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Diesel or Electric Jeepney? A Case Study of Transport Investment in the Philippines Using the Real Options Approach

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Abstract: The Philippines is moving towards a more sustainable public transport system by introducing a public utility vehicle (PUV) modernization program with electric jeepneys (e-jeepneys) and modernized diesel jeepneys. Despite its potential to address problems related to air pollution, traffic congestion, dependence on fuel imports, and carbon emissions, transport groups show resistance to the adoption of the government program due to costs and investment risk issues. This study aims to guide transport operators in making investment decisions between the modernized diesel jeepney and the e-jeepney fleet. Applying the real options approach (ROA), this research evaluates option values and optimal investment strategies under uncertainties in diesel prices, jeepney base fare price, electricity prices, and government subsidy. The optimization results reveal a better opportunity to invest in the e-jeepney fleet in all scenarios analyzed. Results also show a more optimal decision strategy to invest in the e-jeepney immediately in the current business environment, as delaying or postponing investment may incur opportunity losses. To make the adoption of the e-jeepney more attractive to transport operators, this study further suggests government actions to increase the amount of subsidy and base fares, establish public charging stations, and continue efforts to rely on cleaner, cheaper, and renewable sources of electricity.

Keywords: electric vehicle; jeepney; Monte Carlo simulation; optimization; investment under uncertainty; real options

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1. Introduction

In order to address the global problems of greenhouse gas (GHG) emissions, air pollution, and dependence on fossil fuels, different countries and regions are finding cleaner and more sustainable modes of transportation. Currently, the transport sector accounts for 23% of global energy-related CO_2 emissions and is continuously growing due to increasing passenger and freight activity [1]. As aviation, shipping, and heavy-duty roads are the most difficult modes to decarbonize, the electrification of passenger cars and public utility vehicles (PUVs) appears to have the potential to reduce GHG emissions and other pollutants [2,3]. Developed countries put considerable effort into making electric mobility more attractive by providing fiscal incentives, subsidy schemes, and public charging infrastructure. This resulted in a record 1.1 million electric vehicles (EVs) sold worldwide in 2017, which is expected to increase to 11 million in 2025 and surge to 30 million in 2030 [4]. Meanwhile, developing countries adopt electric mobility that suits the local circumstances such as electric scooters in India, electric "tuk-tuks" in Thailand and Kenya, second-hand electric cars in Jordan, and e-jeepneys in the Philippines.

Jeepneys, refurbished American vehicles left after the Second World War, are the Philippines' most popular mode of transportation, providing cheaper rides and allowing millions of passengers to hop on and off anywhere. There are around 270,000 franchised jeepney units on the road across the country, with some 75,000 units in Metro Manila alone. With the country's fast development and economic growth, old-model jeepneys have become the main contributor to air pollution and traffic congestion in the cities. According to the Manila Aerosol Characterization Experiment (MACE 2015) study, jeepneys, which account for 20% of the total vehicle fleet, are responsible for 94% of the soot particle mass in Metro Manila, with 2000 times higher emissions compared to the EURO 6 standard for diesel in Europe [5]. To address this problem, the government recently launched the "Public Utility Vehicle (PUV) Modernization Program", which aims to make the country's public transportation system efficient and environment-friendly by phasing out jeepneys, buses, and other PUVs that are at least 15 years old and replacing them with safer, more comfortable and more sustainable alternatives [6]. Replacement PUVs, such as e-jeepneys and modernized diesel jeepneys, are required to have at least a Euro 4-compliant engine or an electric engine and must contain safety features like speed limiters, accessibility features like ramps and seatbelts, closed-circuit television cameras, Wi-fi and USB ports, GPS, and a dashboard camera (see Figure 1) [7]. Currently, the government provides a 5% subsidy to every e-jeepney unit, which costs between USD 64.19 M and USD 73.36 M/unit, payable within 7 years at a 6% interest rate. This e-jeepney investment cost is three times the average price of a brand new modernized diesel jeepney, which only costs USD 18.34 M to USD 27.51 M/unit. Regardless of the potential to solve traffic conditions and air pollution, provide new jobs, enhance the tourism industry, and streamline public transport, the modernization program has faced numerous protests from drivers and operator organizations due to financing issues. This gives an impetus to conduct a study that analyzes the economic viability of adopting the modernized PUV and suggests investment strategies making the e-jeepney more attractive than the diesel jeepney.

(a) (b) (c)

Figure 1. Most common public utility vehicles in the Philippines: (**a**) traditional diesel jeepney; (**b**) modernized diesel jeepney with Euro 4-compliant engine; (**c**) air-conditioned e-jeepney. Source: Land Transportation Franchising and Regulatory Board (LTFRB).

Traditional valuation methods for transportation investment projects in the Philippines include return on investment (ROI), payback period, net present value (NPV), internal rate of return (IRR), and cost-benefit analysis (CBA) [8–10]. However, these methods do not account for possible uncertainties that affect investment decisions such as fuel prices, demand and prices of products, fare prices, government policies, and technological advancement. The real options approach (ROA) overcomes these limitations by combining uncertainty and risk with flexibility in making investment decisions, as potential factors that give additional value to the project [11]. Several literature works analyze investment decisions, particularly for electric vehicles, using this approach. Among these studies include a choice between hybrid vehicles and EVs, while considering the option to change promotion from hybrid vehicles (HVs) to EVs in the future [12]; redesigning or investing in gas, hybrid electric and EVs under uncertainties in gas prices and regulatory standards [13]; the adoption of EVs for mail and parcel distribution, considering the uncertainty about future fuel prices and future battery costs [14]; market growth of investments in plug-in EVs and charging infrastructure for plug-in EV users under fluctuations in gasoline prices [15]; investment decisions and patterns related to HVs under technological and market uncertainties and irreversibility, which impacts the investment and innovation decisions of automotive firms, supporting the development of more sustainable vehicle technologies [16]; and analyzing flexible lease contracts in the fleet replacement problem with alternative fuel vehicles considering CO_2 prices, fuel prices, mileage covered by a vehicle, fuel consumption, and technological uncertainties [17].

