To What Extent is the Present Value, of User and External Costs, Influenced by the Car Type, Gas, Hybrid or Electric?

Sanat Parmar

Received July 23, 2024
Accepted October 27, 2024
Electronic access November 15, 2024

This paper estimates the financial costs of using different vehicle categories over time (gas vs electric vs hybrid). This model encompasses the purchase, insurance, maintenance, repair, fuel, and electricity costs. It also examines the social and environmental ramifications of utilizing these vehicles from an economic standpoint. We determined the total economic cost by following a comprehensive quantitative analysis of these variables and aggregating the costs. These values were obtained from research with established methods of estimation, with a focus on comparing the present value of these costs across different vehicle types. We found that hybrid cars are the most economically efficient in the US: the present value of a hybrid car is estimated to be 5.8% less than that of a gasoline car and 17.6% less than that of an electric car. In Singapore, gasoline cars are the most economically efficient: the present value is 7.57% less than an electric car and 13.34% less than a hybrid car. This analysis can support policymakers in identifying the specific aspects of car costs that need to be reduced and help them determine the degree to which they must intervene to enhance the appeal of electric vehicles.

Introduction

Cars are a ubiquitous good in modern society, due to their convenience, and the impact they can have on social change. By considering the financial cost, social cost and sustainability of car usage, individuals can make choices that benefit themselves and society. Financial costs include short-term purchasing costs and variable costs like maintenance, fuel, insurance, and loans. Social costs include private safety and environmental costs - costs borne by both the individual and society. Current automobile market incentives and policies primarily tend to focus on the one-time fixed purchasing cost of vehicles, often underestimating the long-term private and social cost of car usage, both private and social. To address this, the paper combines these two factors to establish a new variable—total economic cost (TEC)— which defines the sum of the financial and social costs of using a vehicle. The TEC accounts for depreciation and externalities like noise pollution and traffic congestion, which provide a more accurate estimate of the true cost of car usage. As there are insufficient comprehensive metrics regarding the TEC of car usage, this oversight hampers individuals from making socially and financially optimal decisions. It prevents policymakers from incorporating the most effective policies to make the automotive market more environmentally oriented.

The paper studies the TEC in the United States and Singapore, to compare two developed nations with notable differences. The US covers a much more expansive region with a variety of terrains whereas Singapore is a small and densely populated city-structured nation, with strict car ownership policies. The climactic differences between these nations also provide more diverse and applicable contexts for policymakers. By comparing these nations, the report gives insights into how different geographical, political and environmental differences can significantly alter the TEC of vehicle usage. This comparison is crucial in widening the applicability of the paper's findings, which would better inform policymakers in their decisions regarding environmental regulations and incentives for more sustainable vehicles.

The paper focuses on three types of vehicles: battery electric vehicles (BEVs), Hybrid vehicles and traditional internal combustion engine (ICE) vehicles. By definition, BEVs are powered by electric power from their batteries; Hybrid vehicles can alternate between gasoline and electric power, and ICE vehicles function using the traditional gasoline engine. While BEVs and Hybrid vehicles have higher fixed costs than ICE vehicles, they benefit from significantly lower variable costs, such as maintenance, repair, insurance, and fuel costs. It is imperative to note that financial costs are not the only costs associated with vehicle usage; gasoline cars impose higher environmental and social costs than electric and hybrid cars.

This paper addresses the current knowledge gap by evaluating additional costs, quantifying the TECs of 3 car types, comparing them, and examining the possible reasons for the differences. Through this approach, consumers gain a more comprehensive understanding of the full range of costs associated with each vehicle types usage. Additionally, the analysis utilised existing literature and established statistical values to determine monetised values of costs, illustrating disparities in TEC across nations. This report offers insights by synthesising data and monetising qualitative concepts into a unified TEC estimate. This is crucial in informing policy decisions and individual decision-making regarding cars' financial and societal aspects. For policymakers, it could influence structural changes in incentives and tax rebates, allowing for a shift to more sustainable forms of transportation. For individuals, it could inform them on how they could make more sustainable decisions that maximise societal benefit and optimise financial costs. Overall, this paper could allow for the adoption of more socially and financially optimal decisions, which would contribute to a healthier world.

Literature review

Existing literature has examined some of the financial costs of using all car types, often illustrating the long-term benefits of fuel and maintenance costs from using EVs over their gasoline and hybrid counterparts. This literature, however, does not extensively analyse the social costs of these cars' usage, thereby leaving gaps in knowledge regarding their TEC.

Papers partially explore the financial costs of using EVs in the US by determining the long-term financial cost of using EVs compared to traditional gasoline-powered cars, specifically maintenance and fuel/electricity costs. This paper report suggests that EVs cost significantly less due to money saved on not spending on fuel and the fall in manufacturing costs of lithium-ion batteries - the battery that powers EV vehicles. The report also briefly covers the costs of home and public charging facilities, emphasising the money saved compared to traditional gasoline vehicles. Nevertheless, it does not provide a comprehensive analysis of all the financial and broader social costs, thus leaving a gap in the TEC understanding[1]. Papers also review the sustainability benefits of EVs, emphasizing reduced emissions and long-term social and environmental advantages. However, the paper does not consider whether hybrids are a viable alternative and does not provide any depth regarding the financial implications of EV ownership[2].

Singapore collates data regarding all cars, thereby providing an in-depth understanding of the financial costs of vehicles in Singapore[3] There is a comprehensive paper that includes Cost Of Entitlement (COE), Engine Capacity (cc), CO_2 g/km, Average Open Market Value (OMV), and Goods and Service Tax (GST) whilst factoring in all model types. By including such parameters, this compilation allows individuals and policymakers to understand the one-time fixed cost of purchasing and the current state of the automotive market[4]. The report, however, lacks an analysis of social costs and does not provide any statistical summaries such as averages or median values, limiting its influence on policy making.

In addition, only a few papers have conducted a cost-benefit analysis of factors beyond the financial costs of using EVs and traditional gasoline cars. They have briefly monetised some of the environmental and social costs, but have not considered enough factors to estimate the total environmental and social costs of car usage. They quantify some of the social costs such as congestion, noise and safety costs, thus providing some insight into understanding the total economic cost of gasoline car usage in the US[5]. Moreover, in pursuit of ascertaining whether electric cars are the most economically viable vehicle, a paper briefly compares the environmental efficiency of EVs vis-à-vis their Hybrid alternative. It determines the degree to which power plant emissions have to be reduced to maximise the benefits of EVs, emphasising the need for better electrification[6].

