Economic Effect of Implementing Electric Cars

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Abstract in Icelandic

Rafmagnsbílar og íslenskur efnahagur

Ísland býr yfir gríðarlegum náttúruauðlindum í formi jarðhita og vatnsorku en er þó að öllu háð innflutningi á olíuafurðum til að viðhalda bílaflota sínum. Rafmagnsbílar eru taldir hagkvæm lausn fyrir Íslendinga í ljósi lágs orkuverðs miðað við það sem gengur og gerist úti í hinum erlenda heimi, en þar sem rafmagnsbílar eru almennt mun dýrari í kaupum en hefðbundnir getur meðalökumaður átt von á því að aka rafmagnsbíl sínum árum saman áður en hann í raun byrjar að njóta góðs af hinu lága eldsneytisverði hans. Hátt innflutningsverð rafmagnsbíla og sú staðreynd að allir bílar á Íslandi eru innfluttir bendir til að innleiðing rafmagnsbíla stuðli að vöruskiptahalla í landinu. Enn fremur er verðmunur á rafmagns- og bensínbílum þess valdandi að útskipting bensínbíls fyrir rafmagnsbíl hefur í för með sér greinilegan tekjumissi ríkisins yfir líftíma hans. Nauðsynleg ígrip vegna aukinnar rafmagnsnotkunnar í kjölfar innleiðingar eru í lágmarki.

Abstract

Iceland is a country rich in both geothermal and hydroelectric resources but remains dependent upon foreign gasoline to supply its car fleet. Electric Vehicles (EVs) have been hailed as a cost-efficient solution for Icelanders due to relatively low domestic energy prices, but this paper finds that since EVs are generally more expensive to purchase than traditional cars the average consumer must drive for years before truly receiving the benefits of low refueling costs. The relatively higher list prices (and the fact that all Icelandic cars are imported) indicate that EV implementation today would contribute to a national trade balance deficit. The price difference for EVs would cause government tax income to decrease significantly over a period of an EVs suggested lifetime. Required infrastructure to accommodate the increased energy demands following EV implementation would be minimal.

Keywords: Cars, electric, energy, sustainability, economy

Signature Page

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The undersigned hereby certify that they recommend to the School of Science and Engineering at Reykjavik University for acceptance this thesis entitled Economic Effect of Implementing Electric Cars submitted by Jóhann Sigurðsson in partial fulfillment of the requirements for the degree of Master of Science.

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Introduction

History

Ever since horseback riding was displaced as the most popular means of travel, various automotive technologies have contended for the title of man's preferred way of transportation. Two of those are the electric vehicle (EV) and the internal combustion engine (ICE) based car. Today most anyone will agree that the ICE based car emerged as the triumphant competitor of the 20th century. [1]

A brief summary of the two technologies' development is in order. Francois Isaac de Rivaz of Switzerland designed the first internal combustion engine in the year 1806. The engine was fueled by a mixture of hydrogen and oxygen. Rivaz applied his design to develop the first internal combustion engine based car. The design proved unsuccessful and ICE based cars would not really begin their venture until 1859, when Etienne Lenoir developed the first mass produced internal combustion engine. [2]

That same year, in 1859, Gaston Planté invented the lead-acid battery, later the first commercially feasible rechargeable battery technology [3]. Coupled with electric motor vehicular technology originally pioneered by Ányos Jedlik in 1828[4] and made practical by Frank Julian Sprague in 1886 [5], production of electric cars in numbers became feasible shortly thereafter.

At the dawn of the 20th century, 40% of American automobiles were powered by steam, 38% by electricity and 22% by gasoline. Electric cars were favored over their gasoline powered counterparts due to their comfortable driving, low noise and emitting no odor. Sales of EVs peaked in the United States in 1912, but started to decline thereafter. In 1914, breakthroughs with large-scale, production-line manufacturing lowered selling prices of ICE based cars to less than half of an EV at the time [6][7].

The reduced prices for ICE based cars, along with increasing demand for longer distances before refueling culminated with effective extinction of the EV from the American market by 1935. Technological improvements for the EV have effectively remained stagnant, except for spiking interests in EV development during energy crises of the 1970s, 1980s and the 1990s. With the most recent energy crisis of the 2000s, interest in the EV is renewed. More importantly, speculations arise on whether or not today's EV can contend with the needs of ICE based car users [8, 9].

State of the Art

Related work on the subject of this paper includes an article published 1995 in the Economic Systems Research scholarly journal wherein utilization of the INFORUM LIFT (Long-term Inter-industry Forecasting Tool) model for large-scale modeling of the U.S. domestic economy regarding EV implementation, whereby aggregate investments, total exports and employment are not determined directly but rather computed by the sum of their parts Significant technological breakthroughs in the area of both electric cars and battery technology have occurred since the article's original day of publishing, however. [10][11].

Another paper, published in 2008 by the University of California, Berkley, explores the impact of widespread EV adoption in place of ICE vehicles in the United States, modeling various growths and shrinkages of domestic industries directly affected by EV or ICE penetration, i.e. electricity generation and gasoline [12] and an impressive implementation scheme with regards to composition of car fleet for time periods spanning decades into the future.

A key difference in the work of the aforementioned American articles from the current one is the one of circumstances being analyzed. The United States imports, manufactures and, in the case of gasoline, refines domestic goods related to the car industry whereas the country of Iceland is wholly dependent upon most any car related commodity.

In 2008 a research sponsored by the Icelandic ministry of industry on hypothetical EV implementation in Iceland was made public. In the paper, the author proposes several added levies to ICE based cars necessary to retain government revenue at its present level and estimates the number of and plausible locations for special EV recharging facilities in villages and towns on popular rural highways outside major Icelandic cities [13]. While very informing, the article is found to be lacking in certain areas concerning data collection and assumptions, rendering it hard or impossible to confirm figures and numbers presented therein. In this article an attempt is made to base findings upon official data where available.

A report was done by a team of students at Bifrost University in December 2009, Iceland to confirm or disprove claims of the beneficial economic impact of EV implementation made by Northern Lights Energy Iceland. Among tasks analyzed in the report is the subject of national financial gain due to EV implementation by way of decrease in gasoline imports. However, the imported EVs intended to facilitate said decrease in gasoline imports are not accounted for at all in trade balance calculations which renders the proposed surplus from decreased gasoline imports somewhat misleading [14].

The ecological impact of EV implementation and new transportation technologies based on alternative, renewable energy sources was considered in detail in a 2009 report written by a team of experts and published by the Ministry for the Environment in Iceland. The report's main subject is one of greenhouse gas emissions and feasible methods for reduction thereof. Of special interest is Iceland's position in the worldwide emissions trade, where emission credits are effectively traded by nations with surplus quota to others without [15].

In this paper attempts are made to analyze four aspects of EV implementation in particular:

1. **Consumer Interests -** Assuming that EVs are and will remain more expensive than ICE based cars for the next few decades, how do cost terms for comparable cars of either engine type relate to consumer interests as years go by?

2. **Trade Balance -** How does substituting an average imported ICE based car with an EV affect the Icelandic trade balance in the following years and what is the net impact of a single such substitution?

3. **Government Revenue -** What sources of government revenue are lost and gained for each ICE based car that is dropped for an EV in and what is the net impact of a single such substitution on the Icelandic government's revenue over the lifetime of a car?

4. **Energy Infrastructure -** How much is the added load of EV implementation compared to the present demand on Icelandic energy infrastructure and is it substantial enough to warrant specific considerations?

Technology

The lithium-ion battery was invented 20 years ago, followed 10 years later by the development of lithium-ion polymer batteries. With the latter technology's increased energy to weight ratio, EV driving distances on a single charge have steadily climbed upwards to the point that people accustomed to ICE based cars can accept the EV as a city car. The new battery technology is still very expensive and remains the main reason for why EVs are generally more expensive than ICE vehicles [16].

