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Life Cycle Cost Analysis of Electrical Vehicles in Australia

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Abstract

Electric vehicles (EV) have tremendous potential due to their 'zero tail-pipe emission' and low maintenance costs. However, a higher upfront cost comparing to internal combustion engine vehicles (ICEVs) threatens the popularity of EVs in Australia. Moreover, the uncertainties of the new technology are often responsible for unanticipated costs over the vehicle life cycle. Hence, this paper aims to investigate the economic feasibility of EVs in Australia. A Life Cycle Cost (LCC) analysis was conducted on the 2011 Nissan Leaf in order to estimate the total economic impact over its life cycle under Australian conditions.

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Keywords: Life Cycle Cost; Electric vehicle; Economic feasibility

1. Introduction

Australia, as a developed country, is not immune from a high level of car use across the globe. In fact, the transport sector contributes to approximately 14% of Greenhouse Gas Emissions in Australia and it is also the second fastest source of emissions growth. Road travel, at 89%, is the main contributor to the 14% of greenhouse gas emissions attributable to the transport sector [1]. Recently, there is a total of 17.63 million vehicles registered across Australia with an annual growth of 2.5% from 2009 to 2014. Petrol powered vehicles compose 78.8% of the total vehicle fleet whilst diesel-powered vehicles account for another 18.5% [2]. This larger proportion of Internal Combustion Engine Vehicles (ICEVs) currently in Australia, combined with a decrease in traditional automobile pricing [3], has the potential to significantly worsen Australia's road pollution problem. It is therefore of prime importance to assess the capacity of alternative fuel vehicles to mitigate associated issues including health problems, global warming and fossil fuel dependence.

Electric vehicles (EV) are being increasingly seen as a form of sustainable personal transport in the future. This idea has been reinforced through government policies across the world that aims to reduce greenhouse emissions and improve energy security. For example, the European Union has aimed to substitute 10% of the conventional fuels used in the road transport sector prior to 2020 [4]. If all the potential benefits of EVs can be realised upon widespread utilisation, greenhouse gas emissions, ambient air pollution and foreign oil dependency can all be significantly reduced.

However, the operating cost savings, brought about by the lower electricity price in comparison to liquid fuels, are deemed to be not a sufficient incentive for adoption [1]. Moreover, the added uncertainties of the new technology are often responsible for unanticipated costs over the vehicle lifecycle. Since the modern society has become progressively cost and risk averse, an unclear net benefit of adopting EVs would further hinder its popularity.

In order to quantify both the cost savings and extra cost attributed to EVs, a life cycle cost (LCC) analysis must be conducted. This allows for the identification of the key input parameters that make the EVs less competitive in relation to conventional ICEVs. This can then be used to focus future research efforts in an attempt to enhance the efficiency of these crucial components as well as determine the extent of the necessary government interventions to enable EV

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feasibility. In this paper, the LCC framework is applied to quantify the economic impact of a 2011 Nissan Leaf under Australian conditions and provide a comparison with an equivalent ICEV, the Toyota Corolla.

2. Background

The lifecycle cost is often referred to as the sum of all costs incurred during an asset's useful life and allows for a more appropriate cost-benefit analysis. The 'realistic appraisal' conducted through LCC analysis is further reinforced by considering the time value of money. This method assists in the reduction of the total cost of a product, identification of high-cost components in a product's lifecycle, and comparison of competing products. The LCC procedure used in this analysis is based on the AS/NZS 4536:1999 Standard, which follows 6 steps including analysis plan, model development, model analysis, analysis documentation, review of results, and implementation & update [5].

For a typical automobile, the LCC can be defined as [6]:

$$Total\ LCC = Acquisition\ Cost + \Sigma_{i=1}^{n} (Operating\ Cost\ for\ a\ Given\ Year_i + Scheduled\ Maintenance\ Cost_i + Unscheduled\ Maintenance\ Cost_i) + Car\ Disposal\ Cost \quad (1)$$

These cost elements have been successfully utilised by [7-8], for automobile lifecycle studies in Singapore and the United States respectively. However, many other studies, including that conducted by [9] have omitted the "Unscheduled Maintenance Cost" category due to limited first-hand data availability which limits the accuracy of time and cost prediction. As a result, this paper also excludes the unscheduled maintenance aspects of vehicle ownership.