This report builds on the methodologies and findings of these papers by collating the data, conducting a thorough quantitative analysis of it and incorporating additions to their methodologies to gain a comprehensive understanding of both the financial and social costs in one. In doing so, the paper addresses the gaps and limitations of these papers to provide a thorough understanding of the impacts of car usage on the present value of user and external costs. Consequently, it aids consumers and policymakers in making more sustainably oriented economic decisions.

Methods

The paper used a systematic approach to obtain the most relevant information, specifically utilising databases such as Google Scholar and PubMed. The main keywords involved were "emissions", "total vehicle usage", "Singapore", "United States", "gasoline vs hybrid vs EVs", "costs", "financial costs" and "social costs" and the main filters were set to avoid non-English papers, papers unrelated to costs, and papers published before 2019 (with the exception of one paper). Before extracting data, the studies were assessed by the Critical Appraisal Skills Programme, which allowed us to systematically assess them and review their validity, reliability and applicability. We did not use studies that did not meet the minimum quality requirements. We extracted relevant quantitative data from the papers, which include purchasing, insurance, maintenance, fuel and electricity costs, analysed them and synthesised an estimate for the TEC.

Some factors, specifically social costs, do not have a universally accepted method for valuation. For example, noise pollution varies widely based on location and urban density. Some studies utilize willingness-to-pay (WTP), or property value regression, or healthcare cost approaches to estimate its costs. However, the huge difference in these methodologies depict the lack of agreement on a specific way of quantifying noise pollution[6]. As such, this paper uses the best available estimates but acknowledges there may be some uncertainty in the figures. Similarly, congestion costs are estimated using different approaches, ranging from time lost in traffic to increased fuel consumption. However, based on the Critical Appraisal Skills Programme, our assessment of the methodologies led us employ the most appropriate methodology.

This report is structured in the following manner: It begins with a quantitative analysis of the TEC in the US, divided into two main categories: Financial and Social costs. The same quantitative analysis is conducted for Singapore. The objective is to estimate the comprehensive cost breakdown of all car types in the US and Singapore, thereby providing actionable insights to policymakers and promoting more informed choices to consumers.

Results

In the US, the TEC of a newly purchased hybrid car is estimated to be 5.8% less than that of a gasoline car and 17.6% less than that of an electric car. In Singapore, the present value of a gasoline car is 7.57% less than that of an electric car and 13.34% less than that of a hybrid car. In the United States, the TEC for Hybrid cars is the lowest at $107,166.90, whereas in Singapore, the TEC for gasoline cars is the lowest at $517,355.68.

Quantification of total economic costs of car usage in the United States

This section examines the TEC of car ownership in the US through a comprehensive analysis of the financial and social costs of car usage. This section evaluates how these costs contribute to the TEC and also gives reasons for the patterns observed. By understanding the cost breakdown, stakeholders can make informed decisions and assessments regarding the financial and social efficiency of using all car types in the US.

This paper utilises average values to provide key insight into policymaking. By analysing the average prices and costs associated with all 3 car types, policymakers can determine whether these financial costs disincentivise consumers from switching to more sustainable alternatives like BEVs and hybrids. It allows policymakers to ascertain the degree by which BEVs and Hybrids must be cheaper to increase their usage over traditional gasoline vehicles. Despite the limitations, average values still provide valuable insights for effectively shaping policy.

Financial Costs:

Financial costs cover all fixed and variable costs of owning a vehicle in the United States, including purchasing, insurance, maintenance, repair, fuel and electricity costs.

1. Purchasing costs:

Initial purchasing costs depend on factors such as the type of vehicle, size and brand. However, in the US, the average purchasing cost can be summarised into the following:

Electric cars, which cost around $66,997 on average, are nearly double the price of gasoline, $39,040, and Hybrid cars, $33,797[7]. This price deferential renders electric cars less appealing to consumers, as consumers would have to allocate a higher proportion of their income to purchase them. The before-tax incentive value was taken to determine the societal cost of car ownership, not only the private costs and benefits.

2. Insurance, loan and tax costs:

Across the United States, the average annual cost of full-coverage auto insurance is approximately $2,008, while minimum-liability coverages are roughly $627 per year[8]. It is worth noting that the average state sales tax in the United States is approximately 6%, which is the second-largest financial cost of owning a car[9] —moreover, expenses related to licensing, registration and other taxes amount to approximately $762. Loans were around $1,253, calculated using a 5-year loan duration, 10% down payment, and the average interest rate[10]. This is subject to change depending on loan duration and interest rates.

Similar to the purchasing costs, the average insurance costs vary for the different vehicle types. Using a 3.00% discount factor per year and the annual insurance cost, the total cost over 15 years can also be determined:

Electric cars have the most significant insurance costs, amounting to $2,280, compared to Hybrids' $1,637 and gasoline cars' $1,529. This is due to the higher purchasing price associated with electric cars. Insurance firms would experience higher financial liabilities in an electric vehicle accident. It is noted that average insurance costs can significantly vary as they are influenced by a few factors: the driver's age, past crashes, credit history, and vehicle type.

The main limitation of averaging out costs, through this methodology, is that a luxury car and a budget car will significantly differ in any of the aforementioned costs. Not all cars are comparable and thus, these values may not be appropriate to apply to luxury models.

3. Maintenance costs:

Drivers use their cars, on average, for a total of 200,000 miles in the span of its functionality[1]. Car maintenance costs, however, vary depending on the total miles driven. Hence, the data collected regarding the financial costs was split into three categories based on the miles driven: 0-50,000 miles, 50,000-100,000 miles, and 100,000-200,000 miles. A vehicle's average maintenance cost per mile, depending on the type, is provided below.

By utilising the average cost and the total number of miles driven since the base year, the following maintenance costs for each car type have been determined. A discount factor of 3.00% per year has been applied to future maintenance costs, to make them comparable to initial costs:

This quantitative analysis was conducted based on the average 15-year lifespan of cars in the United States. Gasoline-powered vehicles have a total maintenance cost nearly double that of battery-operated electric vehicles: a significant $9713.53

Table 1: Purchasing costs for all 3 car types in the US[7]

Gasoline	$33,797
Hybrid	$39,040 before tax incentives and rebate
Electric	$66,997 before tax incentives and rebate

Table 2: Annual and 15-year costs of insurance in the US[7].