Modern day EVs are extremely energy efficient and use up to 95% of all energy stored in their batteries, while conversely ICE vehicles only use about 14%-30% of all energy available in petroleum for mechanical energy purposes. The remaining energy is in most part converted to heat. Furthermore, EVs are able to recharge the batteries while driving downhill and utilize almost frictionless, regenerative breaking technology where the motor acts as a generator, extending the driving range up to 10% - 15%. [13, 17]

The difference between vehicles based on these two technologies is quite extensive. An ICE based vehicle contains an exhaust system, a gas tank, transmission, radiator and a relatively complicated engine, itself with subsystems such as an ignition. Many conventional car components are likely to fail without regular check-ups and/or replacements at certain points over its lifetime.

Figure 1 describes the biggest difference between EVs and ICE based cars. EV mechanism is mostly built up out of three parts: A battery, an electric motor and a battery management system (BMS). The BMS is made out of electronics that don't wear out much and are unlikely to break down throughout the lifetime of the car. The electrical motor is much simpler in construction than the internal combustion engine, and with a brushless motor wear and tear is reduced to a minimum. The simpler mechanism of EVs has prompted rumors of EVs requiring far less maintenance than ICE based cars, although to the best knowledge of the authors there is no published literature available on EV/ICE based car maintenance comparison [17].

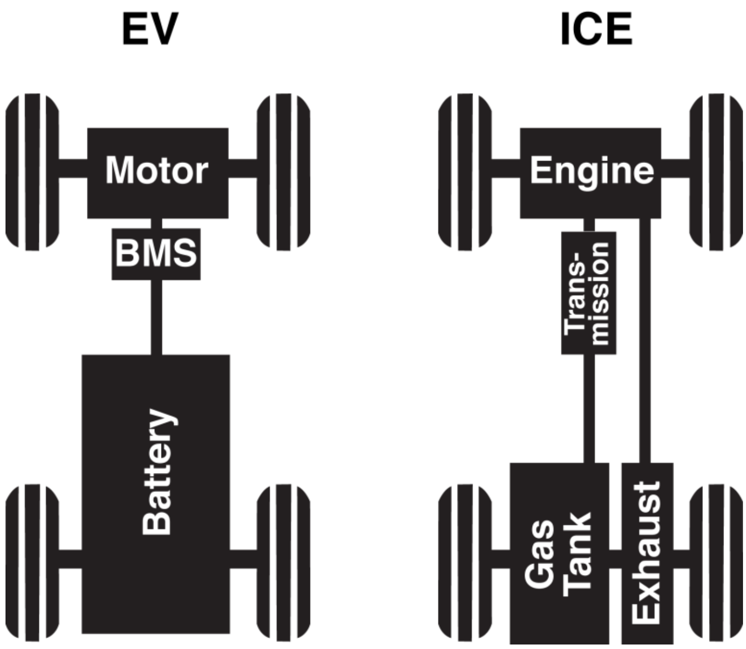

Figure 1: Basic building blocks of ICE based cars and EVs

The most expensive maintenance cost terms of EVs are undoubtedly battery replacements. In most cases an EV battery will last for about 5 – 10 years with an annual driving distance of 15.000 km before needing a replacement. The most crucial factor for battery lifetime is the quality of the charger. [16, 18]

Finally, given the two car technologies, it is inevitable that former ICE based car owners will have to adapt to the different refueling requirements of the EV. Having to plug one's vehicle to an electrical outlet for hours at home as opposed to driving to the nearest gas station for a quick refill within minutes will likely require some adjustments in personal routines [6].

Ecology and Sustainability

Among the Internal Combustion Engine's features are the infamous carbon emissions that follow from its chemical reaction. The process involves breaking down polymeric hydrocarbons by way of burning, causing several poisonous gases to form. It is important to understand the ecological effect of the Hydrocarbon breakdown; the reaction can be roughly described as in Equation 1 [19].

$$H_xC_y + O_2 + N_2 \rightarrow H_xC_y + NO + CO + CO_2 + H_2O$$

Equation 1: Chemical reaction of common ICE based cars

The hydrocarbons in Equation 1 (H_xC_y, where $6 < x < 11$ and $15 < y < 25$) that remain come out of the initial reaction process are partly burned residues of gasoline molecules and can be both poisonous and cancer inducing. These molecules react to the Nitric Oxide to form ozone at ground level, which is a major contributor to smog (smoke and fog combination) that irritates human ears, noses, throats and lungs [19].

Nitric Oxide (NO) is formed when Nitrogen and Oxygen react under great pressure in an Internal Combustion Engine. As previously mentioned NO helps form ozone on ground level and furthermore contributes to acid rain. Catalytic converters in car exhaust systems break down the more substantial Nitrogen gases to form Nitrogen Dioxide (NO_2), a greenhouse gas 300 times as potent as Nitric Oxide that and one that counts as roughly 7.2% of all greenhouse gases.[19]

Carbon Monoxide (CO) is a colorless, odorless, poisonous gas formed by partially burned hydrocarbons from the initial reaction. Two-third of global CO formation stems from the transportation sector, most of which originates from common ICE based cars. Up to 90% of CO formation in densely populated areas can be attributed to ICE based cars.[19]

Carbon Dioxide (CO_2), while initially considered by the United States' Environmental Protection Agency (EPA) to be the result of a "perfect combustion", is today classified as a pollutant. It is a greenhouse gas which traps the planet's heat and actuates climate changes [19].

Contrary to the ICE based car's chemical processes, an EV releases almost no air pollutants but can increase demand for electrical generation. The new demand may require augmenting current energy infrastructure and have an environmental impact. However, emissions intensity of a centralized electricity infrastructure is generally easier to manage than that of millions of automobiles [9].

The lithium-ion battery technology introduced in a previous chapter is prevalent in most of today's EVs. According to Tesla Motors lithium-ion batteries manufactured therein do not contain lead, mercury, cadmium, hexavalent chromium, polybrominated biphenyl ether or heavy metals and could legally be disposed of in a landfill. Tesla furthermore estimates about 60% of battery pack materials recyclable and a further 10% reusable by weight [20].

With increasing interest and awareness of pollution and global warming, as well as the world's ever-decreasing oil supply, signs point to the re-emergence of EVs as the preferred mainstream method of transportation once more [9].

Developed nations use overwhelmingly more oil than third world countries. A good example is the United States, which in the year 2001 used more 25% of the annual worldwide oil production with only 5% of the world's population. The European Union came in second, composed of 7.4% of the world's population while using slightly less than 19% of worldwide oil production. Other nations thereafter on the list include Japan, China, Russia, Canada, Brazil and India, by and large developed industrial nations [21][22].

Case Study in Iceland

In light of their relatively low numbers, Icelanders are huge consumers of oil. On January 1st 2007, Iceland is a country of 307,672 people [23]. In the year 2007 Icelanders used 765,000 tons of oil [24]. Of those 765,000 tons, 347,000 tons or a little less than 45.4% were due to car consumption and smaller ICE based machinery, as seen in Table 1.

Year	Oil consumption [tons]	Cars and devices [tons]	Cars and devices [%]
2007	765,000	347,000	45.4%
2008	702,000	328	46.7%

Table 1: Oil consumption in Iceland 2007 and 2008 [24]

Assuming that one ton of oil amounts to 7 oil barrels, a worldwide population of 6.6 billion (6,606,214,786) mid-year 2007 [22] and a worldwide oil production of 84.1 million oil barrels per day for the year 2007 [25], Icelanders use roughly 0.0174% of the world's 2008 oil production while numbering about 0.0047% of the world's overall population. As seen in Figure 2, Iceland's relative consumption levels are on par with nations such as the United States, Canada, Saudi Arabia and Norway, all of which are top ten players in worldwide domestic oil production [25].