The majority of previous EV life cycle costing studies highlight battery cost as the most contributing factor to the current high price of EVs. The retail cost of a typical EV Lithium-Ion battery is estimated at 300A$/kWh. For the Nissan Leaf's 24kWh battery, this amounts to A$7,200, which is a significant cost premium [10]. The battery production costs are however decreasing at present in conjunction with the rise of the specific energy of the batteries. It is hoped that as EVs become increasingly popular due to rising environmental and energy concerns, the high volume of battery production will further decrease the costs per unit in line with the experience curve.

It is nonetheless important to note, that the total life cycle cost results for an EV are heavily dependent on the assumptions within each model as well as the scope of the study. Whilst some of the previous analyses depict EVs as unfeasible in the near future, others demonstrate the significant cost savings that may be realised. For example, a study conducted by [11], reveals such positive cost savings in a scenario that assumes EV home recharging and no replacement/repair costs. The availability of a replacement ICEV, for travel on days when the EV range was exceeded, had been assumed. However, pollution and public charging infrastructure costs were not incorporated. A study conducted by [12] has evaluated the reductions in air pollution that are viable with EV vehicle introduction in Australia if the social costs of pollution are incorporated into the LCC of an EV.

The 2011 Nissan Leaf represents the most successful fully electric vehicle on the market today and as such is deemed to be the most appropriate for representing a small to medium passenger electric vehicle in this study. The key specifications are listed in table 1.

Table 1. 2011 Nissan Leaf Specifications

Country of Origin	Japan
Motor	80kW AC Synchronous
Battery	24kWh Lithium Ion
Battery Weight	294kg
On Board Charger	3.3kW
Kerb Weight (Max)	1541kg
Max Pay Load	395kg
Overall Dimensions (L x W x H)	4445mm x 1770mm x 1550mm
Rated Range per Charge	175km
Electricity Consumption	150Wh/km [13]
	30kWh/100miles [14]
	289Wh/mile [11]
	108-240Wh/km [15]

3. LCC model development

In this analysis, the functional unit is 1 km driven by the 2011 Nissan Leaf in NSW metropolitan region, Australia. This analysis uses a "cradle-to-grave" approach that all costs associated with the purchase, operation and disposal of the vehicle will be incorporated.

The useful life of 2011 Nissan Leaf is assumed to be 200,000km, or more specifically 20 years with an annual mileage of 10,000km. This assumption is based on Australian statistics that an average registered vehicle has an age of 10 years and annual mileage of 14,000km [16].The adjustment is made because EVs are expected to outlast their ICEV counterparts due to lower range availability and below average annual mileage of 10,000km combined with adequate maintenance. At a replacement cost of approximately A$7,300 [17], it is assumed that battery replacement would be economically feasible for selected vehicle owners. Since the vehicle was purchased in 2014, all prices have been quoted in 2014 Australian Dollars. Based on the guidance of the NSW Department of Treasury and Finance, an interest rate of 7% has been implemented in this study [18].

Although the electricity consumption of driving EVs is heavily dependent on regional factors [15], this study assumes the energy consumption during the operation phase is 0.137kWh/km due to simplicity. In addition, the efficiency of the level 2 charging process has been taken into account that additional 20% energy is required due to the losses associated with the assumed sole charging method [19].

3.1. Consumer LCC Model

Based on above scope and assumptions, Fig. 1 illustrates the framework of the base case consumer LCC model for this study.