	Annual cost	**Discounted 15-Year Cost**
Gasoline	$1,529	$18,253.10
Hybrid	$1,637	$19,542.40
Electric	$2,280	$27,218.49

Table 3: Maintenance costs per mile depending on distance driven[1]

Vehicle type	**0-50k miles**	**50k-100k miles**	**100k-200k miles**
Gasoline	$0.03	$0.06	$0.08
Hybrid	$0.02	$0.03	$0.03
Electric	$0.01	$0.03	$0.04

Table 4: Maintenance costs per year of car ownership for all three car types[11]

Year	**Gasoline**	**Electric**	**Hybrid**	**Total miles**	**Gasoline**	**Electric**	**Hybrid**
	Maintenance cost (USD)				Discounted value (USD)		
1	377.692	161.868	283.269	13489	377.692	161.868	283.269
2	377.692	161.868	283.269	26978	366.691	157.153	275.018
3	377.692	161.868	283.269	40467	356.011	152.576	267.008
4	504.284	225.164	322.829	53956	461.491	206.057	295.434
5	809.34	377.692	418.159	67445	719.088	335.574	371.529
6	809.34	377.692	418.159	80934	698.143	325.8	360.708
7	809.34	377.692	418.159	94423	677.81	316.311	350.202
8	959.668	496.372	433.983	107912	780.298	403.596	352.868
9	1065.631	580.027	445.137	121401	841.219	457.879	351.395
10	1065.631	580.027	445.137	134890	816.717	444.542	341.16
11	1065.631	580.027	445.137	148379	792.93	431.595	331.224
12	1065.631	580.027	445.137	161868	769.835	419.024	321.576
13	1065.631	580.027	445.137	175357	747.412	406.819	312.21
14	1065.631	580.027	445.137	188846	725.643	394.97	303.117
15	881.166	479.622	368.082	200000	582.555	317.087	243.346
				Discounted Totals	**9713.53**	**4930.85**	**4760.06**

compared to $4930.85. Their maintenance costs are more than double that of Hybrid vehicles as well: $9713.53 in comparison to $4760.06. Hybrid cars have a total maintenance cost of $170.79 less than a battery-operated electric vehicle. However, battery-operated electric cars have a lower maintenance cost for the first ten years of these two vehicle types' lifespan.

The operation dynamics and component number of the vehicles can explain this observation. The dual mechanism of Hybrid vehicles, in which they operate on both the engine and the battery, significantly reduces the work required from the engine. This, therefore, reduces engine wear. Additionally, Hybrid and electric vehicles are equipped with regenerative braking systems, which reduce pressure and wear on the brake pads. Lastly, Hybrids and EVs "contain only about 21% of the moving parts that an internal combustion vehicle contains"[11]. Hence, fewer parts can be damaged and worn out over time. For these reasons, EVs and Hybrids incur significantly less maintenance and repair costs than traditional gasoline cars.

4. Fuel and electricity costs:

The average gasoline price per gallon was approximately 3.46*and*3.50 in 2022 and 2023, respectively[12]. However, ascertaining the cost of gasoline per mile for a traditional gasoline car depends on the engine size. Hence, this price does not uniformly reflect every gasoline car's gasoline cost per mile. To understand the fuel costs comprehensively, manufacturers have classified car engine sizes into three categories: Small, medium and large. These are determined based on the combustion chamber sizes, up to 1.6L, 1.6L to 2.5L, and 2.5L and above, respectively. Correspondingly, the miles per gallon are 35, 30 and 20[13]. As there is no exact data on car size distribution, the paper assumes that 40% of gasoline car engines are small, 40% are medium and 20% are large. This is because small and medium-sized cars are used the most. As larger cars are more expensive, a smaller percentage of car owners will purchase and utilise them.

The average electricity usage per mile for an EV in the US is 0.346kWh, and the average consumer spends around $0.16 per kWh[14]. Hence, the total electricity expenditure over 200,000 miles amounts to 69,200 kWh. In contrast, an electric car's average cost per mile is $0.055 - almost half the approximate cost per mile of a traditional small-engined gasoline car. The average operating cost of a Hybrid vehicle would be a combination of both, totalling $0.078 per mile. Thus, fuel and electricity-wise, electric cars are the most efficient.

Over 200,000 miles, which is deemed the average total miles driven in the US, the total cost for refuelling and electricity would come down to:

Social Costs:

Social costs are the broader negative personal safety and environmental impacts that arise from using a vehicle and are not covered by the fees or taxes paid by the user. In this paper's context, these are costs to society or the environment due to one additional vehicle mile driven. Social costs encompass many variables, such as congestion, crashes, noise pollution, safety, battery production, CO_2 emissions, and non-CO_2 emissions costs.

Some of the following social costs are monetised and depicted in the table below.

By evaluating the different forms of costs associated with various car types, focusing on congestion, noise, and safety, patterns have been observed. Congestion costs for all car types are approximately the same, as car sizes are roughly equal. Consequently, EVs don't contribute more to traffic than a typical gasoline or hybrid car. Additionally, EVs are so quiet that they have a minimum decibel requirement for pedestrians to be able to hear the car[15]. Lastly, EVs are safer than their gasoline and Hybrid counterparts due to advanced driver-assistance systems, lower fire risk, and greater stability, minimising their rollover probability. However, as EVs are heavier cars than their Hybrid and gasoline counterparts, the force during accidents involving EVs tends to be higher. Thus, overall, EVs are estimated to be 40% safer, which is accentuated by 40% fewer claims on insurance[16].

A few main types of Non-CO_2 emissions from vehicle usage are detrimental to society. These are Nitrogen Oxides (NOX), Sulfur Oxides (SOX), Particulate Matter with sub 2.5-micrometer diameters (PM2.5), and Carbon Dioxide (CO_2). The cost of emissions per metric ton highly exceeds the price of the car itself. "Approximately 3605 premature deaths were attributed to PM2.5 from on-road transportation in 2010, and about a total of 50,223 premature deaths ascribe to PM2.5 taking 6.49% from 2003 to 2016." These deaths are mainly in cities where pollution and population densities are high[17]. PM2.5 emissions, however, are only 1–3% lower for EVs than modern gasoline cars[18]. Thus, there is no significant difference between the three types of vehicles.

