Cost (TCO) of vehicles running on fossil fuels, Compressed Natural Gas (CNG), and electric power; with the imminent energy transition (Costa et al., 2021), several variables exist (Seixas et al., 2015), like Capital Expenditure (CAPEX) and Operational Expenditure (OPEX) on last-mile delivery, which potentially impacts operators'

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decisions. The study by Contestabile et al., 2017 indicates that the initial cost of electric passenger vehicles is high. However, as battery prices decrease and technology advances, these costs are expected to decline over time. This study aims to answer the question: are EVs cost-effective compared to their fossil fuel counterparts, and will this transition influence the prices of goods and services?

Considering that the World Bank data shows that in 2020, approximately 58.6% of Thailand's Gross Domestic Product (GDP) was derived from exporting goods and services, this study will have significant implications. It will provide valuable insights for policy and business decisions and contribute towards attaining net-zero emissions, thereby driving the transition towards Green Logistics. Furthermore, this research will bring to light the potential challenges and benefits that lie within this transformative path, paving the way toward a sustainable future for Thailand's transportation sector.

Aims

This research aims to evaluate the potential for transitioning from Internal Combustion Engines (ICE) to Electric Vehicles (EVs) within Thailand's commercial trucking sector as follows.

1. The study will compare the Total Ownership Cost (TCO) of vehicles driven by fossil fuels, Compressed Natural Gas (CNG), and electricity. It will consider key factors such as Capital Expenditure (CAPEX) and Operational Expenditure (OPEX) for last-mile delivery, which can significantly influence operators' decisions.

2. Furthermore, the research addresses whether EVs are a cost-effective alternative to fossil fuel-powered vehicles and how this transition might impact the prices of goods and services.

3. Lastly, given that a significant portion of Thailand's Gross Domestic Product (GDP) comes from exports, the study will provide insights that could shape policy and business decisions related to the country's transportation and logistics sector. These insights are crucial in supporting Thailand's transition towards net-zero emissions and promoting the adoption of Green Logistics practices.

Literature review

Commercial vehicles are pivotal in goods and passenger transportation, significantly revolutionizing supply chain management (Qinyu et al., 2019). The escalating use of ICE vehicles, reliant on non-renewable conventional fuels, has sparked considerable energy and environmental challenges (Li et al.,2019; Raugel et al., 2018). Consequently, several countries have introduced Alternative Energy Vehicles (AEVs) as substitutes to decrease reliance on oil and curb air pollution. AEVs predominantly utilize energy sources such as electricity (batteries), hydrogen, natural gas or compressed natural gas, methanol, and ethanol. (Bin Zhao., 2017) Among the array of AEVs, Electric Vehicles (EVs) are perceived as the most impactful in delivering environmental and socioeconomic benefits.

To mitigate CO_2 emissions, EU and Germany have set ambitious targets to bring one million EVs into operation by 2020 (Ahmad et al., 2017; Siskos et al., 2015). Similarly, France and the UK plan to

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impose restrictions on the domestic sale of conventional vehicles by 2040 (Chrisafis and Vaughan., 2017; Hirst et al., 2021). Numerous countries have rolled out subsidies and distinct tax policies to catalyze the shift towards EVs, e.g., China and ASEAN countries (Qiao and Raufer, 2022; Purtanto., 2023). These include the plug-in vehicle subsidies in the UK (Mahdy et al., 2022), the clean vehicle rebate project in the US (Williams, 2022), and measures to promote the purchase of green vehicles, e.g., hydrogen fuel cells in Japan (Khan et al., 2022) and China (Li et al., 2022).

The commercial truck industry gravitates towards electrification, supported by numerous significant technological developments. As of 2022, the market saw the introduction of approximately 220 new models of heavy-duty electric vehicles, pushing the total count to over 800 models. These offerings come from over 100 Original Equipment Manufacturers (OEMs) (IEA, 2023). Electric drivetrains are supplanting traditional internal combustion engines, supported by advancements in lithium-ion batteries that offer high energy density and extended life cycles (Zhou et al.,2017). Crucial to EV adoption is expanding charging infrastructure, which encompasses slow and fast charging stations (Al-Hanahi, 2021) with wireless charging technologies being explored (Wang et al., 2023).