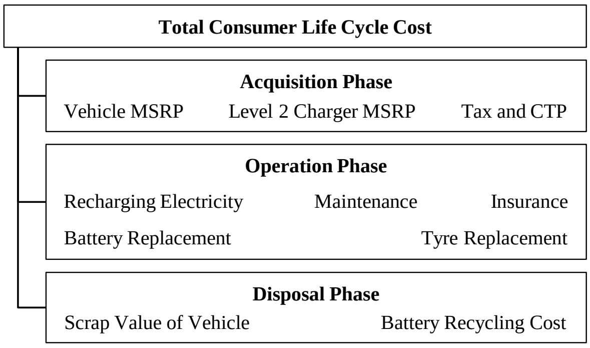

Fig. 1. Base case consumer LCC framework

- **Acquisition phase**

The acquisition cost of the Nissan Leaf has been composed of three components. Firstly, the manufacturer's suggested retail price (MSRP) of the studied vehicle has been obtained for the Sydney postcode with a base configuration. This amounts to a figure of A$39,990. Additionally, the price of a Level 2 standalone charger, including installation and 3-year user warranty has been included at A$3,000. Furthermore, registration, compulsory third party insurance (CTP) and stamp duty taxes have been included as per regulations in Australia and have been extracted from the Roads and Maritime Services (RMS) website. This leads to an additional cost of A$2,352.70.

- **Operation phase**

To quantify the cost of electricity for recharging, the annual electricity requirement is firstly calculated by using average energy consumption per kilometre (0.137kWh/km) and assumed charging inefficiency (20%), which leads to 1645kWh/year. For the base case, usage has been fixed at 80% off-peak charging and 20% peak charging to reflect the likelihood of the consumer taking advantage of time-based rates. According to the local energy retailer, off-peak electricity has been initially set at 16.522c/kWh while peak electricity is priced at 35.046c/kWh. The base case model has also assumed that electricity rates grow in line with Australian historical trends, a rise of approximately 72% every 5 year period [20].

Regular maintenance costs for the studied vehicle are assumed to be incurred only once per annum at a fixed rate of A$380 upon consultation with Nissan Australia. Notably, costs associated with repairs have not been included due to the limited availability and quality of first-hand user data. Moreover, the occurrence of repairs is often unexpected and so it was deemed that the timing of these costs being incurred could not be predicted with reasonable accuracy.

The cost of battery replacement is one of the largest costs sustained with electric vehicle use. Nissan guarantees the Leaf's battery for a total period of 8 years or 100,000miles ($\approx$160,000kms). With the model's assumed annual mileage of 10,000km, it is evident that the 8-year period will be reached sooner. Hence, the battery replacement period is fixed at 8 years due to the model undertaking a conservative approach. The battery replacement cost has been fixed at A$7,300 for this analysis. This is based on a combination of the individual battery's cost, equating to US$5500 and a cost of US$225 for an adaptor kit that is compulsory for the new batteries to be implemented in the 2011-2012 Nissan Leaf models [17]. Fixing the cost of battery replacement over the whole useful life of the vehicle can be viewed as a limitation of this model. This assumption has however been considered reasonable due to the conservative nature of the base model. In hindsight, it is quite likely that lithium ion battery costs will keep decreasing in the future, as they have historically, and this will be addressed separately in the sensitivity analysis.

The cost of tyre replacement must also be accounted for. Upon enquiries with several tyre retailers, it was determined that the retail price for one similar replacement tyre is A$180. Based on driver-documented experiences, the average tyre life for the Nissan Leaf is 30,000km which is equivalent to 3 years in the model. Thus, it was determined that the user will incur a total cost of A$720 for a set of new tyres every 3 years during vehicle ownership.

The final component of the operating expenses is the ongoing insurance charges. Previous LCC analysis of EVs commonly omitted insurance costs due to their disparity between EVs and ICEVs being "secondary to variation in location and driver history" [11]. Upon careful investigation into this phenomenon in Australian, it was discovered that this assumption is not reflective of the situation for this study. Due to the existence of this discrepancy in local insurance pricing, and the assumption that consumers would select comprehensive insurance to cover unforeseen circumstances with the new technology, full insurance costs from one reputable car insurance provider, have been incorporated into this study. This includes mandatory annual registration (A$433) and CTP (A$720) charges as well as a yearly comprehensive insurance fee (A$1299.06). The figures were obtained for a regular 30-year-old male driver, with a no claim record over the past five years. The car was assumed to be parked overnight in a garage in a central Sydney area.