Based on the miles per gallon of the car type, the grams of CO_2 emitted by combusting one gallon of gasoline (8887 grams), and the cost per metric ton of CO_2, the total social cost of CO_2 emissions can be calculated for if an individual were to buy a car in 2024 and drive it a total of 200,000 miles over 15 years. Additionally, EVs are charged using convenience charging with an assumed emission factor of 597g of CO_2/kWh[6]. As previously mentioned, an average EV in the US uses 69,200 kWh of electricity over 200,000 miles. Both these factors can be used to determine the CO_2 cost for all three types of cars:

As time progresses, the cost of CO_2 per metric ton increases. This is because the damages are non-linear due to the growing societal concern about CO_2 emissions. The societal concerns driving the increasing cost of CO_2 can be attributed to the escalating impacts of climate change. As the concentration of CO_2 and other greenhouse gases in the atmosphere rises, the severity of environmental and economic damages intensifies.

Although electric vehicles are free of NOx and SOx

Table 5: Cost per mile for each gasoline engine type ([13]

Engine type	Miles per gallon	Approximate cost per mile
Small	35	$0.10
Medium	30	$0.12
Large	20	$0.18
Weighted average	NA	$0.12

Table 6: Average total fuel and electricity costs over 200,000 miles

Car type	Approximate cost over 200,000 miles
Gasoline	$24,400 (weighted average)
Hybrid	$15,600
EV	$11,000

Table 7:[5]

Vehicle Type	Congestion Cost per Mile	Noise Pollution Cost per Mile	Safety Cost per Mile	Total social cost over 200,000 miles
Gas and Hybrid	$0.12	$0.00	$0.04	$31,420
Electric	$0.12	$0.00	$0.02	$28,000

Table 8: CO_2 emissions from car usage

Year	Cost per metric ton of CO_2	CO_2 Cost for Gas Car	CO_2 Cost for Sedan Hybrid Car	CO_2 Cost for SUV Hybrid Car	CO_2 Cost for Electric Vehicles
2024	$233.00	$970.95	$620.70	$798.04	$641.72
2025	$237.00	$987.61	$631.35	$811.74	$652.74
2026	$241.00	$1,004.28	$642.01	$825.44	$663.75
2027	$245.00	$1,020.95	$652.66	$839.14	$674.77
2028	$250.00	$1,041.79	$665.98	$856.26	$688.54
2029	$253.00	$1,054.29	$673.97	$866.54	$696.80
2030	$257.00	$1,070.96	$684.63	$880.24	$707.82
2031	$262.00	$1,091.79	$697.95	$897.36	$721.59
2032	$265.00	$1,104.29	$705.94	$907.64	$729.85
2033	$270.00	$1,125.13	$719.26	$924.76	$743.62
2034	$274.00	$1,141.80	$729.92	$938.46	$754.64
2035	$278.00	$1,158.46	$740.57	$952.16	$765.66
2036	$282.00	$1,175.13	$751.23	$965.86	$776.67
2037	$287.00	$1,195.97	$764.55	$982.99	$790.44
2038	$291.00	$1,002.73	$641.01	$824.16	$801.46
Total	**NA**	**$15,816.46**	**$10,321.73**	**$12,446.63**	**$10,810.08**

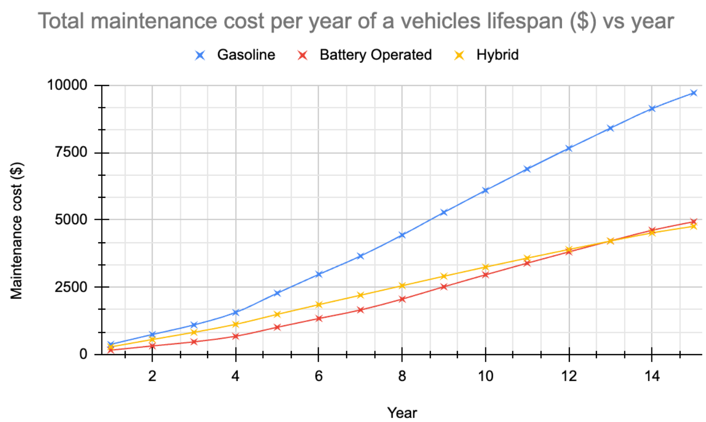

Figure 1: Total maintenance cost per year of a vehicles lifespan

emissions, as they are direct products of combustion in the engine, they are not free of PM2.5 emissions or CO_2 emissions costs. PM2.5 is emitted through a car's exhaust and tyre wear, brake wear, road surface wear, and road dust resuspension[18]. Depicted below are the additional emissions costs for all 3 car types over 200,000 miles (for the applicable emissions). The emissions (grams/mile) were obtained and then monetised using the US Department of Transportation's established values of each emissions cost per metric ton::

In 2023, gasoline and Hybrid cars produced 11,000 tons of SO2. This amounts to 165,000 tons over 15 years of usage, ceteris paribus. NOx emissions in 2024 came to a rate of 0.123g per mile. This costs the environment $497.08, which EVs do not. PM2.5 emissions came to a rate of 0.006g per mile for gasoline and Hybrid cars, whereas for EVs, it was at 0.004g per mile. Though this may seem small, PM2.5 is one of the most life-threatening car emissions as it inflicts a more significant social cost. The data reflects this: the total non-emission costs for gasoline and Hybrid cars are $1640.37, compared to EVs of $770.40.

Production of EV lithium-ion batteries is a water and CO_2-intensive process. To make 100 batteries for EVs, the process "requires approximately 2 million tonnes of water"[20]. This table compares the tonnes of CO_2 emitted during production and ascertains the cost to the environment from doing so:

The production of EVs has the highest carbon footprint of the 3 - the process emits 8.8 tonnes of CO_2 to produce one car. Hybrids and traditional gasoline cars are more sustainable in production - emitting 6.5 tonnes and 5.6 tonnes of CO_2, respectively. The monetised values determine that the environmental cost of producing one electric vehicle, $2050.40, is nearly double that of manufacturing one gasoline vehicle, $1304.80. The environmental cost of producing one Hybrid vehicle is around $1514.50. While these figures highlight the social costs of EV production, this cost is outweighed over time by the emissions savings during the vehicle's use. The long-term benefits of EVs, such as zero tailpipe emissions and the potential for renewable energy charging, significantly reduce overall emissions.

Total Economic Cost (TEC):

The TEC for the United States is determined by adding up the financial, social, and environmental costs of purchasing a car, using it for 15 years, and driving 200,000 miles. This approach considers the changing costs of ownership over an extended period.