Environmentally, they significantly decrease greenhouse gas emissions, contributing to a reduction in the effects of climate change and air pollution. Economically, despite higher upfront costs, EVs exhibit lower operating costs due to increased energy efficiency and reduced maintenance needs, resulting in potential long-term savings (Bhardwaj and Mostofi, 2022). Furthermore, the growth of the EV sector can stimulate job creation and economic development in areas such as battery manufacturing and charging infrastructure IEA (2022).

A multitude of studies has undertaken Total Ownership Cost (TCO) analyses comparing Electric Vehicles (EVs) with Internal Combustion Engine (ICE) and Compressed Natural Gas (CNG) vehicles, considering various cost elements (Topal and Nakir, 2018). The initial purchase price of EVs is often higher than ICE vehicles; however, rapidly advancing technology and economies of scale are anticipated to bring parity shortly. Energy or fuel costs generally favor EVs due to higher efficiency and lower per-mile electricity costs than fossil fuels (Basma et al., 2022). In terms of maintenance, EVs incur lower costs due to their more straightforward mechanical design and fewer moving parts. Resale value is a developing area of study, with some evidence suggesting that EVs can retain value effectively, remarkably, as battery longevity improves (Basma et al., 2022). Future trends suggest that as technology evolves and adoption increases, the TCO for EVs will continue to become more competitive (Suttakul et al.,2022).

The transition to EVs has potential implications for the prices of goods and services, predominantly driven by changes in transportation costs. Some studies suggest that, despite higher initial costs, EVs' decreased operating and maintenance costs could lower overall transportation costs over time (Vijayagopal and Rousseau, 2021). This reduction could influence the prices of goods and services, particularly in industries heavily reliant on transportation (Interlake Mecalux, 2023). However, the extent to which these cost savings might be passed on to consumers is yet to be fully explored and may vary

by charge times are constrained, such as overnight taking place. (Woddy et al., 2022). Future research is required to comprehensively understand these potential economic impacts and guide policy and business decision-making in the era of transport electrification.

Xue et al., 2021 studied the various factors to encourage users to purchase the EV by selecting incentives and Socio-Economic factors, e.g., tax reduction, subsidiary, gasoline price, and income level. The analysis results suggest that ownership tax benefits, charger density, and income are key driving factors in all expanding EV markets. Supporting from Santos and Davies (2020) show that the respondents consistently charge EV stations as the priority of purchasing decisions (Fang et al., 2020.) Price subsidies follow in five EU countries. However, most studies show that EV buyers face upfronts cost higher than ICE significantly. Therefore, buyers preferred one-off financial incentives such as tax havens in Australia (Gong et al., 2020.), China (Kiao, 2021).

Electric Vehicles (EVs) play a crucial role in realizing green logistics and achieving net-zero carbon emissions targets. Numerous studies have demonstrated the potential of EVs to significantly reduce greenhouse gas emissions compared to ICE vehicles, thereby minimizing the environmental impact of transportation (Wand and Tang, 2022; Sathiyan et al., 2022). Beyond tailpipe emissions, holistic assessments of the carbon footprint of EVs need to account for emissions during the production of vehicles and the generation of electricity to power them. Although EV manufacturing, particularly battery production, can initially produce higher emissions than ICE vehicles, lower emissions during operation are often offset over time, primarily when powered by renewable energy sources (Martz et al., 2021.) Thus, transitioning to EVs and a decarbonized energy grid are crucial to achieving sustainable logistics and meeting climate goals (Strbac et al., 2021).

Therefore, cost analyses that influence business decisions, such as those by Basma et al. (2022), Vijayagopal and Rousseau (2021), Bhardwaj and Mostofi (2022), and Suttakul et al. (2022), as well as other decision-related factors like pressures from global warming, green corporate branding, incentives, and various governmental regulations (as highlighted by Qiao and Raufer, 2022; Purtanto, 2023; Khan et al., 2022; and Li et al., 2022), underscore the interest in comparing the Total Ownership Cost (TCO) between electric trucks and Internal Combustion Engine (ICE) trucks in the commercial trucking industry.