- **Disposal phase**

Firstly, the cost of battery recycling has been approximated using established Lithium-Ion processes at Toxco Incorporation. The initial cost of battery recycling was set at US$10/kg of battery but this has been halved at present to a cost of US$5/kg [21]. Therefore, in the case of the Nissan Leaf battery, which has a total module weight of 294kg, the cost of battery recycling equates to US$1470. This is equivalent to A$1935 and is a cost that the user will have to endure upon disposal of the vehicle.

Moreover, due to the fact that the user essentially sells the car at the end of its useful life, it has been assumed that the scrap value of EVs will be the same as that of ICEVs. This is believed to be a reasonable approximation as the key difference between the two vehicles i.e. the battery and engine are not typically components of vehicle scrap. The scrap value of a general vehicle has therefore been approximated at 0.3% of the original retail price of the vehicle [10].

3.2. Comparative LCC Model

In order to compare the cost-effectiveness of the 2011 Nissan Leaf, a comparable ICEV chosen for this study is the

2014 Toyota Corolla Ascent Sport Hatch model, with the 7-speed multi-drive option, at an MSRP of A$26,120. This option is not the base model version of the vehicle but has been selected due to its additional features including GPS navigation and rear parking cameras, which make it more comparable to the “luxury” nature of the Nissan Leaf [11].

For the acquisition phase, the lower MSRP of Toyota Corolla produces a smaller stamp duty expense. The essential registration and CTP payments upon purchase of a vehicle in Australia also exhibit this favourable trend towards the conventional vehicle.

For the operation phase, the ICEV consumes 9.4L/100km in Australian terrain [22]. The recent 5-year average of gasoline price (1.42A$/L) was taken for the base case. According to [10], the maintenance costs of ICEV are approximately 30~35% higher than EVs. Also, major services have been accounted for at mileages of 80,000km and 160,000kms with the cost obtained from online service centre resources. The tyre replacement cost was assumed as same as the EVs. Lastly, the mature technology of ICEVs permits reduced insurance costs due to smaller uncertainties in failure and repairs. A$965 was quoted for Toyota Corolla under the same conditions.

According to previous research conducted by [10], it is the combination of the purchase price of a vehicle and the usage costs over the lifecycle, that lead to significant differences in ownership costs. Subsequently, this model has disregarded the cost difference involved in the disposal phase.

4. Results and Analysis

In order to validate the financial results of this study, a comparison was firstly made with the overall findings from other available literature [1,4,9,11], as shown in Fig. 2. In order to make the comparison more meaningful, the results of the comparison studies had to be converted to values representing the present study’s functional unit, A$/km. The operating costs were converted to the equivalent of a 200,000km lifespan if necessary. Furthermore, due to the varying locations and time periods of the comparative studies, the associated results have also been converted to a common currency, the Australian dollar and adjusted for changes in inflation.