To the best of our knowledge, we rarely find any literature applying ROA in EV investments in the context of developing countries, particularly for countries that are highly dependent on imported fossil fuel products. These studies include a replacement of old conventional fuel-powered vehicles with hybrid EVs under uncertainty in fuel prices [18]; optimal rail transit investment under time-inconsistent preferences and population uncertainty [19]; and a ROA model addressing transit technology investment considering uncertainty in urban population size [20]. We try to contribute to the existing literature by proposing a ROA framework for analyzing a PUV investment project by taking the case of the Philippines. This study is very valuable and timely as the country is moving from a carbon-intensive towards a low- to zero-carbon public transport system. Applying the ROA, this research aims to analyze the decision of a transport operator to invest either in the modernized diesel jeepney or in the e-jeepney fleet. As the country is heavily dependent on imported fossil fuel products with 55% import from diesel demand [21], we consider using the volatility of diesel prices as the main uncertainty in estimating the option values and optimal timing of investment in PUV projects. Further, we analyze how base fare price, electricity price, and government subsidy in the e-jeepney affect the investment decision-making process. We then compare the usefulness of the proposed ROA model over the traditional valuation methods in analyzing PUV investment projects. We finally aim to suggest government policies that boost investments in EVs to realize the government's goal of a more sustainable and environment-friendly transport system.

2. Materials and Methods

We consider a transport operator or company who has the option to invest in a project of buying a fleet of modernized diesel jeepneys, or a fleet of e-jeepneys. The net present value of investing in diesel jeepneys NPV_j can be expressed in Equation (1).

$$NPV_j = \sum_{t=0}^{T_j} \rho^t \pi_j - I_j = \sum_{t=0}^{T_j} \rho^t \left(P_j Q_j - P_{d,t} Q_d - C_j\right) - I_j \quad (1)$$

where π_j is the annual cash flow of diesel jeepney operation from period 0 to T_j, the effective lifetime of the jeepney; ρ is the social discount factor equal to $1/(1+\delta)^t$; δ is the risk-free interest rate, and I_j is the cost of investment in the diesel jeepney fleet including the disposal cost. The annual cash flow is computed from the average earnings P_j from an individual vehicle unit Q_j minus the operations and maintenance costs C_j, which include the driver salary, boundary, registration, franchise, and maintenance, and the fuel cost that is equal to the amount of fuel Q_d used by the fleet times the price of diesel.

In line with previous studies [22–24], we assume that the price of diesel $P_{d,t}$ is stochastic and follows the Geometric Brownian motion (GBM), as shown in Equation (2):

$$dP_{d,t} = \alpha P_{d,t} dt + \sigma P_{d,t} dW_t \quad (2)$$

where W_t is a Wiener process, and the percentage drift, α, and the percentage volatility, σ, are constant. We apply Ito's formula to solve Equation (2) and obtain:

$$ln\frac{P_{d,t}}{P_{d,0}} = \left(\alpha - \frac{\sigma^2}{2}\right)t + \sigma W_t \tag{3}$$

Using Equation (3), we apply the Augmented Dickey–Fuller (ADF) unit root test to determine the drift and variance of diesel prices, as shown in regression Equation (4):

$$ln\frac{P_{d,t}}{P_{d,0}} = g(1) + g(2)lnP_{d,0} + \sum_{j=1}^{L} \lambda_j \Delta lnP_{d,t-j} + \epsilon_t \tag{4}$$

where $g(1) = \left(\alpha - \frac{\sigma^2}{2}\right)t$, $g(2)$ is a coefficient estimated in the unit root test, λ_j is a coefficient for L number of lags for $\Delta lnP_{d,t} = lnP_{d,t} - lnP_{d,0}$, and $\epsilon_t = \sigma W_t$. From the ADF test result, we estimate the future diesel prices, as shown in Equation (5):

$$P_{d,t+1} = P_{d,t} + \alpha P_{d,t} + \sigma P_{d,t}\varepsilon_t \tag{5}$$

where α and σ are the drift and variance parameters representing the mean and volatility of the price process, and $\varepsilon_t \sim N(0,1)$, a random number.

On the other hand, the net present value of investing in e-jeepneys $NPVe_j$ is expressed in Equation (6):

$$NPV_{ej} = \sum_{t=0}^{T_{ej}} \rho^t \pi_{ej} + s - I_{ej} = \sum_{t=0}^{T_{ej}} \rho^t \left(P_{ej}Q_{ej} - P_e Q_e - C_{ej}\right) + s - I_{ej} \tag{6}$$

where π_{ej} is the annual cash flow of e-jeepney operation from period 0 to T_{ej}; s is the government subsidy for jeepney modernization; and $I_{ej} = \sum \rho^t I(1+i) + D_{ej}$ is the e-jeepney investment cost, which can be loaned at i interest rate with I monthly amortization up to a certain number of years and incur a disposal cost at the end of its lifetime T_{ej}. The annual cash flow is calculated from the average annual earnings P_{ej} of each e-jeepney Q_{ej} minus the cost of electricity P_e consumed by the fleet Q_e and the operations and maintenance cost C_{ej}, as described in Equation (1).