Materials and Methods

The study is primarily classified according to the Department of land transport's law. It categorizes nine types of commercial trucks, and the TCO comparison falls into the seventh category (Semi trailer). The truck usage determines its requirements regarding cargo mass, driving range, electrical and mechanical accessories, etc.

In the cost-effective comparison study between EV, ICE (Diesel), and CNG (Compressed Natural Gas) trucks, the study shares the costs associated with the three truck types using cost accounting theory. Consists two cost comparisons will be made:

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1. Fixed costs, also known as overhead costs, are expenses that do not change with the level of output or production, such as rent, salaries, and insurance.

2. Variable costs, on the other hand, fluctuate in direct proportion to the level of output or production. Examples include direct labor costs and utilities like electricity, fuel, and gas, which can change based on how much is produced.

The data collection involved a sample of four diesel trucks, two compressed natural gas (CNG) trucks, and one electric truck. These were sourced from five transportation companies participating in this research. All vehicles commenced their routes from the Dry Port (Inland Container Depot-ICD), Lat-krabang district, Bangkok. The data was collected between January and June 2023, recording 423 containers, including types 20-foot- and 40-foot types, through a datasheet, capturing container size, fuel consumption per refill cycle, and average fuel usage rates based on the total number of served containers and the weight carried per trip. This data was then converted to the "Baht/kilometer" unit for easier comparison. It should be noted that the trucks were restricted to a maximum payload of 25 tons and exclusively dealt with export-bound containers.

To calculate the average energy consumption per kilometer. Obtained from experimental carrying export containers between Bangkok and Laem Chabang. The containers hold goods for export and empty backhaul. The round-trip distance is 300 kilometers at maximum, shown in Fig 1. Diesel and CNG's average price at Bangkok gas stations is 33.75 baht/liter and 17.59 baht/kilogram. The average price of a charging station, the electricity, is 4.70 Baht/unit.

The Excel sheet is downloaded as a tool developed by the Department of Land Transport and the Faculty of Engineering, Kasetsart University, and it reaffirms the accuracy of costs from entrepreneurs.
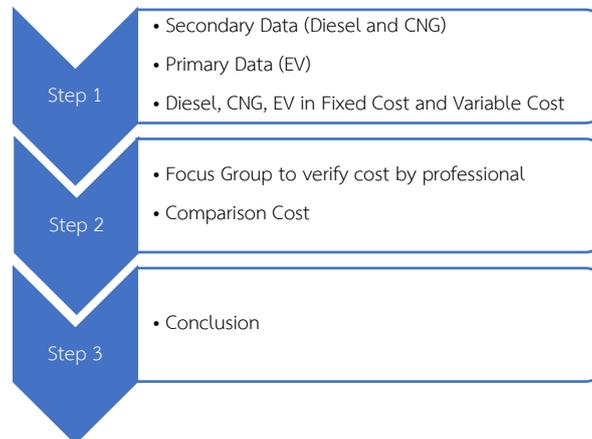

Figure 1. Testing route of trucks cost comparison.

A comprehensive Excel spreadsheet compared the total costs associated with Diesel, Compressed Natural Gas (CNG), and Electric Vehicles (EV) in the commercial truck sector. This spreadsheet encapsulates fixed and variable costs pertinent to each type of vehicle. The variables accounted for include, but are not limited to, initial purchase costs, fuel or energy costs, maintenance costs, and any additional expenses specific to each vehicle type. The data collected was meticulously analyzed to determine the overall operational

costs of each type of truck, providing a quantitative foundation for understanding the economic implications of transitioning from Diesel and CNG trucks to EVs in the commercial truck industry.

The study method displays in Fig 2; the data collection involves secondary and primary sources. Secondary data for Diesel and Compressed Natural Gas (CNG) trucks were collected from reliable existing literature, research papers, and industry reports. On the other hand, primary data for Electric Vehicles (EVs) was gathered directly from online resources, transportation providers, and industry experts.