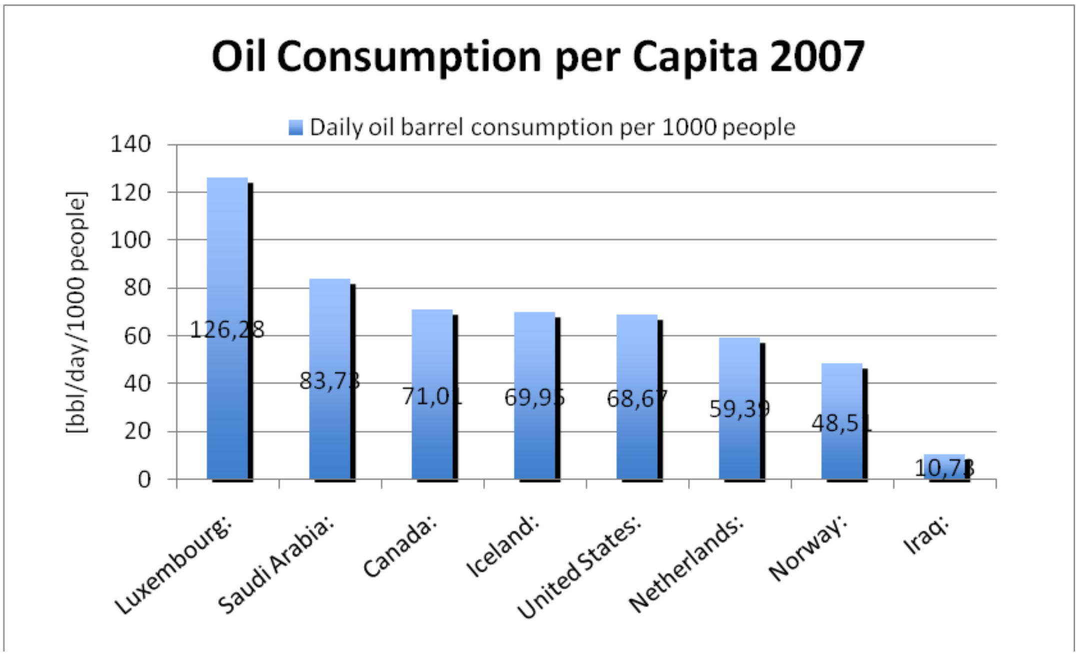

Figure 2: Oil consumption per capita of Iceland and several other countries [26]

Figure 2 shows Iceland's oil consumption per capita standing among several other countries with either shared economic or cultural traits or countries with relatively high domestic oil production [25]. Several smaller countries with astoundingly high oil consumption per capita have been omitted from Figure 2. For example are the Virgin Islands, a nation in the Caribbean of 108,448 in 2007 with a remarkable daily oil consumption of 91,680 barrels, or roughly 845 barrels per 1000 inhabitants [26].

Iceland's oil consumption is relatively small compared to the world's overall population and oil consumption but per capita it is remarkable. While The United States has similar relative oil consumption to population ratio as Iceland, the US satisfies a substantial part of its oil consumption with its own production whereas Iceland does not. With that in mind, Iceland may very well be among the most oil consuming nations in the world. Indeed, when taking into account overall energy consumption, Iceland is second only to Qatar in terms of worldwide commercial energy usage per capita [27].

Countering Iceland's relatively vast oil consumption per capita are natural resources present in the country. Geothermal heating and hydroelectric power have provided Icelandic homes with heat and electricity for decades [24] and there is a strong opinion present in the country that those very same internal resources should be used to fuel the Icelandic car fleet in its entirety, lowering the nation's dependence on imported oil [28].

While the energy supplied by Icelandic geothermal and hydroelectric sources is not infinite, analysis by the National Energy Authority of Iceland predicts technically harnessable hydroelectric and geothermal energy to be around 64 TWh and 59 TWh a year respectively, though neither are considered feasible. Hydroelectric and geothermal energy harnessable by practical means are estimated to be 35-50 TWh and 20 TWh per year respectively.

In the year 2008 Icelanders used 15.6 TWh of electrical energy [24]. Substituting Iceland's entire passenger car fleet with EVs would increase the load as detailed in later chapters. However, while power plants generate roughly the same amount of energy over 24 hours, more energy is generally consumed at daytime rather than at night. If EVs tend to be charged at the end of the day over night time then, assuming the infrastructure can handle such an increased workload, the impact of increased load on the energy infrastructure could result in a higher overall efficiency rate [13].

EVs have the potential to make a considerable economic impact in Iceland. With sustainable and relatively cheap energy sources, it is possible that refueling costs for the average car owner could decrease by as much as 90% [13]. The remaining refueling costs would for the most part be invested in domestic energy production instead of foreign gasoline imports, a scenario which could be highly profitable for Iceland's balance of trade. Utilizing domestic energy resources in Iceland could also mean significantly reduced price volatility for the average car consumer, as Icelandic electrical energy prices are relatively more stable when compared to oil prices [29].

Possibly the EVs biggest downside is its high import price when compared to an ICE based vehicle of similar class. For a successful implementation of EVs to take place in Iceland, the operational cost of EVs must be low enough to justify the initial price difference in a span of only few years [13].

Consumer Interests

When given a choice of two cars which both appeal equally to a consumer's aesthetic values and senses, it is reasonable to assume that the consumer will go for the one with a cheaper list price in order to save money. Yet, if the more expensive car touts cost-effective features for the customer in the long run, the consumer has reason to pause for a bit [13].

We identify three main economic factors of interest regarding a consumer's prospective car. First, how much does the car itself cost? Second, how much is its energy cost per km driven? Finally, how high is the expected maintenance and repair cost for the car?[13]

The total cost of buying and owning a car can be broken down to terms of its list price (P_*) in ISK, a refueling cost (C_*) dependent upon ISK per distances driven (D) along with annual maintenance and repair cost in ISK per year (M_*) over time (t). The terms, when summed up and present-valued with a discount factor (DF) over a set amount of years, show how long it will take an initially more expensive EV owner to break even with his more fuel consuming ICE based counterpart [13]. Equation 2 shows the relation between the total cost of owning and operating a car and the aforementioned cost terms.

$$\text{Total Cost} = \mathbf{P_*} + \left(\sum_{t=1}^{T} ((\mathbf{C_*})_t \times \mathbf{D_t} + (\mathbf{M_*})_t) \times \mathbf{DF_t} \right)$$

Equation 2: The total cost (no residual value) of purchasing and operating a car

Equation 2 can be used to derive at what time (T) the total cost of purchasing and operating two cars is the same, based on cost terms alone. Like many investments however, a car purchased by a single consumer can be sold to another, presumably (though not necessarily) at lesser price than the original due to depreciation. A consumer that purchases, operates and subsequently sells a car after a set amount of years therefore experiences a net cost (or even revenue in certain cases) lesser than the total cost of Equation 2. The net cost of purchasing, operating and selling a car in a set amount of years (T) is as described in Equation 3.

$$\textbf{Net Cost} = \mathbf{P_*} + \left(\sum_{t=1}^{T} ((\mathbf{C_*})_t \times \mathbf{D_t} + (\mathbf{M_*})_t) \times \mathbf{DF_t} \right) - \mathbf{RV_T} \times \mathbf{DF_t}$$

Equation 3: The net cost (residual value included) of purchasing, operating and selling a car

Car Purchases as investments

The basis of present-value is that it is more profitable to receive $1000 USD today than to receive that same $1000 USD after 5 years, since if received today it could be deposited into a bank, gain interest and be worth $1361 in 5 years time (assuming 6.36% annual interest). The present value (PV) of any future value (FV) years into the future (t) is, assuming annual discounting with a fixed interest rate (r), as seen in Equation 4.

$$\mathbf{PV} = \mathbf{FV} \times \mathbf{DF_t} = \mathbf{FV} \times \frac{\mathbf{1}}{(\mathbf{1} + \mathbf{r})^{\mathbf{t}}}$$

Equation 4: The present-value of a future value

Cars are a bad investment for most anyone except professional drivers; they depreciate greatly in the first few years and in but the rarest of cases sell at a loss [31]. Nevertheless, the previously mentioned basis of present-value is readily applicable for car purchases. It is essentially in reverse, in that paying an amount of $1000 USD hurts more if paid today rather than after 5 years, during which time it could have gathered precious interest.