The investor's problem is to maximize the value of the investment subject to stochastic prices of diesel fuel, as shown in Equation (4):

$$max\left\{NPV_{ej},\ \mathbb{E}\left[NPV_j\right]\middle| P_{d,t}\right\} \tag{7}$$

where the expected NPV of diesel jeepney $\mathbb{E}\left[NPV_j\right] \approx \frac{1}{M}\sum_{m=1}^{M} NPV_{j,m}$ is calculated using Monte Carlo simulations at a sufficiently large number of times M, subject to stochastic prices of diesel. From Equation (7), investment option values at each initial price of diesel $V\left(P_{d,t}\right)$ are solved using the optimization, as shown in Equation (8):

$$V\left(P_{d,t}\right) = max\left\{NPV_{ej},\ \mathbb{E}\left[NPV_j\right]\middle| P_{d,t}\right\} \tag{8}$$

We describe the optimal timing of investment in e-jeepneys P_d^* as the minimum price of diesel fuel, where the maximized option value $V_{P_{d,t}}$ at the initial diesel price t is equal to the maximized option value $V_{P_{d,t+1}}$ at the initial diesel price $t+1$, as shown in Equation (9):

$$P_d^* = min\left\{P_{d,t}\middle| V_{P_{d,t}}\left(P_{d,t}\right) = V_{P_{d,t+1}}\left(P_{d,t}\right)\right\} \tag{9}$$

Comparing P_d^* with the current price of diesel yields various strategies, as described in Equation (10), where no investment should be made if $V\left(P_d^*\right) < 0$; otherwise, invest in:

$$\left.\begin{array}{ll} e-jeepney,\ if & P_d^{cur} > P_d^* \\ diesel-fueled\ jeepney\ ,\ if & P_d^{cur} < P_d^* \\ indifferent,\ if & P_d^{cur} = P_d^* \end{array}\right\} \tag{10}$$

To estimate the real option values, we create a dynamic optimization program using Matlab divided into four segments. The first segment estimates the stochastic prices of diesel fuel and follows GBM using Equation (5). In the second segment, we incorporate these prices into the NPV_j in Equation (1). The third segment includes the Monte Carlo simulation to calculate the expected NPV of the diesel jeepney $\mathbb{E}\left[NPV_j\right]$. The last segment is the dynamic optimization to calculate the maximized value of either investing in the e-jeepney or in the diesel jeepney, at each initial price of diesel. We plot all estimated values of NPVs and optimization results using Excel, as shown in the following section.

We finally compare the ROA estimations with traditional valuation methods including the NPV, payback period (PBP), returns on investment (ROI), and internal rate of return (IRR), using Equations (1), (6), and (11–13) as shown below. The PBP refers to the amount of time it takes to recover the cost of an investment. This is equal to the cost of the investment divided by the annual net cash flow, as described in Equation (11):

$$PBP = \frac{investment\ cost}{annual\ net\ cash\ flow} \tag{11}$$

The ROI is the benefit to an investor resulting from an investment and is described using Equation (12):

$$ROI = \frac{net\ income - expenses}{total\ investment} \times 100 \tag{12}$$

The IRR is the discount rate that makes the NPV equal to zero, as shown in Equation (13). We calculate the IRR using MS Excel Solver.

$$IRR = NPV = \sum_{t=1}^{T} \frac{annual\ net\ cash\ flow}{(1+IRR)^t} - I\ = 0 \tag{13}$$

In this research, we use data from various government agencies to estimate the parameters for the optimization problem. Investment data, including the costs, fare prices, electricity price, subsidy schemes, operations and maintenance cost, proposed driver salary, franchising, diesel consumption for a jeepney, and electricity consumption for an e-jeepney, are estimated using the data from the Philippines' Department of Transportation (DoTr), Land Transportation Franchising and Regulatory Board (LTFRB), and Department of Energy (DOE). 26-period average annual price data from World Bank -development indicators are used to run the Augmented Dickey–Fuller unit root test for the stochastic process of diesel (see Supplementary Material Table S2). The test result confirms that $P_{d,t}$ follows GBM with $\alpha = 0.01143$ and $\sigma = 0.02608$. These parameters are then used to generate stochastic prices of diesel, as described in Equation (2). The optimization results are tested for sensitivity analysis with respect to fare prices, electricity prices, and government subsidy. Six jeepney fares are analyzed: USD 21.81c (PHP 10) current base fare; a proposed higher fare, USD 26.17c (PHP 2 addition); and some reductions in fare prices, USD 17.45c (reduced by PHP 2), USD 15.27c (by PHP 3), USD 13.09c (by PHP 4), and USD 10.91c (by PHP 5). For the electricity price scenario, the current USD 22.20c (PHP 10.18/kWh) electricity rate is adjusted to a possible PHP2 decline in prices to USD 17.45c/kWh, and PHP3 and PHP5 increases to USD 28.35c/kWh and USD 32.72/kWh. Finally, proposed 10% and 0% subsidies are analyzed along with the current government subsidy of 5% of the investment. All data and variables, including the description and estimation, are summarized as shown in Supplementary Material Table S1.

3. Results

3.1. Traditional Valuation Methods

Table 1 summarizes the financial estimation results for PUV modernization projects using the traditional valuation methods. The results show that NPVs for both the e-jeepney and the modernized diesel jeepney projects are positive, which indicates positive returns for investing in any of the alternatives. Despite the high investment cost for each e-jeepney unit, results reveal a better investment opportunity for the e-jeepney fleet, with USD 4.892 million NPV rather than USD 3.138 million for the modernized diesel jeepney fleet. The main reasons for this include the more energy efficient e-jeepney, higher earnings from the larger seating capacity of the e-jeepney, and the high fuel cost for the traditional jeepney. This result supports previous claims that investing in electric PUVs is more profitable than combustion vehicles in the Philippines due to higher passenger capacity, lower fuel consumption, and safer body design [8,9].