Step 1
• Secondary Data (Diesel and CNG)
• Primary Data (EV)
• Diesel, CNG, EV in Fixed Cost and Variable Cost

Step 2
• Focus Group to verify cost by professional
• Comparison Cost

Step 3
• Conclusion

Figure 2. The process of studying the cost comparison of each type of truck

These sources provide real-time and in-depth insights into EV trucks' pricing, operational, and maintenance aspects. A focus group of industry experts was formed to validate the data, cross-checking the collected information for accuracy and comprehensiveness. All data, once validated, were inputted into a comprehensive Excel spreadsheet. This digital tool enabled an efficient and in-depth data analysis, fostering clear comparisons among Diesel, CNG, and EV trucks, leading to robust and relevant conclusions. The TCO per kilometer influences pricing decisions, and if the government truly wishes to support environmental initiatives, its policies should reflect this commitment.

Results

The data utilized in this study were gathered through transportation cost calculation tables, a collaborative effort by the Department of Land Transport and the Faculty of Engineering at Kasetsart University. Compiling these data was executed via an Excel macro function explicitly developed for this purpose. A comparative assessment of Diesel, Compressed Natural Gas (CNG), and Electric Vehicles (EV) was conducted, with Bangkok as the point of origin and Laem Chabang as the destination. This comparative route analysis served to validate the accuracy of the calculated costs, corroborated by data from five distinct transportation operators.

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Table 1: Details of the participants who contributed to the data collection and validated the accuracy of the information.

Respondent	Position	Work Experience (Years)	Quantity
Company 1	Vehicle Control Supervisor	3-5	2
Company 2	Operations Manager	8	1
Company 3	Operations Manager	6	1
Company 4	Vehicle Control Officer	1-2	3
Company 5	Director of Operations	11	1
		Total	8

Table 1 provides an overview of the participants in this study's data collection and verification of data accuracy. The respondents' profile varies regarding their positions and years of work experience, reflecting diverse perspectives.

Respondents from companies 1 and 4 are involved in direct vehicle control, with work experience ranging from 1 to 5 years, and they collectively represent five individuals. Their firsthand experience with vehicle operation offers valuable insights into the practical aspects of vehicle management. Respondents 2 and 3 hold managerial roles in operations, each bringing 6 to 8 years of experience, respectively. Their experience likely provides a more strategic viewpoint, understanding the broader implications of operations management. Finally, Respondent 5, as the Director of Operations with 11 years of experience, offers the most senior-level perspective, likely providing a comprehensive understanding of the overall operational process.

Eight individuals with varying roles and experience levels contributed to the data collection and validation process, ensuring a multi-dimensional understanding of the subject matter. This diverse range of inputs strengthens the validity of the collected data, thereby enhancing the reliability of the research findings.
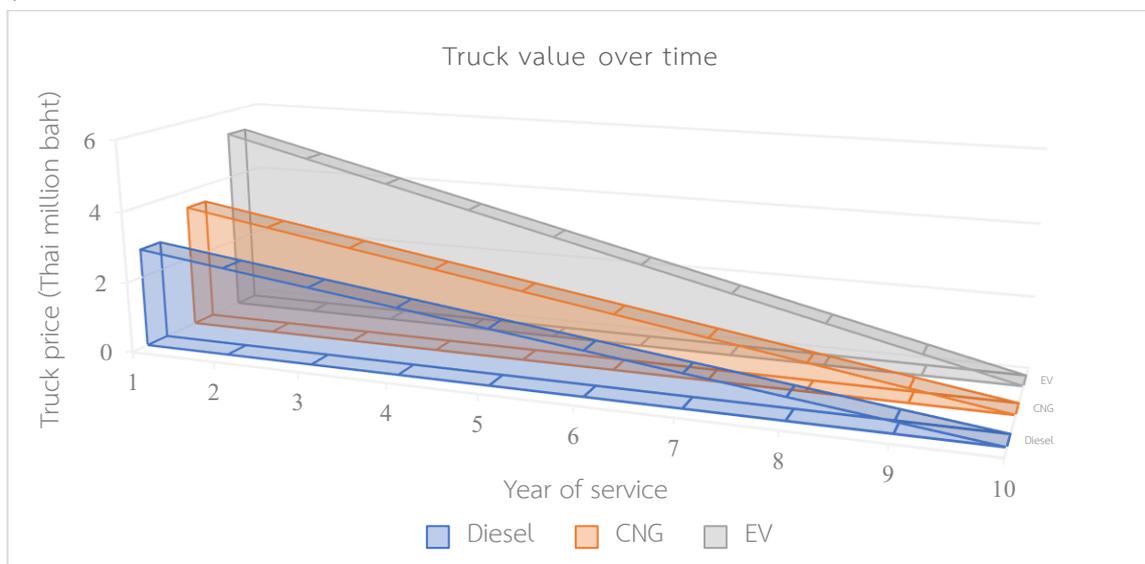
Figure 3. Variation of truck value in the years of service.