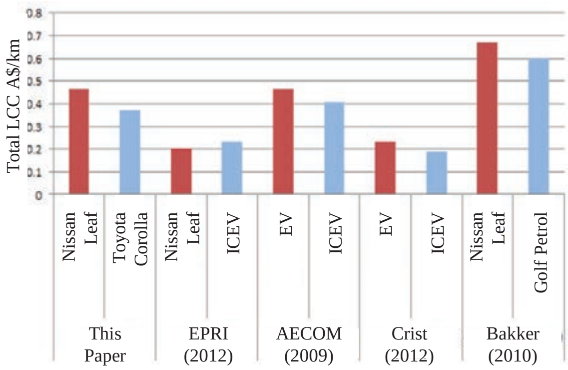

Fig. 2. Validation of LCC results with previous electric vehicle studies

The Nissan Leaf’s total cost of ownership calculated in this study was 0.46A$/km. This embodies the costs involved in the acquisition of the vehicle, its operation and disposal. The conventional ICEV vehicle used for comparison had a total cost of ownership equivalent to 0.37A$/km, which results in a cost premium of 0.09A$/km for operating the Nissan Leaf in Australia. With the exception of EPRI [11], this pattern of the cost advantage of the conventional vehicle is consistent across all previous studies with the lifecycle cost premium of an electric vehicle ranging from 0.04A$/km to 0.09A$/km.

The reason for the different conclusion in the EPRI study lies within the model’s assumptions, which significantly favoured the electric vehicle scenario [11]. Firstly, the study assumes a ‘useful life’ period of 8 years thereby eliminating the need for battery replacement, a significant cost associated with the use of electric vehicles. Secondly, the EPRI analysis is based in the state of California which thus allows the model to incorporate an overall tax credit of US$2,798 for the Nissan Leaf. Since this is realised at the time of purchase, it represents a substantial offset for the consumer in present value terms. Ultimately, the significantly lower prices of electricity compared to gasoline in the United States, combined with the omission of rising energy prices, further amplify the benefits of the Nissan Leaf.

To compare the economic impacts across the different vehicle lifecycle phases, the greatest one is attributable to the operation phase. The cost contribution of the acquisition phase is decidedly a close second, with only a marginal reduction in magnitude. It is also clear that the economic impacts of the disposal phase of the vehicle lifecycle are insignificant, which substantiates the decision made in previous studies [4,9] for their exclusion. This minimisation of the costs attributable to the final lifecycle phase may be further enhanced in the future, as the cost of lithium battery recycling further decreases.

The breakdown of the acquisition and operation phases presented in Fig. 3, indicates that the purchase price (MSRP) and the vehicle insurance costs are the components most responsible for the total lifecycle cost. Further investigation revealed that the largest contributor in the insurance segment is the comprehensive insurance unit. This is to be expected as the insurance of novel technology is usually expensive due to uncertainty in performance and failure risk. The expenses attributable to battery replacement and the electricity required to recharge the Nissan Leaf, are additional key contributors.

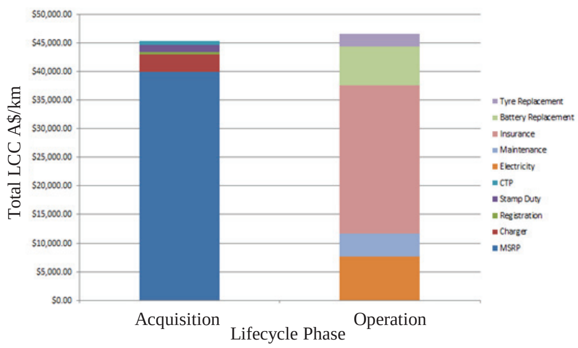

Fig. 3. Impact of individual cost units on total consumer lifecycle cost

4.1. Sensitivity Analysis

The base case analysis assumes a Nissan Leaf retail price of A$39,990 in line with current market value. However, according to market analysis, it is evident that the price of the Nissan Leaf, along with other electric vehicles, is highly susceptible to movements pertaining to the novel nature of the technology and the government incentives on offer. As such, this sensitivity analysis firstly investigates the effect of a changing vehicle price on the total LCC. At the moment, the Nissan Leaf retails in the United States for the lowest price of US$29,010. Therefore, a value of A$29,990 will be utilised for the low bound value of this sensitivity analysis, in an attempt to replicate a scenario where Australian automobile prices adjust to the U.S level. The upper bound selected for this investigation is equivalent to A$49,990 due to its close representation of the Nissan Leaf's Australian introductory price of A$51,500 in 2012.