Table 1. Financial estimation results using traditional valuation methods.

Valuation Method	E-Jeepney	Modernized Diesel Jeepney
Net present value (NPV) (USD)	4.892 million	3.138 million
Payback period (PBP) (years)	4.09	3.28
Return on investment (ROI) (30 years)	373%	490%
Internal rate of return (IRR)	32.36	43.89

On the other hand, other traditional valuation methods favor investment in the diesel jeepney fleet with shorter PBP, higher ROI, and higher IRR. The PBP estimation shows that an investment in the modernized diesel jeepney fleet can be recovered in 3.28 years, while it is 4.09 years for the e-jeepney fleet. Over the 30-year lifetime of jeepney operation, the diesel project returns the investment by 5 times while it is quadruple for the e-jeepney project. These results are due to higher investment costs for the e-jeepney, which are triple the cost for the diesel jeepney. Further, the IRRs for both projects are also higher than the hurdle rate of 15% set by the Philippine government [25], which implies that both projects are profitable.

While the traditional financial tools are already practical methods for PUV project valuation, these all-or-nothing strategies, outsetting all future outcomes as fixed, pose several potential problems. These include a constant nature of weighted average cost of capital through time, undervaluing the investment, the estimation of economic life, which forecasts errors in creating the future cash flows, and insufficient tests for the plausibility of the final results [26]. In a stochastic world, there would be fluctuations in business conditions that would change the value of the project [26]. Meanwhile, ROA can mitigate some of these problematic areas by combining risks and uncertainties in the future cash flow, with managerial flexibility in making investment decisions that give additional value to the project [11].

3.2. Baseline Scenario

The baseline scenario in Figure 2 describes different investment values under the business as usual environment. This figure compares the NPVs for the e-jeepney (green curve) and the diesel jeepney (yellow curve), expected net present value (ENPV) for the diesel jeepney (blue curve), considering the volatility of diesel fuel prices, and the maximized option values (dotted black curve) for the investment project at different initial prices of diesel. Initial results show a higher NPV for the e-jeepney, indicating a more profitable project than the diesel jeepney. This result supports the NPV results from the previous subsection, showing a better investment project for the e-jeepney.

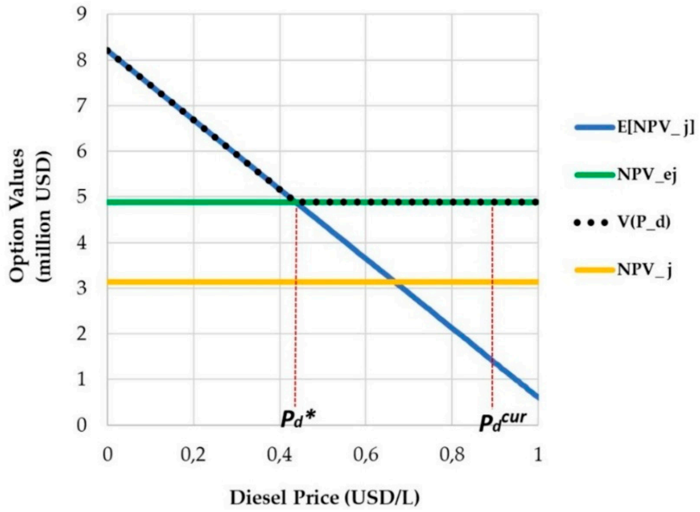

Figure 2. Investment values at initial prices of diesel fuel. P_d^* is the minimum price of diesel for the e-jeepney project; $P_d^{cur} = USD\frac{0.8992}{L}$ is the current price of diesel. Optimization results are tabulated in Supplementary Material Table S3.

The next point of interest is the blue curve, which describes the ENPV of the modernized jeepney at different initial prices of diesel. The Monte Carlo simulation result shows how $\mathbb{E}\left[NPV_j\right]$ decreases with stochastic prices of diesel. This result is expected as higher fuel price incurs higher cost for jeepney operations and therefore lower profits. With the current trend in fuel prices, investment in the diesel jeepney will no longer be feasible in the future, which will further support the country's ambitious aim to have a more efficient and environment-friendly transport system. The dotted black curve illustrates the dynamics of real option values. This describes the maximized value of either investing in the modernized diesel jeepney or in the e-jeepney, at different initial prices of diesel. The ROA model estimates the optimal timing of investment in the e-jeepney, denoted by P_d^*, which is the price of diesel that maximizes the investment in the e-jeepney. Below this threshold, the other alternative is a better investment option. Using the decision rule described in Equation (10), the optimization results reveal that investment in the modernized diesel jeepney is a better option if the price of fuel is below P_d^* = USD 0.4362/L. However, the current price of diesel is $P_d^{cur} = USD\ 0.8992/L$, which is greater than the estimated P_d^*. This suggests an optimal decision to invest in the e-jeepney project under the current business environment. This result highlights the advantage of using ROA, as traditional valuation methods assume a single static decision, while ROA assumes a multidimensional series of decisions with management flexibility to adapt to changes in the business environment [26].