A car list price therefore weighs the most of any single cost term presented in Equation 2 and Equation 3. The more profitable of two investments is the one with higher net present value. Hence (not accounting for residual value) the more profitable of two car purchases is the one with lower total cost after an arbitrary number of years (T). Equation 5 shows the total cost of a car in after T years.

$$\mathbf{Total\ Cost} = \mathbf{P_*} + \sum_{t=0}^{T} \frac{(\mathbf{C_*})_t \times \mathbf{D_t} + (\mathbf{M_*})_t}{(\mathbf{1}+\mathbf{r})^t}$$

Equation 5: The total cost of purchasing and operating a car, continued

In calculations the refueling and maintenance cost are assumed to have a fixed value based on circumstances of the originating year for the entire duration. Likewise, the annual driving distance is assumed to stay fixed based on an average value (see Equation 25). Equation 5 then changes a bit as seen in Equation 6.

$$\mathbf{Total\ Cost} = \mathbf{P_*} + (\mathbf{C_*} \times \mathbf{D} + \mathbf{M_*}) \times \sum_{t=1}^{T} \frac{\mathbf{1}}{(\mathbf{1}+\mathbf{r})^t}$$

Equation 6: The total cost of purchasing and operating a car, continued

With a bit of algebra the sum in Equation 6 may be collapsed to a single term, i.e. the uniform series present value.

$$\sum_{t=1}^{T} \frac{\mathbf{1}}{(\mathbf{1}+\mathbf{r})^t} = \sum_{t=1}^{T} (\mathrm{X})^t = X + X^2 + \cdots + X^T$$

$$= \frac{(1-\mathrm{X})}{(1-\mathrm{X})} \times (X + X^2 + \cdots + X^T)$$

$$= \frac{X - X^2 + X^2 - X^3 + X^3 - X^4 \ldots + X^{T-1} - X^T + X^T - X^{T+1}}{1-\mathrm{X}} = \frac{X - X^{T+1}}{1-\mathrm{X}}$$

$$= \frac{X \times (1 - X^T)}{1-\mathrm{X}} = \frac{1}{1+r} \times \frac{1 - \left(\frac{1}{1+r}\right)^T}{1 - \frac{1}{1+r}} = \frac{1-(1+r)^{-T}}{1+\mathrm{r}-1} = \frac{1-(1+r)^{-T}}{\mathrm{r}}$$

Equation 7: Deriving the uniform series present value

Substituting the uniform series present value of Equation 7 into Equation 6 yields the final Equation 8, which subsequently all calculations for break even point of two car purchases without accounting for car residual value are based on.

$$\mathbf{Total\ Cost} = \mathbf{P_*} + (\mathbf{C_*} \times \mathbf{D} + \mathbf{M_*}) \times \frac{1-(1+r)^{-T}}{\mathrm{r}}$$

Equation 8: The total cost of purchasing and operating a car, assuming uniform series present value

Similarly the net cost formula in Equation 3 can be rewritten as Equation 9.

$$\mathbf{Net\ Cost} = \mathbf{P_*} + (\mathbf{C_*} \times \mathbf{D} + \mathbf{M_*}) \times \frac{\mathbf{1}-(\mathbf{1}+\mathbf{r})^{-\mathbf{T}}}{\mathbf{r}} - \mathbf{RV} \times \frac{\mathbf{1}}{(\mathbf{1}+\mathbf{r})^{\mathbf{T}}}$$

Equation 9: The net cost of purchasing, operating and selling a car, assuming uniform series present value

It can be seen from Equation 7, Equation 8 and Equation 9 that a high discount rate causes the ongoing refueling and maintenance cost terms to weigh less than the list price in terms of the total cost. Since the main strength and weakness of an EV is its low refueling cost and high list price, respectively, higher discount rates delay the estimated time of breaking even further into the future.

A relatively low risk discount rate used in calculations is the projected rate for 26th of February 2019 on a yield curve issued by the Central Bank of Iceland (6.36%) selected for the sake of low risk car purchase (investment) scenarios [32]. Representing more risk adverse consumers is double the lower value (12.72%). These discount rates are used in calculations for total cost comparison

List prices

According to list prices detailed in Table 13, the list prices of EVs (P_{EV}) is assumed to be higher than that of ICE based cars (P_{ICE}).

The list price of any car (P_*) is assumed to be constructed of several key factors; the CIF import price of a car in foreign currency (IP_*), the exchange rate (FX) at the time of import, excise duty (ED_*), retailer's assessment (RA_*) and finally value-added tax (VAT). Equation 10 shows the composition of a car list prices based on the aforementioned factors.

$$\mathbf{P_* = IP_* \times FX \times (1 + ED_*) \times (1 + RA_*) \times (1 + VAT)}$$

Equation 10: Car list price factors

According to Equation 10 the list price factors are interchangeable. Thus an assumption can be made that quoted foreign car retail prices (in USD) for car models presented in Table 11 include both the car import prices and Icelandic retailer assessment without distorting the end list price overly much.

The excise duty is a percentage of the import price of an imported car and varies between car engine cylinder volumes. For ICE based passenger cars with cylinder volumes up to 2000cc, the imposed excise duty is 30% whereas for cars with higher cylinder volumes the excise duty is 45% [33]. Excise duty in Iceland is waived for EVs and other zero-emissions vehicles powered by nonconventional energy sources such as electricity and hydrogen fuel cells in Iceland [34].

Imposed VAT on imported vehicles is 25.5% for all imported cars [35].

Finally the list price needs to be converted to Icelandic currency (ISK) so that it can be applied along with other economic factors of interest. Due to economic turmoil the ISK/USD exchange rate is drastically different over the years 2006-2010 as can be seen from Table 2 [36]. The most recent exchange rate of 124.6 in ISK/USD from Table 2 is used in calculations.

Date of quoted exchange rate	Exchange rate (buying rate) FX [ISK/USD]
January 1st 2007	71.66
January 1st 2008	61.85
January 1st 2009	120.58
January 1st 2010	124.6

Table 2: Exchange rates (ISK/USD) from 2007-2010

Refueling cost

While EVs tend to be more expensive than ICE-based cars [37], refueling them is also generally much cheaper. The ratio of refueling costs between an ICE based car and an EV can be up to 20:1 [29, 38] and this is widely considered to be one of the EVs strongest attributes [13].

The refueling cost of a vehicle is measured in units of ISK per km (C_*). It is derived from two factors; the refueling rate in ISK per energy unit (RR_*) and the fuel consumption in energy units per km driven (FC_*). Refueling rate of a vehicle is therefore essentially how much a single unit of its fuel costs [39].

$$\mathbf{C_* = RR_* \times FC_*}$$

Equation 11: Refueling cost factors

Fuel consumption of vehicles (FC_*) specifies how many units of energy a vehicle must spend on the average to drive a particular distance. This parameter is either obtained or derived from specifications for each vehicle and varies somewhat in-between cars of a certain engine type. Fuel consumption is drastically different between EVs and ICE based cars, as seen in Table 15. Heavier cars, such as pickups, tend to require relatively large amounts of fuel to drive a certain distance when compared with their smaller, more economic counterparts.