Figure 3. shows the value of each type of vehicle that decreases each year after being used. In this study, the estimated age of the car was ten years old from the date of purchase of the new vehicle. The graphical representation demonstrates that Diesel vehicles exhibit a lower profile than Compressed Natural Gas (CNG) vehicles. This is indicative of the lower purchase price associated with Diesel vehicles. It is one of the variables calculated in Table 2. All vehicle categories involved in the testing were used to export container loads, functioning as tractors with a weight ranging between 20 to 23 tons per trip.

The collected data, summarized in Table 2, were categorized into fixed and variable costs, each cost type further divided into respective components. Table 3 clarifies the discrepancy between fixed and variable costs, focusing primarily on the truck price and salvage value. Meanwhile, the variable costs, chiefly tire, and other miscellaneous costs, demonstrated minimal variance. The analysis results are presented in Thai Baht, the national currency of Thailand.

Table 2: Data for comparative diesel, natural gas, and electric-powered Tractor truck operational cost calculation.

Row	Description	Unit of measurement	Diesel	CNG	EV
a	Tractor truck service period	Years	10	10	10
b	Semi-trailer service period	Years	10	10	10
c	Average distance traveled	Km/year	123,000	123,000	123,000
d	Tractor truck price	Baht/unit	3,100,000	3,900,000	5,900,000
e	Semi-trailer price	Baht/unit	700,000	700,000	700,000
f	Tractor truck salvage value (20%, 10%, 5%)	Baht/unit	620,000	390,000	295,000
g	Semi-trailer salvage value	Baht/unit	140,000	140,000	140,000
h	Energy consumption rate	Km/Liter, Km/Kg, Km/Kilowatt-hour	2.75	4.50	0.80
i	Energy price	Baht/Liter, Baht/Kg, Baht/Kilowatt-hour	33.75	17.29	4.50
j	Road tax	Baht/year	8,043	8,043	8,043
k	Average vehicle inspection when renewing road tax	Baht/year	1,746	1,746	1,746
l	Average vehicle insurance	Baht/year	65,000	85,000	100,000
m	Average cargo insurance	Baht/year	26,024	26,024	26,024
n	Average toll fee	Baht/year	33,772	33,772	33,772
o	Average expense without receipt	Baht/year	30,665	30,665	30,665
p	Frequency of changing lubricate	Km/time	23,021	23,021	-

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Row	Description	Unit of measurement	Diesel	CNG	EV
q	The expense of changing lubricate	Baht	12,000	12,000	-
r	Average vehicle repair	Baht/year	62,208	62,208	6,221
s	Other maintenance expenses	Baht/year	53,542	83,542	5,354
t	Frequency of tractor truck tire change	Km/time	119,000	119,000	119,000
u	Frequency of semi-trailer tire change	Km/time	113,000	113,000	113,000
v	Cost of the tractor truck tire (10 Wheels)	Baht	76,973	76,973	76,973
w	Cost of semi-trailer tire	Baht	74,998	74,998	74,998
x	Salary of three maintenance officers for ten vehicles	Baht/year	540,000	540,000	540,000
y	Fixed and variable costs for office	Baht/year	360,000	360,000	360,000
z	Driver's Salary	Baht/month	12,000	12,000	12,000
aa	Driver's Allowance, Bonus	Baht/month	10,000	10,000	10,000
ab	Assistant Driver's Salary	Baht/month	8,000	8,000	8,000
ac	Office Staff Salary	Baht/month	15,000	15,000	15,000

Table 3: Comparison of costs in units of Baht per kilometer for diesel, CNG, and EV for semi-trailer trucks.