Figure 3 illustrates the dynamics of investment values at different periods. The simulation results show that while the investment value of the e-jeepney is constant, the expected NPV of investment in the diesel jeepney decreases over time and obtains negative values at some periods. The $\mathbb{E}\left[NPV_j\right]$ curve (blue) suggests that investment in the modernized diesel jeepney is only profitable within 9 years of the decision-making period; otherwise, future investments only obtain negative profits. The main reason for this is the expected rising diesel fuel prices in the world market for the coming years [27,28], resulting in increasing operations cost and lower discounted cash flow. Moreover, we can observe that $\mathbb{E}\left[NPV_j\right]$ across the investment period is as stochastic as the diesel price uncertainty conditions set in the proposed ROA model. Further, the red curve describes the opportunity loss from delaying investment in the e-jeepney. This loss is an opportunity cost by means of the revenue that could be earned from investing in the e-jeepney over the diesel jeepney at different investment periods. The result in the initial investment period $T = 0$ shows that, while both investments are profitable, the operator may incur an opportunity loss of USD 3.5 million for choosing the diesel jeepney over the e-jeepney project. At period $T = 10$ and beyond, the opportunity loss reaches USD 5.07 million and more, which is higher than the value of investment in the e-jeepney. This implies no better investment option but the e-jeepney fleet project from period $T = 10$. These results support the above claim that adopting the e-jeepney is a more optimal investment decision for the current business scenario; otherwise, the transport operator may incur opportunity loss from postponing the investment in the e-jeepney.

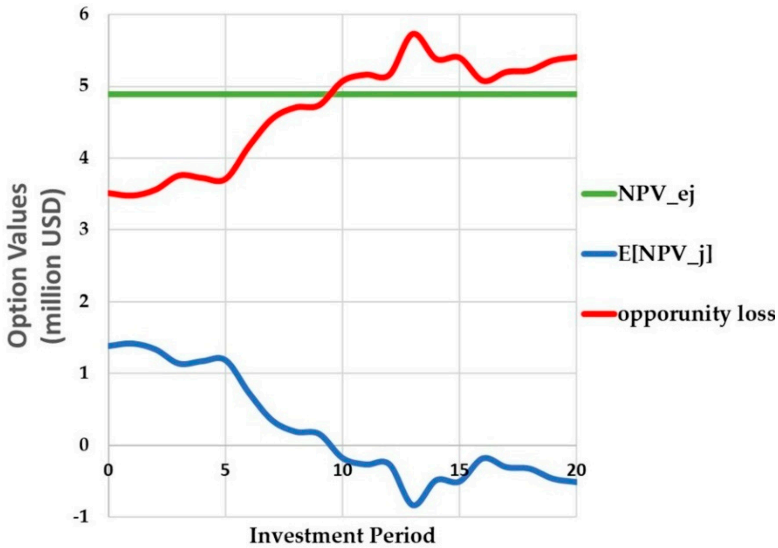

Figure 3. Dynamics of investment values at different periods. $\mathbb{E}\left[NPV_j\right]$ is the expected NPV of investment in the diesel jeepney; NPV_{ej} is the NPV of investment in the e-jeepney; opportunity loss is the value of delaying investment in the e-jeepney. Optimization results for the dynamics of investment values at different periods are tabulated in Supplementary Material Table S4.

3.3. Jeepney Fare Scenario

In this scenario, we analyze the sensitivity of investment decisions with respect to changes in jeepney fares. Currently, public transport vehicles such as buses, jeepneys, and taxis are regulated by the LTFRB including routes, entries, and fares. As of December 2018, the base fare for traditional jeepneys in Metro Manila and nearby regions is USD 19.63c, which covers the first 4 km of public utility jeepney (PUJ) Routes. According to this agency, modern jeepneys that are compliant with the Public Utility Vehicle Modernization Program (PUVMP) can charge a minimum fare of USD 21.81cs. This scenario describes how variations in fares affect the option values and identifies the critical value of fare reduction for the adoption of PUVMP.

Figure 4 describes the option values at different jeepney base fares. The optimization shows an upright shift in the options curve at higher base fares. This result suggests that the government must increase the base fares in order to attract transport operators and prospective investors to adopt the PUV modernization program. This will have no or little effect on the demand, as passengers in the case of the Philippines are price takers due to the limited number of PUVs. On the contrary, a reduction of base fares shifts the option curve down left. Consequently, a fare reduction causes considerable revenue loss for the operator [29], hence, lower profit for operators and lower expected NPV for the project investment. Therefore, careful fare system planning for PUVs must be done to reflect the maximization of demand, revenue, profit, and social welfare [30]. Moreover, the fare USD 13.09c curve indicates the minimum fare reduction possible. Beyond this reduction, investment in any alternative incurs only losses, as described by the fare USD 10.91c (green curve).

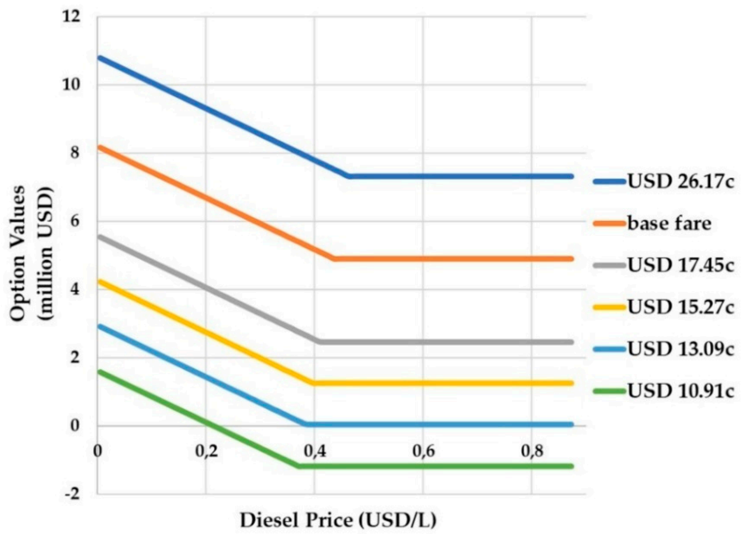

Figure 4. Option values at different jeepney fares. Current base fare = USD 21.81c (PHP 10); USD 26.17c adds PHP 2 onto the base fare); USD 17.45c, 15.27c, 13.09c, and 10.91c reduce the current base fare by PHP 2, PHP 3, PHP 4, and PHP 5 (USD 1 = PHP 45.85). Optimization results are tabulated in Supplementary Material Table S5.