Fuel consumption is rarely a given parameter of EV specifications. Instead two other important parameters, battery capacity in Watt hours (BC_{EV}) and range in km per charge (D_{range}), are generally provided. EV fuel consumption can be derived from BC and R, as see in Equation 12.

$$\mathbf{FC_{EV} = BC_{EV} \times D_{range}}$$

Equation 12: Derivation of EV Fuel Consumption

The refueling rate for ICE based cars (RR_{ICE}) is measured in units of ISK per liter. Since all ICE based cars to be considered in this and later chapters use the same kind of fuel (unleaded gasoline), a single ICE based car refueling rate is applied to all ICE based cars under consideration in Table 11. Like (and due to) the exchange rates in Table 2, gasoline prices can differ drastically over a period of four years as seen in Table 3 [29]. The most recently quoted rate of 204 ISK per liter is used in calculations.

. Date of quoted gasoline rate	RR_{ICE} [ISK/liter]
February 1st 2007	116
February 1st 2008	143
February 1st 2009	149
February 1st 2010	204

Table 3: Gasoline rates (95 unleaded) from 2007-2010

It is of interest to inspect the structure of gasoline rates a bit further. The imported gasoline price (IGP) in ISK per liter is not subject to a single excise duty percentage factor like car list prices in Equation 10 are. Instead, fixed tax terms per liter of imported gasoline are added as excise duty terms to its import price. Among these terms is a gasoline fee (GF), transportation equalization fee (TEF), carbon emissions fee (CEF) and a special excise duty (SED), all measured in ISK per liter. The sum of the imported gasoline price and the import tax terms is then followed by a retail assessment (RA) factor and finally value-added tax (VAT). The gasoline rates in Table 3 are therefore composed of similar terms and factors as seen in Equation 13.

$$\mathbf{RR_{ICE} = (IGP + GF + TEF + CEF + SED) \times (1 + RA) \times (1 + VAT)}$$

Equation 13: Underlying terms and factors of gasoline rates

The Icelandic Directorate of Customs specifies the import terms of Equation 13 as seen in Table 4 [40].

Import tax term	Rate [ISK/liter]
GF: Gasoline fee	37.07
TEF: Transportation equalization fee	0.36
CEF: Carbon emissions fee	2.60
SED: Special excise duty	22.94
Total import tax rate	**62.97**

Table 4: Import tax terms for gasoline [40]

It is assumed that the average EV owner will recharge at his or her EV at home during night or day. The EV refueling rate (RR_{EV}), measured in units of ISK per kWh, is therefore the same as consumer electrical energy rates in residential areas. Like the gasoline rates of Table 3 before, all EVs use the same kind of energy source and thus a single EV refueling rate applies equally to all EVs presented in Table 11. Furthermore, when compared to gasoline rates, electricity rates have been relatively stable in Iceland over the four years presented in Table 5 [29].The most recently quoted rate of 9.85 ISK per kWh is used in calculations.

. Date of quoted electricity rate	RR_{EV} [ISK/kWh]
February 1st 2007	8.28
February 1st 2008	8.82
February 1st 2009	9.15
February 1st 2010	9.85

Table 5: Electricity rates in Iceland from 2007-2010 [29]

The EV refueling rates of Table 5 are used in all relevant calculations. Unlike the gasoline rates the electricity rates introduced in Table 5 do not account for the import tax terms levied upon gasoline import prices. As of January 1st 2010 no such taxes have been levied upon owners of EVs [29, 35] and they are not accounted for in calculations unless otherwise specified. The most recently quoted rate of 9.85 ISK per kWh is used in calculations.

It is nevertheless of interest to find out how the refueling rate of EVs changes if the same fees apply to electricity rates as are levied on imported gasoline, presented in Table 4. To demonstrate the adjusted EV refueling rate should equality of tax income be a requirement, the tax income terms of Table 4 can be converted and added to the electricity rate of Table 5. Equation 14 shows how the added levy on electricity rates, or electricity fee (EF), is calculated.

$$\mathbf{EF} = \frac{(\mathbf{GF} + \mathbf{TEF} + \mathbf{CEF} + \mathbf{SED}) \times \mathbf{FC_{ICE}}}{\mathbf{FC_{EV}}}$$

Equation 14: Electricity fee corresponding to gasoline taxes

Based on numbers in Table 12 and Table 13, the average fuel consumptions of ICE based cars and EVs are 0.085 liters and 0.15 kWh per km driven, respectively. An average ICE based car therefore spends 0.085 liters of gasoline per km, which according to the total import tax rate of Table 4 translates to tax income revenue of 5.35 ISK per km driven. An EV requires 0.15 kWh per km driven and therefore, a levy of 35.45 ISK per kWh is required on EV energy prices in order to maintain government income of special gas-related taxes. For convenience, these numbers can be seen in Table 6.

Car type	Average FC	Tax income [ISK/liter]	Tax income [ISK/km]	Tax income [ISK/kWh]
ICE based	0.085 [liters/km]	62.97	5.35	-
EV	0.151 [kWh/km]	-	5.35	35.45

Table 6: Average ICE based car and EV fuel consumption and tax income

With the added tax income per kWh on electricity rates from Table 6, the adjusted electricity rate for the same years as in Table 5 can be seen in Table 7. The result is a price increase of

460% for the year 2009. As previously stated however, unless otherwise stated the quoted rate of 9.85 ISK per kWh from Table 5 is the only one used in calculations.

. Date of quoted electricity rate	Taxed RR_{EV} [ISK/kWh]
February 1st 2007	43.73
February 1st 2008	44.27
February 1st 2009	44.60
February 1st 2010	45.30

Table 7: Electricity rates in Iceland with hypothetical EV tax from 2007-2010

Maintenance and Repair cost

ICE based or EV engine-specific problems are only a part of a car owner's annual maintenance and repair costs in ISK per year (M_*), the rest is often due to malfunctions of common car components such as windshields, tires and dashboard controls, or insurance and inspection costs. Differentiation between the two is best described with the former as engine type specific maintenance and repair costs in ISK per year (SM_*) and the latter as common maintenance and repair costs in ISK per year (CM). The total maintenance cost M_* is therefore the sum of these two terms, as seen in Equation 15.

$$\mathbf{M}_* = \sum \mathbf{SM}_* + \sum \mathbf{CM}$$

Equation 15: Maintenance cost terms of a car

While speculation has thrived on EV maintenance costs compared to ICE based counterparts [41], there are very few details available due to little practical experience or data of EVs and history of EV breakdowns from mass produced models. EV enthusiasts have claimed that the EVs require less maintenance and have lower repair costs when compared to ICE based cars, based on an EV's relatively simpler structure than that of an ICE based counterpart as seen in Figure 1. EVs do not for example require regular maintenance aspects such as oil changes [13, 41].

Countering the claim of lower maintenance costs for EVs are other factors such as the EVs batteries, both the single most expensive maintenance cost term of its type and one that requires semi-regular replacements [42]. Ideas of common and specific maintenance cost terms for EVs and ICE based cars can be seen is Table 8. The frequency and severity of EV component breakdowns remains unaccounted for.

Item	Maintenance category (ICE)	Maintenance category (EV)
Brakes	SM_{ICE}	SM_{EV}
Internal combustion engine	SM_{ICE}	-
Exhaust	SM_{ICE}	-
Lights	CM	CM
Batteries	-	SM_{EV}
Electrical motor	-	SM_{EV}
BMS	-	SM_{EV}
Ignition	SM_{ICE}	-
Gas tank	SM_{ICE}	-
Alternator	SM_{ICE}	-
Tires	CM	CM
Body	CM	CM
Fan belt	SM_{ICE}	-
Transmission	SM_{ICE}	-
Connector	-	SM_{EV}
Central heating	SM_{ICE} (Lesser)	SM_{EV} (Greater)

Table 8: Common and specific ICE based and EV maintenance cost terms

Some items from Table 8 warrant further discussion. While EVs will implement conventional disc brakes like ICE based cars, EV specific elements such as regenerative breaking may affect brake lifetime and thus annual maintenance accountable to brakes. Likewise, it is possible that central heating of ICE based cars won't be implemented the conventional way in EVs due to high energy consumption [43].