Row	Cost	Unit of compared	Diesel	CNG	EV	Source table 2
A	Fixed cost		6.13	6.97	8.67	A=(B+C +F+G+H)-D-E
B	Tractor truck price		2.52	3.17	4.80	B=d/(a*c)
C	Semi-Trailer price		0.57	0.57	0.57	C=e/(b*c)
D	Tractor truck salvage value		- 0.50	- 0.32	- 0.24	D=f/(a*c)
E	Semi-trailer salvage value		- 0.11	- 0.11	- 0.11	E=g/(b*c)
F	Office expenses		0.29	0.29	0.29	F=y/(c*10)
G	Office salary	Baht/km	0.44	0.44	0.44	G=x/(c*10)
H	Driver and assistant salary		2.93	2.93	2.93	H=(z+aa+ab)/(c/12)
I	The difference in Total fixed cost		2.02	2.85	4.56	I=B-D
J	The equivalent in Total fixed cost		4.11	4.11	4.11	J=C-E+F+G+H
K	Variable Cost		16.39	8.37	8.66	K = L+M+N+O+P+Q
L	Energy Cost		12.27	3.84	5.63	L=i/h

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Row	Cost	Unit of compared	Diesel	CNG	EV	Source table 2
M	Maintenance Cost	Baht/km	0.94	1.18	0.09	M=(r+s)/c
N	Lubricating oil cost		0.52	0.52	-	N=q/p
O	Other expenses per year		1.34	1.51	1.63	O=(j+l+m+n+o)/c
P	Tractor truck tyre Cost		0.65	0.65	0.65	P=v/t
Q	Semi-trailer tyre cost		0.66	0.66	0.66	Q=w/u
R	The difference in Total variable cost		15.08	7.05	7.35	R = L+M+N+O
S	The equivalent in Total variable cost		1.31	1.31	1.31	S = P+Q
T	TCO		22.52	15.33	17.33	T = A+K

The results demonstrate that Compressed Natural Gas (CNG) yields the lowest operational costs among the energy types examined. Specifically, the operational costs per kilometer are 15.33 Baht for CNG, 17.33 Baht for Electric Vehicles (EV), and 22.52 Baht for Diesel.

Table 4: Energy price sensitivity

TCO (table 2, row T)		Energy Price		
		Diesel	CNG	EV
CNG	15.33 Baht/KM	13.98	17.29	2.90
EV	17.33 Baht/KM	19.48	26.30	4.50
Diesel	22.52 Baht/KM	33.75	49.65	8.65

The sensitivity analysis demonstrated, in Table 4, varying energy prices at different levels sorted from the lowest. Notably, it was discovered that for the total cost to be equivalent to the CNG cost of 15.33 baht per kilometer, the diesel price must be adjusted to 13.98 baht per liter and the electricity price to 2.90 baht per kilowatt-hour. This suggests volatile energy prices will not severely impact the selling price strategy. The primary decisions made by transport owners directly affect the category of trucks (in-depth interviews with companies 2,3,5).

Similarly, to achieve a total cost equivalent to the Electric Vehicle (EV) cost of 17.33 baht per kilometer, the diesel price must be set at 19.48 Baht per liter and the CNG price at 26.30 baht per kilogram. Furthermore, to match this cost with CNG, the price would need to be 49.65 baht per kilogram, and the electricity price would have to be adjusted to 8.65 baht per kilowatt-hour.

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Conclusions and Discussion

This section encapsulates the comparative analysis of the Total Ownership Cost (TCO) for all categories of trucks. Factors such as the sensitivity relative to the battery and other energy costs, the distance covered in daily trips, and the associated electric range will be considered. As evidenced by Table 2 (Row d), among the evaluated vehicles, the most prospective contender to reach purchase price parity with diesel trucks for heavy or commercial trucks poses a more significant challenge, primarily due to the requirement for larger battery packs.

As a result, EV vs. CNG, CNG energy still provides cost savings. Compared to diesel and electricity, which should be attractive energy, a group of countries still yet to commit to a climate change agreement. But since CNG is a relatively sizeable environmental impact energy. Trivedi et al., 2020 did suggest that CNG vehicles even create pollution. The paper found that CNG vehicles emit lower levels of toxins than gasoline or diesel vehicles. However, they emit some pollutants, such as carbon monoxide (CO), nitrogen oxides (NOx), and particulate matter (PM). Yet supporting the study of Kado et al., 2005, they found some contaminants, such as 1,3-butadiene, benzene, and formaldehyde. However, EVs are considered an attractive option. In terms of environmental friendliness, and provide more cost than CNG, only 2 baht/kilometer, according to Table 3, row T.