3.4. Electricity Price Scenario

In this scenario, we analyze the effect of changing electricity prices on the e-jeepney investment. At present, the country has relatively higher electricity rates compared with neighboring countries in the Asia-Pacific region. While Thailand, Malaysia, South Korea, Taiwan, and Indonesia have lower electricity prices due to government subsidies in the form of fuel subsidies, cash grants, additional debt, and deferred expenditures, the Philippines has higher prices due to no government subsidy, fully cost-reflective, imported fuel-dependent, and heavy taxes across the supply chain [31,32]. By changing the value broadly, we present how potential government actions on electricity prices affect investment conditions in the e-jeepney. Additionally, with the increasing investments in renewable energy sources (RES) in the country [33], we assume future reductions in electricity prices as a result of electricity surplus from RES being fed into the grid [34–36].

Figure 5 describes the option values at different electricity prices. The shifts on the bases of the curves show changes only for the NPV of the e-jeepney project. This result is evident as higher electricity prices ($P_e > USD$ 22.20 c/kWh) incur higher costs for e-jeep operation, hence, lower profit and lower NPV. On the other hand, lower electricity prices ($P_e > USD$ 22.20 c/kWh) result lower operations costs and higher profits for the e-jeepney. Note that investment in the other alternative is not affected by the price variability as electricity is not used in diesel jeepney operation. This result supports previous works highlighting a higher profitability of EVs at lower electricity prices [37,38]. This suggests that the government should regulate electricity prices at or lower than the current rate in order to make a better investment environment for e-jeepneys and realize its PUV modernization program. It also suggests that the government should boost investments in RES, as this will not only result in lower dependence on imported fossil fuels for energy generation and lower GHG emissions, but also reduce local electricity prices, which eventually make e-jeepneys a more attractive investment project.

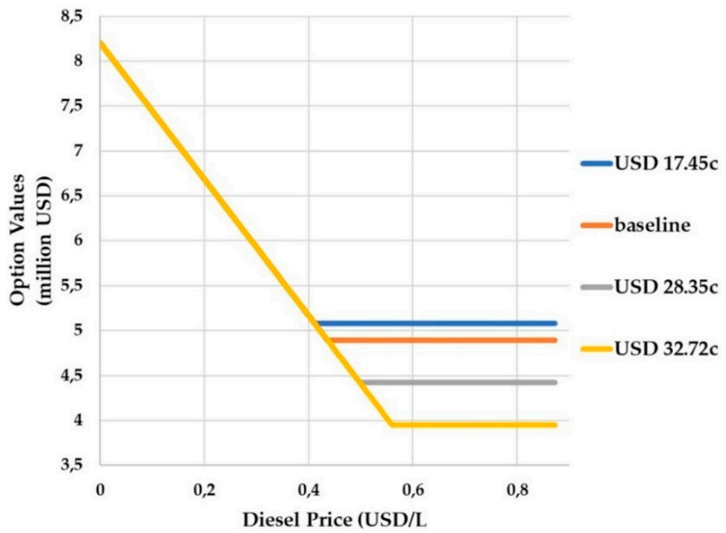

Figure 5. Option values at different electricity prices. Current electricity price = USD 22.20c/kWh; USD 17.45c reduces the electricity rate by PHP 2/kWh; USD 28.35c and USD 32.72c increase the electricity rate by PHP 3/kWh and PHP 5/kWh (USD 1 = PHP 45.85). Optimization results are tabulated in Supplementary Material Table S6.

3.5. Government Subsidy Scenario

Lastly, we describe the significance of government subsidy for the investment in the e-jeepney project. According to the DoTr's order on PUVMP guidelines, existing PUV operators with valid franchises and those applying for new or developmental routes are eligible for a fixed amount of USD 1745 per unit as an equity subsidy, provided that they drop the old PUJ units and substitute them with modernized jeepney units compliant with the Omnibus Franchising Guidelines (OFG) requirements [6]. In this scenario, we analyze how various subsidy schemes affect investment decisions for the adoption of the e-jeepney.

Figure 6 shows the optimization results for the option values of e-jeepney investment at various government subsidies: the current 5% of the total value per unit, 10% subsidy, and no subsidy. The option curves reveal no significant difference between the subsidy schemes analyzed. This result is in contrary to a previous study on bus purchase cost subsidy in the United States, which showed a significant impact on optimal bus type choice and its replacement age, and favoring diesel bus over hybrid EV without subsidy [39]. However, the break-even value of government subsidy in the previous study indicates that hybrid buses are not optimal unless the subsidy is equal to or greater than 63% ceteris paribus, a value relatively higher than the 5% subsidy offered by the Philippine government for the EV project analyzed in the current study. The current research result further indicates that the government intervention of giving modest and scanty assistance for prospective e-jeepney fleet investors makes no significant impact in the investment decision-making process. This implication is in line with previous studies showing electric vehicles to be a good economic option even without governmental subsidies [40,41].