Without solid data that conclusively supports either theory, annual maintenance costs of EVs are assumed to be the same as those of ICE based cars within the same category of Table 11. The Icelandic Automobile Association has published numbers for several aspects of car maintenance based on different price categories and annual driving distances of cars, two of which can be seen in Table 9. These aspects may be summed up to linearly approximate maintenance costs depending on an ICE based car's price and its driver's annual driving distance (D).

	15,000 km annual driving distance (D)		30.000 km annual distance (D)	
	Car 1	Car 2	Car 1	Car 2
Price (P) [ISK]	2,950,000	5,000,000	2,950,000	5,000,000
Maintenance/Repairs [ISK/year]	118,000	153,000	163,000	218,000
Tires [ISK/year]	44,000	57,000	66,000	79,000
Insurances [ISK/year]	172,000	197,000	172,000	197,000
Taxes etc. [ISK/year]	22,500	33,800	22,000	33,300
Total maintenance costs (M_*) [ISK/year]	**356,500**	**440,800**	**423,000**	**527,300**

Table 9: Maintenance related cost of two cars for two driving distances

A linear approximation for the maintenance costs in Table 9 that is valid for both cars therein under one of the driving distance scenarios has a starting maintenance cost term (M_0) and an added incremental cost factor (m) dependent upon the list price of the car (P_*). Equation 16 gives the formula of linear approximation for maintenance cost of ICE based cars.

$$\mathbf{M}_* = \mathbf{M}_0 + \mathbf{m} \times \mathbf{P}_*$$

Equation 16: Linear approximation of car maintenance costs

Applying Equation 16 to total maintenance costs and car list prices under the two different values of annual driving distance D in Table 9 yields the constants M_0 and m, as seen in Table 10.

Annual Driving Distance (D) [km/year]	Starting Maintenance Cost (M_0) [ISK/year]	Incremental cost factor (m) [1/year]
12,369	235,190	0.041
24,738	272,910	0.051

Table 10: Linear approximation of ICE based car maintenance costs

The values of M and m are only used to calculate ICE based car maintenance costs and are selected depending on whichever annual driving distance (D) is closest to the one used in calculations for each car category. Maintaining the assumption that maintenance cost for an EV and ICE based car sharing a category of Table 11 is the same in ISK per year, **Error! Reference source not found.** and **Error! Reference source not found.** are only used to calculate ICE based car maintenance cost with the end result applied to a comparable EV as well.

Residual Value

A car originally bought at a certain list price (P_*) is worth proportionately less each passing year. After a certain amount of years (T), the car's worth has depreciated by a certain percentage (k) as seen in Equation 17. The depreciation percentage used in calculations is assumed to be 13% or 16% from records of the Icelandic Automobile Association [44], depending on the annual driving distance (average or high respectively, see Equation 26).

$$RV_T = P_* \times (1-k)^T$$

Equation 17: The residual value of a car

The present value of the residual value is then as shown in Equation 18.

$$RV_T \times PV_T = P_* \times (1-k)^T \times \frac{1}{(1+r)^T} = P_* \times \left(\frac{1-k}{1+r}\right)^T$$

Equation 18: The residual value of a car, present valued

Vehicle Comparison

Four distinct pairs of ICE based car and EVs are proposed for comparison. In order to compare two types of automobiles with a vastly different internal structure, a set of prerequisites needs to be in place. Each pairing is based on similarities and specifications, such as body type, power, acceleration and area of manufacture, in that order.

Information gathered on several EV and ICE candidates yielded four of each kind considered to be similar enough by specifications, mainly in body type, power and acceleration. When paired together these cars form four distinct tiers of budget, mainstream, pickup truck and sports car candidates, as seen in Table 11.

Category	Electric Vehicle	ICE based car
1. Budget	Mitsubishi i-Miev	Toyota Yaris
2. Mainstream	Nissan Leaf	Toyota Auris
3. Pickup	Phoenix SUT	Nissan Frontier
4. Sports cars	Tesla Roadster	Porsche Cayman

Table 11: EV and ICE based car model pairs by category

Useful parameters for the proposed ICE based cars are accessible on manufacturers' websites [45-48]. The same accessibility does not necessarily apply to EVs [49-51], as extracting parameters such as fuel consumption requires derivation from other specifications, such as battery capacity and maximum driving range, which are possibly unrealistic "best case scenario" values.

Most of the ICE based cars in this comparison, as well as the Tesla Roadster, are already present on the current market and their suggested retail prices readily available from either manufacturer or automobile dealers' websites. Most EV price estimates are significantly less accurate however, as few EVs have yet made their presence truly felt on the market.

Nissan company spokesmen have suggested a base retail price of $32,780 USD for the Nissan Leaf but prefer to describe the price as $25,280 USD inclusive of a $7,500 USD federal income tax credit [52, 53]. Calculations herein make use of the suggested base retail price of $32,780, as an estimate.

Mitsubishi first announced a price tag of $45,000 USD for the Mitsubishi i-Miev, but with a bolstered mass production of 30,000 units scheduled for 2012 the price is expected to lower down to as little as $22,000 USD [49, 54].

In an interview with Phoenix Motorcars, the company predicted the Phoenix Sports Utility Vehicle to retail for $45,000 USD [55].

Parameters attained or derived from car manufacturing sources for eight cars can be seen in Table 12 and Table 13.

Parameter	Mitsubishi i-miev	Toyota Yaris 1.5	Nissan Leaf	Toyota Auris
Length [mm]	3395	4300	4445	4245
Width [mm]	1475	1689	1770	1760
Height [mm]	1610	1440	1550	1515
Weight [kg]	1100	1059		1280
Top speed [km/h]	130	170	140	175
0-100 acceleration [s]	9.0	10.7	10.0	13.1
Seats	4	5	5	5
Power [kW]	47	79	80	74
Torque [N.m]	180	140	280	132
Range [km]	160	575,34	160	-
Battery capacity [kWh]	16,000	-	24,000	-
Fuel consumption [kWh/km]	0,125	-	0,15	-
Fuel consumption [l/km]	-	0,073	-	0,058
Import price [USD]	$22,000	$12,905	$32,780	$21,672

Source: [45, 46, 49, 52, 54, 56-58]

Table 12: Specifications of Budget and Mainstream EV and ICE based car models

Parameter	Phoenix SUT	Nissan Frontier	Tesla Roadster	Porsche Cayman
Length [mm]	4965	5080	3946	4347
Width [mm]	1900	1825	1851	1801
Height [mm]	1755	1715	1126	1304
Weight [kg]	2186	1857	1238	1360
Top speed [km/h]	152		200	263
0-100 acceleration [s]	10		3,9	5,7
Seats	5	5	2	2
Power [kW]	110	98	215	195
Torque [N.m]	500	304	370	300
Range [km]	160	824,18	390	680,85
Battery capacity [kWh]	35,000	-	53,000	-
Fuel consumption [kWh/km]	0,2185	-	0,11	-
Fuel consumption [l/km]	-	0,091	-	0,094
Import price [USD]	$45,000	$26,620	$109,000	$51,400

Source: [47, 48, 51, 55, 59, 60]