Car ownership's social cost is the least for an electric vehicle. This observation is expected due to the significantly lower carbon emissions from electricity production and zero tailpipe emissions. The social costs of using an EV, Hybrid and Gasoline car amount to $45,041.28,45,959.05$ and $51,416.2, respectively. However, the TEC for an EV is the highest at $130,078.35, while the TEC for a Hybrid and a gasoline car are $107,166.90 and $122,588.73, respectively. The significantly high TEC difference between EVs and Hybrids, 17.6%, and EVs and gasoline cars, 5.8%, can be explained by how the high purchasing cost offsets the social benefits.

From an overall maintenance standpoint, EVs cost the lowest, at $18,040.06, while Hybrid and gasoline cars amount to around $22,167.85 and $37,375.53. EVs contain the simplest mechanical systems and fewer parts overall, which results in the most negligible wear and tear and the least maintenance. Hybrids benefit from gasoline and electric vehicle systems and regenerative braking and have a lower maintenance cost than gasoline cars due to the lowered wear and tear. This reflects the vast difference in technological systems in the different car types. Although purchasing costs are higher, they do provide technological systems that can operate with lower maintenance.

Table 9: Non CO_2 emissions from car usage[19]

Vehicle type	NOx	SOx	PM2.5	Environmental Cost	Total Cost
Gasoline and Hybrid	$497.08	$31.83	$1,155.60	$1,640.37	$3,324.88
Electric	NA	NA	$770.40	$760.80	$1,531.20

Table 10: Emissions from car manufacturing

Vehicle type	Tonnes of CO_2 emitted during production	Total cost to the environment
Gasoline	5.6	$1,304.80
Hybrid	6.5	$1,514.50
Electric	8.8	$2,050.40

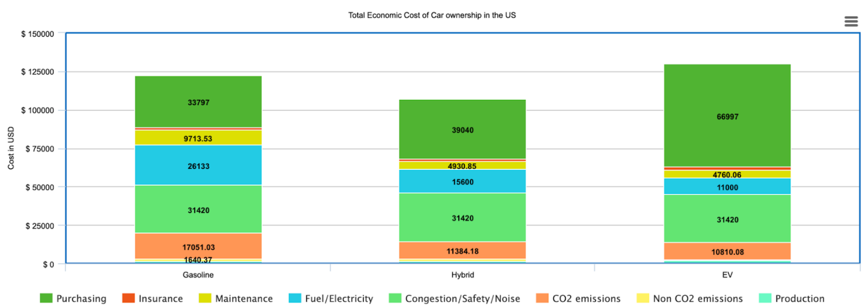

Figure 2: TEC comparison of all 3 car types in the US

Quantification of total economic costs of car usage in Singapore

This section examines the TEC of car ownership in Singapore in the exact manner the analysis was conducted for the United States. All values are converted to USD for this report.

Financial costs:

In Singapore, the costs of purchasing are highly influenced by the Certificate of Entitlement (COE) and Additional Registration Fee (ARF). To prevent traffic congestion in a geographically small but highly affluent country like Singapore, COE is a deterrent to prevent vehicular overcrowding. COE is a system implemented by the Singapore government that allows people to bid for a certificate to purchase a vehicle for ten years. This limits the number of cars on the road by significantly increasing the cost. On top of the COE, the ARF is a tax on a vehicle's Open Market Value (OMV). This is to achieve the same result as the COE. Additional financial costs influence an individual's decision to purchase a car in Singapore. These include parking, Electronic Road Pricing (ERP), road tax and maintenance costs.

1. Purchasing costs:

Singapore does not provide an exact average price for a gasoline vehicle due to the complexities of the Cost of Entitlement (COE) and the additional registration fee based on the Open Market Value (OMV). Thus, an average range will be ascertained for the purchase price of gasoline vehicles. The COE in Singapore ranges from a minimum of $62,900 and a maximum of $100,148.64. Correspondingly, the additional registration fee ranges from a minimum OMV of $14,800 to a maximum additional OMV of $43,808. Consequently, prices range from $77,700 to $159,348.64[3]. It must not be overlooked that the price can surpass the range as the car becomes more luxurious, such as Bentley's models.

The initial purchasing price for similar electric and hybrid cars in Singapore are nearly equivalent to each other. However, financial costs still differ between the two. As there are a limited number of electric vehicles in Singapore, the purchasing costs for each are outlined in the appendix. On average, electric and hybrid cars would have a fixed purchasing cost of $234,279. This is higher than the price range for gasoline cars, thus once again making gasoline cars more appealing from a fixed-cost perspective.

2. Insurance, loan and tax costs:

Singapore's average yearly car insurance cost typically falls from 1,181.04to1,162.78 for men and 1,166.24to1,541.42 for women[21]. These costs are incurred based on age, driving history and vehicle type.

Car loans in Singapore average around 3.4% for commercial vehicles[22]. Using this, a 5-year loan duration and a 10% down payment, on the price range, the loan costs range from $1,698.74 to $3,269.91 for gasoline cars. There is an excise duty of 20% of the car's OMV and a goods and services tax of 9% on all goods. The costs of car taxes range from $22,999.20 to $47,167.20

for gasoline cars. Similarly, car loan and tax costs for EVs and Hybrids amount to $5,375.73 and $51,316.47, respectively.

3. Maintenance and other costs On average, the costs of parking, Electronic Road Pricing (ERP), Road tax and maintenance are presented below:

Parking costs amount to $9,768, ERP $2,664, road tax $4,203.20, and maintenance $4,376.80 over 10 years. These values are all tallied based on averages and, once again, depend on the type of car and its usage (Chan, 2023). Overall, they are approximately the same for all car types as each factor is determined by usage rather than the car itself.

4. Fuel and electricity costs:

As of April 2024, the price of gasoline stands at SGD 2.82/litre or USD 2.07/litre[24]. The average distance travelled per year is 17,500km[25]. Given that cars in Singapore can only be owned for ten years, as per the regulations of the COE, the cumulative distance driven over ten years is 175,000km. Now, evaluating the fuel usage, an annual distance of 12.5-20 km per litre is considered good, 8.3-12.5 km per litre is considered average, and anything below 8.3km per litre would be considered poor[26]. Considering the average range, the total individual expenditure in 10 years is estimated to fall between $29,215.20 to $43,998.18.

Hybrid vehicles tend to have a mileage range of around 16 km per litre to 19 km per litre, significantly higher than gasoline cars[3]. This was determined by exhaustively collecting all the individual mileage of Hybrid vehicles and computing the average range. Considering this range, the total individual expenditure in 10 years is estimated to fall between $19,220.52 to $22,824.38.