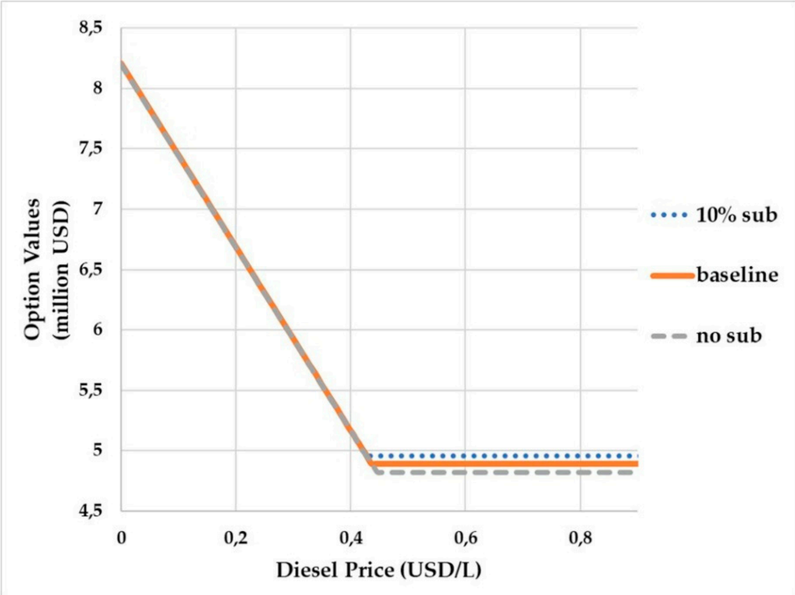

Figure 6. Option values at different government subsidies for investment in the e-jeepney. Baseline = 5% subsidy; 10% sub = 10% subsidy; no sub = removal of subsidy. Optimization results are tabulated in Supplementary Material Table S7.

4. Discussion

In this research, we only focus on the financial side of public transport investment. In real project valuation, there are also several factors considered that are equally important in the decision-making process. These may include an economic impact assessment of job creation and less dependence on imported diesel fuel; health and social impacts of providing safe and more comfortable modes of public transportation; public perception; and environmental impacts on noise, CO_2 emission, and air pollution reductions [42–45]. The results of a previous study on alternative technologies for the Philippine utility jeepney [46] showed that the modernization project acquires additional benefits of USD 3076/vehicle in tax collections and USD 276/vehicle in employment income generated from the e-jeepney, while the benefits were USD 310/vehicle and USD 303/vehicle from the EURO-4 diesel jeepney. This study further quantifies the health and non-health benefits (USD 19,522/vehicle and USD 4157/vehicle) for the e-jeepney, with USD 16,616/vehicle and USD 3205/vehicle for the EURO-4 diesel jeepney. The health impacts account to respiratory illnesses and premature mortality caused by particulate matter, and NOx and SOx emissions emanating from vehicle tailpipes and from power generation (for the e-jeepney), while non-health impacts account to corresponding visibility reduction, soiling, and material damage [46]. As the urban air pollution in the Philippines has considerable health implications at about 1.5% of the country's GDP [46], the shift from combustion engines to EVs is beneficial to health and environment, especially when the government also transitions to greener sources of energy [45,47,48]. On the other hand, one study [46] estimated a negative USD 1470/vehicle of GHG savings from the e-jeepney, while it was positive USD 928/vehicle for the EURO-4 diesel jeepney. This implies that the shift to electric jeepneys will not provide GHG benefits under the current energy environment, as the baseline grid mix in the country is dominated by coal (75% of total energy generation) [11], which increases the grid GHG emission factor. In terms of public perception, market research on the future of EVs in Southeast Asia revealed that 46% of Filipinos expressed interest in owning an e-vehicle (e-jeepney or e-tricycle), while more commuters preferred to ride EVs than the conventional transportation in areas where EVs are available [49]. The study stated that the figure increased to 75 percent if the government gives incentives to EV buyers including waived taxes, more charging infrastructure, priority lanes for EVs during car registration, and free parking [49]. The study further reiterated the support from local government units in the deployment of EV units, while more cooperatives and operators are becoming involved by replacing their old units and obtaining new franchises with the help of the DoTr [49]. While the public perception of EVs is relatively low in other countries due to concerns about high battery costs, safety, reliability, range per charge, and poor public charging infrastructures [50,51], Filipinos' environmental awareness is now increasing with the adoption of more sustainable modes of public transport. While the GHG savings and the traditional valuation methods favor modernized jeepneys with shorter PBP, higher ROI, and higher IRR; other analyses including economic impacts on employment and additional tax collection, health and non-health impacts, and public perception favor the e-jeepney project, which further complements our analysis using the proposed ROA model.

In the jeepney fare scenario, we analyze how the changing base fare affects investment decisions for the PUV project. We assume that the USD 2.18c (PHP 1) fare difference between modern and traditional jeepneys has no or little effect on the demand, as passengers in the case of the Philippines are price takers due to the limited number of PUVs. In the medium to long-run, this assumption is true as traditional jeepneys will be phased out in 10 to 15 years [6]; hence, there will be a uniform price for all types of jeepney. It should be noted that in the short-run, fare differences may affect the demand as consumers may prefer traditional jeepneys with lower fares. In this case, future studies may include the cross-price elasticity of demand, which reflects the substitution pattern between the traditional and modernized jeepneys [52]. Moreover, cross-price elasticity may also include the availability of charging stations; charging prices of the stations; and PUV substitutes such as hybrid, hydrogen-fueled, and other modes of public transportation [53,54].