In an alternative comparative scenario between EVs and Diesel, it was observed that EVs exhibit a lower TCO than Diesel, amounting to 5.19 Baht per kilometer. This represents 23.05% of the total cost of Diesel. Moreover, EVs pose a more environmentally friendly alternative to Diesel. Further to these findings, it is pertinent to consider the environmental implications of the energy types, particularly in terms of greenhouse gas emissions and pollution. Given the global shift towards sustainable and green practices, the environmental advantages of EVs should not be underestimated. With reduced emissions, EVs contribute significantly less to air pollution and climate change than their Diesel counterparts.

Therefore, the initial investment decision in choosing the category of trucks by owners will have the most significant impact on the selling price strategy. The volatility of energy prices will not significantly affect setting a price, consistent with the in-depth interviews with companies 2,3,5 and the works of Vijayagopal and Rousseau (2021), Suttakul et al.(2022), and Interlake Mecalux (2023). Opting for EVs (Electric Vehicles) is thus an attractive choice, especially for businesses that need green policies.

Moreover, another perspective to consider is the evolution of the energy market and infrastructure. The development of charging infrastructure and renewable energy sources can further decrease the operational cost of EVs in the long run. Lastly, adopting EVs could contribute positively to energy security by decreasing dependency on fossil fuels. This aspect is particularly crucial for countries that heavily rely on oil imports. However, it is essential to study the implications of this shift on the electricity grid and to ensure adequate capacity to support increased electricity demand.

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Suggestion

Entrepreneurs

While EVs present a lower total cost than Diesel, amounting to 5.19 Baht per kilometer, it's essential to consider that the initial purchase price of EVs, particularly for tractor-trailers, is significantly higher than that of Diesel vehicles. These differential impacts investment calculations, especially when interest is factored in and when determining the payback period for the price difference of 2.8 million Baht between EVs and Diesel vehicles. Consequently, a strategy that emphasizes reducing transport fees, particularly during the first five days of EV operation, may not be suitable due to the substantial upfront costs associated with EV tractor-trailers. This strategy could contradict customer expectations primarily based on the lower energy costs of EVs aligned with the study of Vijayagopal and Rousseau (2021).

An interesting point from the in-depth interview with the participants is the battery degradation due to the heat from Thailand's climate, especially for commercial trucks constantly exposed to the outdoors. However, there has been no research that confirms or proves this. The information is only based on observations of the charging behavior of the trial vehicles. Thus, research on the degradation rate of batteries in various environmental conditions, especially in relation to the climate, is of interest for future studies.

Government policy

In terms of governmental policy, if a nation aims to promote increased usage of EV trucks, it could consider implementing tax incentives for EV operators consistent with the work of Qiao and Raufer (2022) and Purtanto (2023). For instance, one such measure could be to encourage extensive depreciation value by allowing 1.5 times over the standard rate for seven years, as per the stipulations set by the Internal Revenue Agency. This would support the price differential between EVs and Diesel over approximately 400,000 (four hundred thousand) Baht annually.

Green Loans are specialized financing options banks or financial institutions provide to support environmentally sustainable projects. These loans often come with favorable terms, such as reduced interest rates or more extended repayment periods, to incentivize individuals and businesses to invest in green initiatives. Projects eligible for green loans typically include a transport provider that would like to change to an EV truck to fulfilling a customer's requirement. By offering green loans, financial institutions promote environmental sustainability and position themselves as socially responsible entities in the eyes of their stakeholders.

In addition to these measures, other policy recommendations could include direct subsidies or grants for EV purchases, particularly for commercial fleets. Furthermore, the government could invest in and promote the development of charging infrastructure, which would reduce range anxiety and thus make EVs a more attractive option for long-haul transport. Lastly, renewable energy policies could further decrease the operational cost of EVs and make them even more environmentally friendly, thus providing additional incentives for their adoption.

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