Expenses for EVs in Singapore comprise of the average cost of charging, inclusive of SP fast charging, SP normal charging, Shell, BlueSG, Charge+, and Charge+ Fast Charging, is roughly 0.48253/kWh[27]. A typical electric car in Singapore consumes 18.5 kWh per 100km[26]. Accordingly, the expenditure for recharging EVs at charging stations over ten years is $23,957.50. Home charging costs the standard electricity price of 0.3247/kWh, bringing the total charging expenditure over ten years to $7,778.88[4]. Supplementary to the electricity charges is the installation fee. The mid-range EV charging station ranges from $740-$1,850; for higher capacity charging stations, the price is around $2,960[28]. If consumers were to spend half the time at a home charging station and half the time at a charging station outside, the charging cost over 10 years would be $15,868.19.

Social Costs:

The table below depicts the social cost per km of driving. The congestion cost is determined by the price the government sets on the road to deter traffic and noise pollution in Singapore was calculated using the FHWA model. Using the value for fatal and non-fatal crashes in the US, the number of crashes per year, the total number of cars, and the fact that electric cars are estimated to be 40% safer, the safety cost can be determined.

Noise pollution costs in Singapore are low, compared to the US. This is because cars in Singapore drive at low average speeds, and there is a relatively low number of cars overall. Safety costs are relatively higher than in the US due to the greater concentration of vehicles in an area and the high price of cars overall. Since Singapore is a small island nation, congestion costs are higher to disincentivise the use of private transportation. At the same time, it is possible that noise pollution is higher in Singapore due to higher population density. However, qualitatively the value of noise pollution being 0.0007 or 0.0027 does not affect the overall social cost, which is driven by safety costs. Hence, the value of approximately 0.0007 can be used in confidence.

The average gasoline car in Singapore emits about 4.6 metric tons of CO_2 annually[29]. Conversely, for electric cars, CO_2 emissions during electricity production are 0.4085kg/kWh[4]. By utilising the consumption rate of 18.5 kWh/100km, the electricity usage of an electric car can be ascertained, which is 32,375 kWh. The need for more data on Hybrid cars in Singapore makes it challenging to estimate the cost. However, the average Hybrid car emits 30% less CO_2 than its gasoline counterpart. Accordingly, the cost of CO_2 emissions per vehicle type can be calculated as follows:

This is a comprehensive projection of the total environmental costs of buying and owning a car in 2024 for ten years. As aforementioned, the cost of CO_2 escalates as the years progress, depicting the mounting damage of carbon emissions and the greater need for a proactive response to global warming. The data elucidates that gasoline cars have the most significant environmental burden of $11,548.24, while hybrid and electric vehicles consistently emit lower amounts of CO_2 at $8,083.77 and $3,320.17, respectively. Hence, transitioning to hybrid and electric cars is environmentally beneficial.

However, it is crucial to recognise that these CO_2 costs are partially offset by the emissions released from production. Since car manufacturing occurs outside Singapore and cars are imported worldwide, a global estimate of emissions during production can be used.

EVs produce a social manufacturing cost of $2050.40, as manufacturing one car emits 8.8 tonnes of CO_2. Hybrids follow with a cost of $1514.50, emitting 6.5 tonnes of CO_2. Despite emitting the most CO_2 during usage, gasoline vehicles emit the least CO_2, 5.6 tonnes, during production, which amounts to an environmental cost of $1304.80. As lithium-ion batteries in EVs and two energy sources, electric and gasoline, in Hybrids require additional manufacturing, more CO_2 is released.

This section compares a gasoline vehicle (Hyundai Accent) and a similar EV (Hyundai Ioniq) in Singapore, determining the external cost of non-CO_2 emissions such as SOx and PM2.5[30]. According to the Vehicle Emissions Scheme implemented in Singapore, the average gas car falls into the C1 category, the

Table 11: 10-year maintenance and miscellaneous costs[23]

	10 Year Cost
Parking	$9,768
ERP	$2,664
Road tax	$4,203.20
Maintenance	$4,376.80

Table 12: Congestion, noise and safety costs per kilometre

	Congestion cost	**Noise pollution**	**Safety cost**	**Total Cost**
Gasoline and Hybrid	$0.37 to $2.22 (edf.org)	$0.00	$0.36	$290,170.65
Electric	$0.37 to $2.22 (edf.org)	$0.00	$0.21	$264,180.00

Table 13: CO_2 emissions from car usage

Year	**Cost per metric ton of CO_2 (USD)**	**CO_2 Cost for Gasoline Cars**	**CO_2 Cost for Hybrid Car**	**CO_2 Cost for Electric Cars**
2024	$233.00	$1,070.73	$749.51	$307.84
2025	$237.00	$1,089.11	$762.38	$313.12
2026	$241.00	$1,107.49	$775.25	$318.41
2027	$245.00	$1,125.87	$788.11	$323.69
2028	$250.00	$1,148.85	$804.20	$330.30
2029	$253.00	$1,162.64	$813.84	$334.27
2030	$257.00	$1,181.02	$826.71	$339.55
2031	$262.00	$1,203.99	$842.79	$346.15
2032	$265.00	$1,217.78	$852.45	$350.12
2033	$270.00	$1,240.76	$868.53	$356.72
Total	**NA**	**$11,548.24**	**$8,083.77**	**$3,320.17**

Table 14: CO_2 emissions from car manufacturing

Vehicle-type	**Tonnes of CO_2 emitted during production**	**Cost to the environment using $233 per tonne of CO_2**
Gasoline	5.6	$1,303.50
Hybrid	6.5	$1,512.99
Electric	8.8	$2,048.35

average Hybrid falls in the A2 category and the average EV in the A1 category[31]. Using this, the average cost for each vehicle type can be calculated:

Total Economic Cost:

The TEC for Singapore is determined by adding up the financial, social, and environmental costs of purchasing a car, using it for ten years due to COE, and driving a total of 175,000 kilometres.

The social cost of car ownership is the lowest for electric vehicles in Singapore - $266,231.61. This is expected as CO_2 and non-CO_2 from EVs are much lower. The social cost of using a Hybrid and Gasoline car amounts to $301,044.85 and $300,835.36, respectively. However, the TEC for a Hybrid is the highest at $575,947.74, while the TECs for an electric and a gasoline car are $535,980.24 and $517,355.68, respectively. The purchasing cost for EVs and Hybrids offset these car types' social benefits. Hence, the TEC for gasoline cars amounts to the lowest value.