As shown in Fig. 4, the LCC model was highly sensitive to changes in the assumed retail price of the vehicle. Since the consumer's initial outlay on the vehicle (cash purchase) does not experience any discounting effects, the total magnitude of price adjustments has a direct impact on the overall lifecycle cost. Consequently, an A$5,000 increase in the Nissan Leaf's MSRP transferred to an increase in lifecycle cost of 0.025A$ /km.

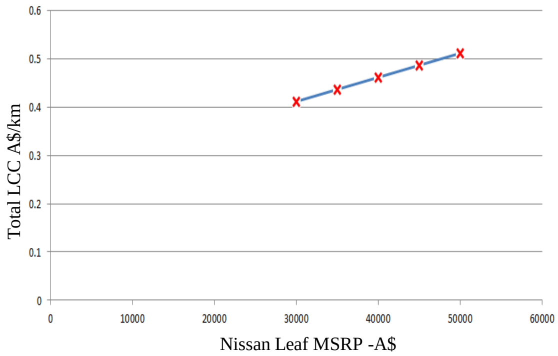

Fig. 4. Total LCC versus vehicle MSRP

Even though it is of significant magnitude, no sensitivity testing has been conducted on the insurance costs of the vehicle. This is because of the assumption that these costs will directly shadow the changes in vehicle MSRP. Once EVs gain consumer popularity and the technology becomes reliable, insurance costs will decrease as a consequence of reduced risk and lower retail pricing. As such, the model effects of this change will be a close match to those associated with alterations in MSRP.

The battery replacement cost implemented in the base case of this analysis is equivalent to 300A$/kWh. However, figures present in current news and literature articles vary considerably in their assumptions in this regard from 100A$/kWh to 706A$/kWh [21]. In addition, a decrease in replacement battery costs is imminent in the near future. As a consequence of this reality, it is critical to conduct a sensitivity analysis and investigate the effect of these changes on the total consumer lifecycle cost.

As shown in Fig. 5, an increase in the costs of battery replacement will result in a higher overall vehicle lifecycle cost as illustrated in the figure above. However, due to the scarcity of these replacements and the combined effect of time value discounting, battery replacement costs do not have a drastic effect on the LCC. An increase in the battery costs by 50A$/kWh corresponds to an average rise of 1.2% in total LCC. Thus, it is evident that a decrease in the initial price of the vehicle has a much greater potential to incentivise consumers when compared with the costs of battery replacement.

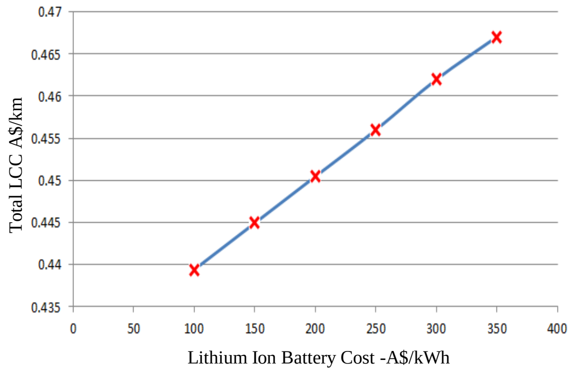

Fig. 5. Total LCC versus battery cost

The previous experimental study suggests that the range per charge is heavily dependent on regional factors (e.g. terrain, climate), which can vary from 100km to 222km per charge [15]. A sensitivity analysis has been performed as shown in Fig. 6. There is direct evidence that an increase in the Nissan Leaf's range per charge causes a decrease in LCC. However, it can also be observed that the magnitude of savings increases at a decreasing rate. For example, whilst the initial increase in range per charge from 100km to 125km results in an LCC cost decrease of 0.013315A$/km, the final increment only facilities a saving of 0.002959A$/km.