The context of the decision-making analyses in this study focuses on the transport operator who will adopt PUVMP with the e-jeepney; hence, we assume that charging stations for e-jeepneys are located at company and public terminals. We recognize that our results can further be influenced by a supporting project from the government to establish charging infrastructures, which can be placed in strategic places. This can be planned by utilizing PUV recharging information like frequency, amount and time to estimate the distances between the stations [55,56]. However, this is in contrast with a study which suggests that the charging of electric PUVs should be coordinated to minimize potential energy losses and maximize the main grid load factor [57]. Using the same recharging information, operators can manage the charging schedule of the units in their respective terminals. While individual charging may not affect the distributions systems, simultaneous charging of an entire fleet may incur potential problems in old transformers and excessive voltage drops [58]. Moreover, for the last 10 years, there was an average of 11% annual increase in the production of electricity using coal [59]. This indicates that there was an observable increase in the demand for electricity even before the dawn of charging e-jeepneys. It should be noted that emissions from burning fossil fuels like coal release GHGs, which affect the environment. While we are sure that the GHG emissions of the e-jeepney are Euro-4 compliant, the production of electricity that powers these vehicles is not. Therefore, the government should increase its efforts to develop infrastructures that generate electricity from RES.

This study compares the economic attractiveness of investment in the e-jeepney and the modernized diesel jeepney. Future studies may also consider other environment-friendly alternatives such as biofuel vehicles, hydrogen-fueled vehicles, and hybrid vehicles. While this study analyzes the case of PUV investment in the Philippines, future studies may consider applying the proposed model for PUV projects in developing countries such as electric tricycles, electric tuk-tuks, e-scooters, electric water taxis, and other sustainable modes of public transportation that fit with the local setting.

Finally, this study analyzes an investment setting with stochastic diesel fuel prices, while assuming all other variables are constant through time. We acknowledge other uncertainties that affect investment decisions, particularly for public transport, including the prices of electricity, jeepney fares, operation and maintenance costs, demand for more environment-friendly PUVs, technological innovations, investment costs, and other relevant variables. These uncertainties can also be incorporated in the model to better capture a more realistic investment setting relevant to market and climate change policy. Despite these limitations, we believe that the ROA framework proposed in this study could be a good benchmark for further analysis of investment decisions for cleaner and more sustainable modes of public transportation.

5. Conclusions

This study discusses an investment case for adopting the modernized diesel jeepney or the e-jeepney in the Philippines. We apply the real options approach under uncertainty in diesel fuel prices to evaluate the option values and optimal investment strategies in PUV projects. We characterize various scenarios where the e-jeepney is a more favorable investment than the modernized diesel jeepney and analyze how sensitivity to electricity prices, jeepney fares, and government subsidy in the e-jeepney affect the investment decisions for PUVs. We also compare the decision usefulness of the proposed ROA model over the traditional financial tools for analyzing PUV investment projects. Our analysis highlights the advantages of ROA by combining risks, uncertainties, and managerial flexibility in making investment decisions.

Our analyses conclude that there is a better investment opportunity for the e-jeepney over the diesel jeepney. Results are robust with all scenarios investigated. Results also show a more optimal decision strategy to invest immediately under the current business environment, as delaying or postponing investment may incur opportunity losses. While environmental impacts and traditional financial tools such as PBP, ROI, and IRR favor the modernized jeepney project, other investment analyses including public perception, health and non-health benefits, and economic impacts on tax and employment favor the e-jeepney project, which complements the result of our analysis using the proposed ROA. To make the adoption of the e-jeepney more attractive, this study further suggests government actions to increase the amount of subsidy with flexible payment terms; increase jeepney base fares for quick and higher ROI; establish charging infrastructures optimally located in strategic places while considering the driver's spontaneous adjustments, and the interactions of travel and charging decisions; and continue efforts to rely on cleaner, cheaper, and renewable sources of electricity.

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Nomenclature

Acronyms	Description
ADF	Augmented Dickey–Fuller
CBA	Cost-Benefit Analysis
DOE	Department of Energy
DoTr	Department of Transportation
EV	Electric Vehicles
IRR	Internal Rate of Return
GBM	Geometric Brownian Motion
GHG	Greenhouse Gasses
GPS	Global Positioning System
HV	Hybrid Vehicle
IRR	Internal Rate of Return
LTFRB	Land Transportation Franchising and Regulatory Board

MACE	Manila Aerosol Characterization Experiment	
NPV	Net Present Value	
OFG	Omnibus Franchising Guidelines	
PBP	Payback Period	
PUJ	Public Utility Jeepney	
PUV	Public Utility Vehicle	
PHP	Philippine Peso	
PUVMP	Public Utility Vehicle Modernization Program	
RES	Renewable Energy Sources	
ROA	Real Options Approach	
ROI	Return on Investment	
Symbols	**Description**	**Unit**
α	gradient of diesel prices	
σ	standard deviation of diesel prices	
ρ	discount factor	
P_{ej}	average annual earnings from e-jeepney	PHP/yr
Q_{ej}	number of e-jeepney units per fleet; minimum set by the government	unit
P_e	price electricity	PHP/kWh
Q_e	average annual electricity consumed by the fleet	kWh
C_{ej}	average annual operations and maintenance cost for e-jeepney	PHP/yr
s	government subsidy for e-jeepney fleet	PHP
I	annual amortization for e-jeepney fleet	PHP/yr
T_{ej}	effective lifetime of e-jeepney	Yr
$ENPV$	Expected Net Present Value	PHP
NPV_{ej}	net present value of e-jeepney fleet project	PHP
P_j	average annual earnings from diesel jeepney	PHP/yr
Q_j	number of diesel jeepney units per fleet	unit
Q_d	average annual fuel consumption of diesel jeepney fleet	L/yr
C_j	average annual operations and maintenance cost for diesel jeepney	PHP/yr
I_j	average investment cost for diesel jeepney	PHP
T_j	effective lifetime of diesel jeepney	Yr
T	Decision-making period	
$P_{d,0}$	initial diesel price	PHP/L
P_d^{cur}	current price of diesel	PHP/L
NPV_j	net present value of diesel jeepney fleet project	PHP

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