Due to the lack of data differentiating the difference in maintenance costs between car types in Singapore, the value is roughly the same for each, at around $16,808.80. However, with more EVs and more literature, the most probable conclusion is that EV maintenance costs are the lowest as they contain the simplest mechanical systems and fewer parts overall, resulting in the slightest wear and tear and the least maintenance.

Discussion

Every decision offers the opportunity to be more efficient, and cars are a powerful means through which society can optimise social and financial costs. This study set out to conduct a comprehensive quantitative analysis of the total economic cost of car usage in both the US and Singapore. The objective was to equip policymakers with data and knowledge that could help them determine to what degree taxes and prices must be altered to influence more sustainable consumption choices while also educating consumers on the private and social implications of their car usage to make informed sustainable decisions. This paper provides data to achieve this vision. By comparing Singapore and the US, the report becomes more applicable to countries with diverse economic and regulatory environments. The dual analysis allows policymakers to notice trends within these nations' economies and enables them to identify common and unique factors. Furthermore, it allows them to apply the findings to other contexts globally, thereby deepening the understanding of car ownership around the world.

This analysis has a few varied factors: Singapore is an urban nation, whereas the US contains a variety of terrains. Both countries differ in their average car usage, with the US significantly higher due to its larger land mass. The period of car usage and the governmental policies also differ due to their different circumstances. Making direct comparisons of the costs is challenging due to the many uncontrolled variables. Hence, direct comparisons of costs between Singapore and the US are made simply to illustrate how geographical, political, environmental and social differences impact the most economical car to utilise. These findings emphasise the importance of considering individual national circumstances before making policy decisions, mainly when balancing sustainability and economic efficiency.

That said, several comparisons can be made for the present user value and external costs for various types of vehicles. In Singapore, the TEC for an EV is $535,980.24, significantly higher than the $130,078.35 cost of owning an EV in the US. Similarly, the TEC of a Hybrid car in Singapore is $575,947.74, while it is $107,166.90 in the US. Gasoline cars in Singapore cost $517,355.68, while they cost $122,588.73 in the US. However, the lifetime of cars in Singapore is 10 years, compared to the 15 years in the US. This meant the cost gap would be more significant if Singapore's car lifetimes were 15 years.

Maintenance costs also vary between these two countries. In Singapore, maintenance costs are approximately $4376.80 for all car types, lower than in the US. This is explained by the fact that weather conditions are more varied, distances travelled are greater, and years of usage are longer in the US[23]. In the US, the maintenance costs for EVs amount to $4760.06; for Hybrids, it is $4930.85; and for gasoline cars, it is $9713.53[1]. This data indicates that all car types are more economical to maintain in Singapore. It must be noted that car users in the US need to maintain their cars for 5 extra years[10].

Singapore's stringent government policies, COE system and lower maintenance costs, result in higher purchasing costs[30]. However, a compact urban environment and consistent weather conditions can minimise variable costs. The US has lower taxes, a larger landmass and longer lifetimes, which lowers purchasing costs but increases variable maintenance costs - due to the variety of terrains and greater distance travelled.

The social cost difference between the two countries accentuates the difference in car ownership in different countries. In Singapore, the social cost of owning an EV is $266,231.61, significantly higher compared to the US cost of $45,041.28. Hybrid cars incur a cost of $301,044.85 in Singapore, compared to $45,959.05 in the US. Gasoline cars incur $300,835.36 in Singapore, much higher than $51,416.20 in the US.

Due to its small land area and high population density, Singapore has strict regulations and high penalties for social externalities. The social impacts from vehicles are more concentrated than those in the US and perhaps cause more significant damage, incurring greater costs. Additionally, the high cost of living in Singapore results in a higher cost to repair any damages[3].

These patterns and explanations have many implications for policymaking, individual choices and the industry. Policymakers

Table 15: Non CO_2 emissions from car usage over 175,000 kilometers

	NOx	**SO2**	**PM2.5**	**Total**
Gasoline and Hybrid	$77.31	$161.17	$9,122.73	$9,361.21
Electric	NA	NA	$3.26	$3.26

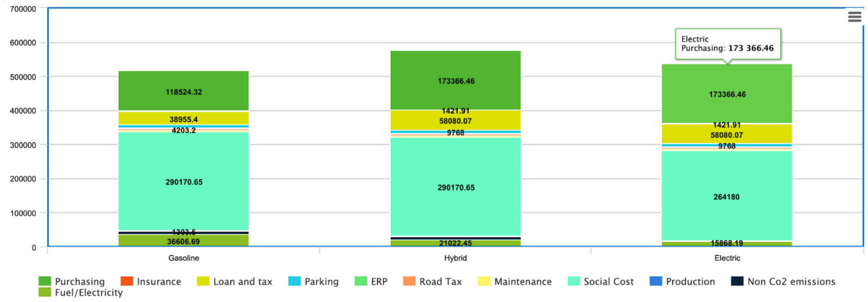

Figure 3: TEC comparison of all 3 car types in Singapore

utilise these patterns to make decisions on regulations and incentives that target each vehicle type's specific financial, social or environmental costs. For example, determining the degree to which subsidies and tax rebates on EVs must be changed to make them more appealing to consumers (Tan). For individuals, they are more likely to experience higher TEC in smaller nations or nations with more stringent governmental policies. These findings also illustrate how different individual circumstances cause high differences in TEC. These findings also illustrate how the automotive industry must work towards lowering its social costs to produce more sustainable cars [11].

The results of this study demonstrate that Singapore's higher TEC for EVs, hybrids, and gasoline cars is largely driven by stringent government policies, including the COE system and higher taxes, which are known to increase ownership costs [30]. This report builds on existing research by providing specific TEC figures, showing that regulatory frameworks in Singapore significantly impact car ownership compared to the lower costs in the US. Additionally, the higher maintenance costs reported in the US can be attributed to longer vehicle lifespans, varied terrains, and extreme weather conditions, while Singapore benefits from lower maintenance expenses due to a controlled urban environment and consistent climate [10]. This study also deepens the understanding of social costs by quantifying the externalities for each vehicle type. Singapore's compact size and population density amplify the social impact of vehicle usage, leading to higher costs for EVs, hybrids, and gasoline cars compared to the US [18]. These findings highlight how geographical and regulatory differences influence not only financial outcomes but also environmental and social externalities.