Table 13: Specifications of Pickup and Sports car EV and ICE based car models

Comparison Formulas

The list price (P_*), refueling cost (C_*) and maintenance cost (M_*) formulas introduced in Equation 10, Equation 11 and Equation 15 can be summed up to form the annual cost of owning and operating a car for various years (T) given an annual driving distance (D). The sum of these cost terms present-valued, as seen in Equation 19, yields the total cost of purchasing and operating a car which is calculated for all car comparisons and can be seen in Results.

$$\overbrace{\mathbf{P}_*}^{\text{List Price}} + \left(\overbrace{\mathbf{RR}_* \times \mathbf{FC}_* \times \mathbf{D}}^{\text{Refueling}} + \overbrace{\mathbf{M}_0 + \mathbf{m} \times \mathbf{P}_*}^{\text{Maintenance}}\right) \times \frac{\mathbf{1} - (\mathbf{1} + \mathbf{r})^{-\mathbf{T}}}{\mathbf{r}}$$

Equation 19: The total cost of purchasing and operating a car, continued

Using Equation 8 to equate the total cost of owning and operating an EV and ICE based car such as those presented in Table 11 yields Equation 20. There is now a question worth answering: How does the total cost differ for a car purchasing consumer if he or she elected to purchase an expensive yet economic EV over a comparable yet cheaper ICE based car?

$$\mathbf{P}_{\mathbf{ICE}} + (\mathbf{C}_{\mathbf{ICE}} \times \mathbf{D} + \mathbf{M}_{\mathbf{ICE}}) \times \frac{\mathbf{1} - (\mathbf{1} + r)^{-T}}{\mathbf{r}}$$
$$= \mathbf{P}_{\mathbf{EV}} + (\mathbf{C}_{\mathbf{EV}} \times \mathbf{D} + \mathbf{M}_{\mathbf{EV}}) \times \frac{\mathbf{1} - (\mathbf{1} + r)^{-T}}{\mathbf{r}}$$

Equation 20: Equating the total cost of owning and operating an ICE based car and an EV

Not accounting for the residual value of the car and isolating T from Equation 20 yields the number of years necessary before the consumer has saved enough on lower refueling costs to make up for the initial price difference between a purchased EV and a comparable ICE based car as seen in Equation 21.

$$\mathbf{T} = -\ln\left(\frac{1 - \mathbf{r} \times (\mathbf{P}_{EV} - \mathbf{P}_{ICE})}{(\mathbf{C}_{ICE} - \mathbf{C}_{EV}) \times \mathbf{D} + \mathbf{M}_{ICE} - \mathbf{M}_{EV}}\right) \times \frac{1}{\ln(1 + \mathbf{r})}$$

Equation 21: Time in years until break even between cars of same category

Writing in the underlying terms for the refueling costs (C_{ICE} and C_{EV}) in Equation 11 and accounting for the assumption that maintenance costs are the same for ICE based cars and EVs sharing a category within Table 11 changes Equation 21 somewhat, as seen in Equation 22. The time of break even is calculated for all comparisons and can be seen in Results.

$$\mathbf{T} = -\ln\left(\frac{1 - \mathbf{r} \times (\mathbf{P}_{EV} - \mathbf{P}_{ICE})}{(\mathbf{RR}_{ICE} \times \mathbf{FC}_{ICE} - \mathbf{RR}_{EV} \times \mathbf{FC}_{EV}) \times \mathbf{D}}\right) \times \frac{1}{\ln(1 + \mathbf{r})}, \qquad \mathbf{P}_{EV} > \mathbf{P}_{ICE}$$

Equation 22: Time in years until break even between cars of same category, continued

Accounting for car residual value is a different matter. Taking together net cost specific information derived in Equation 9 and Equation 18 yields the net cost formula for a car of either type as shown in Equation 23.

$$\mathbf{P}_* + (\mathbf{C}_* \times \mathbf{D} + \mathbf{M}_*) \times \frac{1 - (1 + r)^{-T}}{\mathbf{r}} - \mathbf{P}_* \times \left(\frac{1 - \mathbf{k}}{1 + \mathbf{r}}\right)^{\mathbf{T}}$$

Equation 23: Net cost of purchasing, owning and selling a car, continued

Likewise writing in the underlying terms for refueling cost and that annual maintenance costs of EVs are assumed to have the same value as that of comparable ICE based cars yields the final net cost formula as shown in , used in all comparisons and which can be seen in Results.

$$\overbrace{\mathbf{P}_*}^{\text{List Price}} + \left(\overbrace{\mathbf{RR}_* \times \mathbf{FC}_* \times \mathbf{D}}^{\text{Refueling}} + \overbrace{\mathbf{M}_0 + \mathbf{m} \times \mathbf{P}_*}^{\text{Maintenance}}\right) \times \frac{1 - (1 + \mathbf{r})^{-\mathbf{T}}}{\mathbf{r}} - \overbrace{\mathbf{P}_* \times \left(\frac{1 - \mathbf{k}}{1 + \mathbf{r}}\right)^{\mathbf{T}}}^{\text{Residual value}}$$

Equation 24: Net cost of purchasing, owning and selling a car, continued

One unmentioned property of Equation 22 is how the annual driving distance (D) of a consumer is determined. With all other variables either known or fixed, the annual driving distance is the only remaining variable that determines how many years until a car consumer breaks even on his EV car purchase and can vary greatly on a consumer by consumer basis.

The choice of annual driving distance to be used in calculations should reflect Icelandic traffic behavior somewhat. The Road Traffic Directorate of Iceland has numbers on average annual driving distances acquired during regular vehicle maintenance and checkups which can be seen in Table 14 [38].

2007

Car and fuel type	Number of Vehicles	Weight	Average annual driving distance [km/year]	Weighted a.a.d.d. [km/year]
Passenger car, gasoline	71,887	85.9%	11,857.6	12,606
Passenger car, diesel oil	11,845	14.1%	17,163.6	

2008

Car and fuel type	Number of Vehicles	Weight	Average annual driving distance [km/year]	Weighted a.a.d.d. [km/year]
Passenger car, gasoline	80,189	84.5%	11627,6	12,369
Passenger car, diesel oil	14,663	15.5%	16407,3	

Table 14: Average annual driving distances for the years 2007 and 2008

Table 14 provides a weighted average of annual driving distances in the year 2008 which corresponds to the average consumer's annual driving distance ($D_{average}$) used in calculations. For scenarios in which a consumer has a higher than average annual driving distance (D_{high}), the annual distance is double that of an average consumer. This is shown in Equation 25.

$$\mathbf{D_{average}} \cong \mathbf{12,369} \left[\mathbf{km}/\mathbf{year}\right], \qquad \mathbf{D_{high}} = \mathbf{2} \times \mathbf{D_{average}} \cong \mathbf{24,738} \left[\mathbf{km}/\mathbf{year}\right]$$

Equation 25: Annual driving distances for two kinds of drivers

With all required parameter information for Equation 22, break even points can be established for any two cars that are electric and ICE based and share the same category within Table 11. For the cars specified in Table 12 and Table 13, their derived parameters as well as other previously derived parameters applicable to Equation 22 can be seen in Table 15

Parameter	Budget Cars		Mainstream Cars	
	Mitsubishi i-Miev	Toyota Yaris	Nissan Leaf	Honda Fit
IP [USD]*	$22,000	$12,905	$32,780	$21,672
P_x [ISK]**	3,440,206	2,623,392	5,125,907	4,405,590
FC_x	0,125 [kWh/km]	0,073 [liter/km]	0,15 [kWh/km]	0,058 [liter/km]
M_x [ISK/year]	343,069	343,069	416,357	416,357

Source: [45, 46, 49, 52, 54, 56-58]

Parameter	Pickups		Sports cars	
	Phoenix SUT	Nissan Frontier	Tesla Roadster	Porsche Cayman
IP [USD]*	$45.000	$26,620	$109,000	$51,400
P_x [ISK]**	7,036,785	6,035,841	17,044,657	11,654,480
FC_x	0,21875 [kWh/km]	0,091 [liter/km]	0,11 [kWh/km]	0,094 [liter/km]
M_x [ISK/year]	483,396	483,396	714,445	714,445

Source: [47, 48, 51, 55, 59, 60]

RR_{EV} [ISK/kWh]	9.85
RR_{ICE} [ISK/l]	204.00
ISK/USD	124.60
D [km/year]	$D_{average}$ = 12,369 and D_{high} = 24,738

Source: [29, 38, 44]

Table 15: Compilation of parameters as used in calculations

Results

Comparisons are made between cars in each of the four categories of Table 11. Each category is compared based on Equation 19 for total cost assuming no revenue term (total cost) and based on Equation 24 where revenue is accounted for in the form of car residual value at a given year (net cost). In each comparison annual driving distances and discount rates alternate from $D_{average}$ to D_{high} (see Equation 25) and 6.36% to 12.72% respectively. A table detailing time of break-even based on Equation 22 follows total cost comparisons each car category.