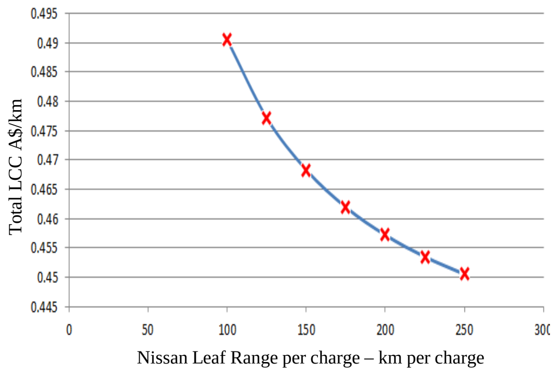

Fig. 6. Total LCC versus vehicle range per charge

4.2. Cost break-even analysis

Fig. 7 illustrates the discrepancy in total LCC during the ownership of a comparable EV and ICEV in Australia. It is clearly evident that the ownership of a Nissan Leaf in Australia does not provide economic benefits relative to a comparable ICEV under current conditions. The savings attributable to the EV's lower annual energy and maintenance expenses are progressively diminished over the lifecycle, due to higher insurance prices and the added costs of battery replacement. As highlighted by the red selections on the dedicated cost curve in Fig. 7, these additional battery costs introduce considerable discrepancy to the comparative lifecycle costs. Furthermore, as indicated by the slope of these cost spikes, the cost of the second battery replacement has a lower magnitude effect on total LCC. This is a direct consequence of the discounting effect. Hence, it can be understood, that savings with regard to battery replacement costs must occur rapidly, as they are much more valuable to the user if they occur within the first 8 years. Alternatively, a prolonged battery lifespan would be beneficial in taking advantage of the 'time value' effect.

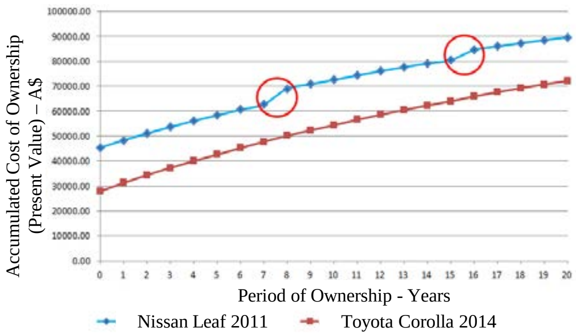

Fig. 7. The accumulated costs of ownership for Nissan Leaf vs Toyota Corolla in Australia

An additional observation from these results is the gradual decrease in the discrepancy between the lifecycle costs of both vehicles, prior to battery replacement. This suggests that the cost advantage of the Nissan Leaf displays greater sensitivity to increases in gasoline pricing as opposed to electricity pricing. By solely varying gasoline pricing in the model, an approximate doubling in fuel price (from 1.42A$/L to 2.96A$/L) is required to achieve breakeven [23]. In contrary, recent price drop on fossil fuel products further reduces the economic feasibility of EVs.

As per the countries where EV's are experiencing increased rates of adoption, a partial solution to this high barrier of market entry may be the introduction of government incentives. For this study, the present value of the required government incentive is equivalent to A$12,011.67 [23]. In order for the government to justify this substantial degree of consumer assistance, it is important to analyse the environmental impact and eco-efficiency as future work.

5. Conclusions

The main finding of this study is that the selected electric vehicle, 2011 Nissan Leaf, performs worse in terms of total lifecycle cost compared to its Toyota Corolla equivalent. The prime contributor to the lifecycle cost is the operation phase, with the acquisition phase placing a close second. The cost units of most influence have been identified as: 1) The Vehicle MSRP, 2) Insurance Cost, 3) Electricity Cost, 4) Replacement Batteries. Additionally, in order for the Nissan Leaf to achieve break-even with the Toyota Corolla over its lifecycle, the price of unleaded gasoline must be equivalent to 2.96A$/L. Alternatively, an upfront government subsidy of A$12, 011 also appears infeasible. Therefore, it appears that the EV market in Australia may only exist for early adopters of 'green' technology. In order to achieve EV competitiveness with the general population, alliances between car manufacturers and governments will need to address the main barrier to their acceptance, the high purchase price of the vehicles.

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