To enhance the study, future research must use a broader dataset, use more sub-costs under financial and social costs, use more established methodologies in monetising costs and address the limitations of this paper. This will increase the applicability and accuracy of the results and refine the TEC variable.

The study provides a thorough understanding of TEC associated with car usage in both the US and Singapore. The study illustrates the importance of taking into account the short and long-term costs as well as the social impacts of private car usage. These findings can guide consumers, policymakers and the industry in making more sustainable decisions, which is a positive outlook. Ultimately, the significance of balancing sustainability with economic viability is underscored, which paves the way for a more sustainable future and highly informed decision-making.

References

1 C. Harto, *Consumerreports.org*, 2020, https://advocacy.consumerreports.org/wp-content/uploads/2020/10/EV-Ownership-Cost-Final-Report-1.pdf, Accessed: 2024-05-03.

2 P. Karunakaran and M. S. Osman, *Jenrs.Com*.

3 L. T. A. Singapore, *Gov.Sg*, 2024, https://onemotoring.lta.gov.sg/content/dam/onemotoring/Buying/Car_Cost_Update/M032-Car_Cost_Update.pdf, Accessed: 2024-05-02.

4 EMA, *Gov.Sg*, 2024, https://www.ema.gov.sg/consumer-information/electricity/buying-electricity/buying-at-regulated-tariff, Accessed: 2024-05-09.

5 U.S. Department of Transportation, *Benefit-Cost Analysis Guidance for Discretionary Grant Programs*, 2023, https://www.transportation.gov/sites/dot.gov/files/2023-12/Benefit%20Cost%20Analysis%20Guidance%202024%20Update.pdf, Accessed: 2024-05-09.

6 M. Singh *et al.*, *Scientific Reports*, 2024, **14**, 1–11.

7 S. Meyer, *Thezebra.com*, 2024, https://www.thezebra.com/resources/driving/gas-car-vs-hybrid-car-vs-electric-car/#footnote-2, Accessed: 2024-05-02.

8 D. Robinson, *Average Cost of Car Insurance*, 2023, https://www.marketwatch.com/guides/insurance-services/average-cost-of-car-insurance/, Accessed: 2024-05-02.

9 *The Cost of Owning a Car in the U.S. - Settle In*, https://www.settlein.support/en-us/articles/6748698771101, Accessed: 2024-04-27.

10 J. Huetter, *AAA: Average Vehicle Service and Repair Cost Is Nearly $1,475 a Year*, 2023, https://www.autonews.com/finance-insurance/aaa-average-car-service-repair-cost-nearly-1475-year, Accessed: 2024-05-03.

11 I. Krzyżewska and K. Chruzik, *Energies*, 2023, **16**, 7842.

12 U.S. Energy Information Administration (EIA), *EIA Annual Energy Outlook*, https://www.eia.gov/outlooks/aeo/IIF_carbonfee/index.php, Accessed: 2024-04-27.

13 Getroadtrip.App, *How Much Is Gas per Mile in the USA?*, https://www.getroadtrip.app/blog/how-much-is-gas-per-mile-in-the-usa, Accessed: 2024-04-27.

14 S. Zargary, *How Much Electricity Does an Electric Car Use?*, 2023, https://www.gencellenergy.com/resources/blog/ev-charging-power-car-electricity-usage/, Accessed: 2024-05-01.

15 *EVs and Noise Pollution*, Pod Point, https://pod-point.com/guides/evs-and-noise-pollution, Accessed: 2024-05-17.

16 Z. Shahan, *CleanTechnica*.

17 C. Li and S. Managi, *Scientific Reports*, 2021, **11**, 1–12.

18 V. R. J. H. Timmers and P. A. J. Achten, *Atmospheric Environment (Oxford, England: 1994)*, 2016, **134**, 10–17.

19 Bureau of Transportation Statistics, *Estimated U.S. Average Vehicle Emissions Rates per Vehicle by Vehicle Type Using Gasoline and Diesel*, 2023, https://www.bts.gov/content/estimated-national-average-vehicle-emissions-rates-vehicle-vehicle-type-using-gasoline-and, Accessed: 2024-05-15.

20 R. B. Lakshmi, *The Environmental Impact of Battery Production for EVs*, 2023, https://earth.org/environmental-impact-of-battery-production/, Accessed: 2024-05-02.

21 GetGo, *How Much Does It Cost to Buy a Car in Singapore? - Singapore's 24/7 Car Sharing Service*, 2023, https://getgo.sg/blog/how-much-does-it-cost-to-buy-a-car-in-singapore/, Accessed: 2024-05-02.

22 Sgcarmart, *Car Loan Calculator*, 2024, https://www.sgcarmart.com/resources/car-loan-calculator, Accessed: 2024-05-18.

23 A. Chan, *True Cost to Maintain A Car in Singapore (2023)*, 2023, https://www.singsaver.com.sg/blog/car-maintenance-cost-in-singapore, Accessed: 2024-05-09.

24 L. L. C. Globalen, *Singapore Gasoline Prices*, 2024, https://www.globalpetrolprices.com/Singapore/gasoline_prices/, Accessed: 2024-05-03.

25 B. D. Insurance, *Car Running Costs Singapore 2023*, 2019, https://www.budgetdirect.com.sg, Accessed: 2024-05-08.

26 Carsnap Singapore, *How to Save Money on Petrol Prices in Singapore?*, 2023, https://carsnap.sg/blog/save-money-on-petrol-prices-in-singapore/, Accessed: 2024-05-09.

27 T. B. Hun, *Average Cost of Electric Vehicles in Singapore*, 2022, https://www.valuechampion.sg/car-loans/average-cost-electric-vehicles-singapore, Accessed: 2024-05-09.

28 M. Aw, *Complete Guide to EV Home Charging in Singapore*, 2021, https://getsolar.ai/blog/ev-home-charging/, Accessed: 2024-05-09.

29 Quickcharge, *The Environmental Impact of Gasoline Cars vs. Electric Vehicles: Why EVs Are the Greener Choice*, 2023, https://www.quickcharge.sg/2023/03/30/the-environmental-impact-of-gasoline-cars-data-and-statistics/, Accessed: 2024-05-03.

30 T. Doshi, *A Preliminary Cost-Benefit Analysis of Electric Vehicle Policies in Singapore*, 2022, https://www.researchgate.net/publication/359518832_A_Preliminary_Cost-Benefit_Analysis_of_Electric_Vehicle_Policies_in_Singapore, Accessed: 2024-05-09.

31 C. Tan, *The Straits Times*, 2022.