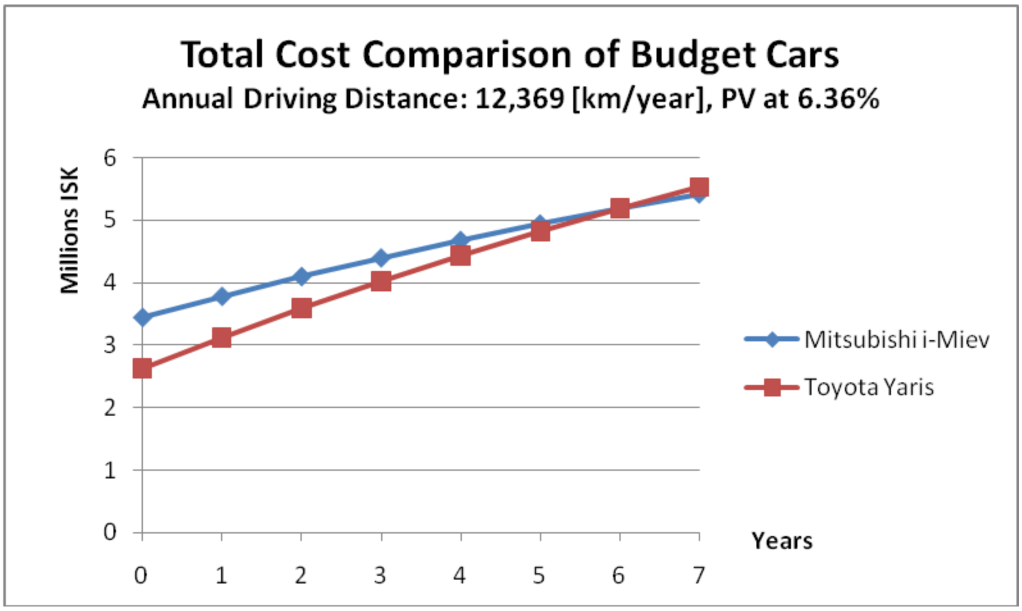

Figure 3: Total cost of budget cars, D = 12,369 km/year, Present-Valued at 6.36%

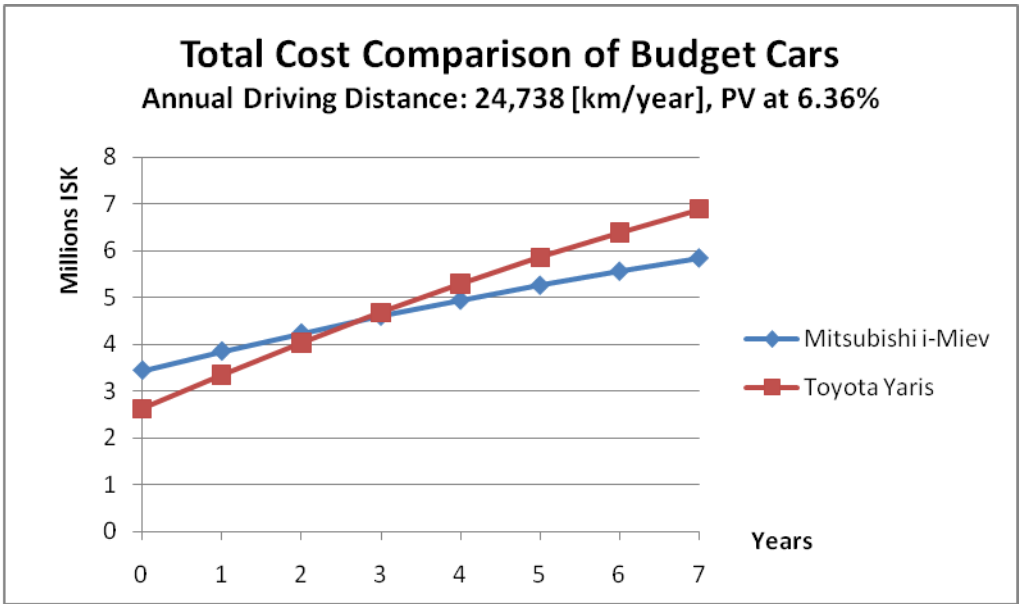

Figure 4: Total cost of budget cars, D = 24,738 km/year, Present-Valued at 6.36%

Figure 3 and Figure 4 show total cost comparison between an EV and ICE based budget car for two annual driving distances, with maintenance and refueling cost present-valued assuming yield 6.36%. Break even occurs at 5.96 and 2.71 years, respectively.

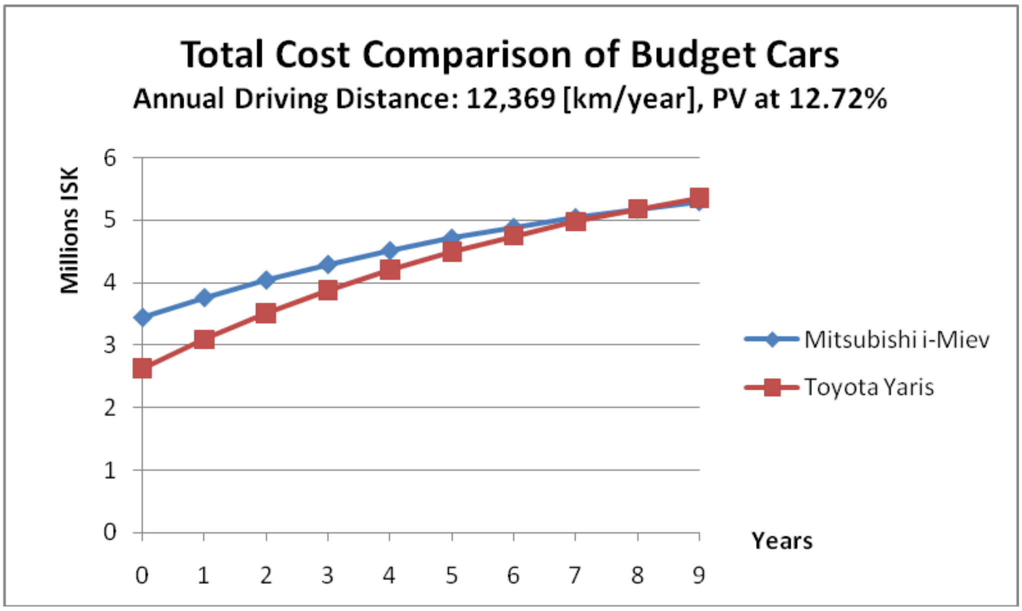

Figure 5: Total cost of budget cars, D = 12,369 km/year, Present-Valued at 12.72%

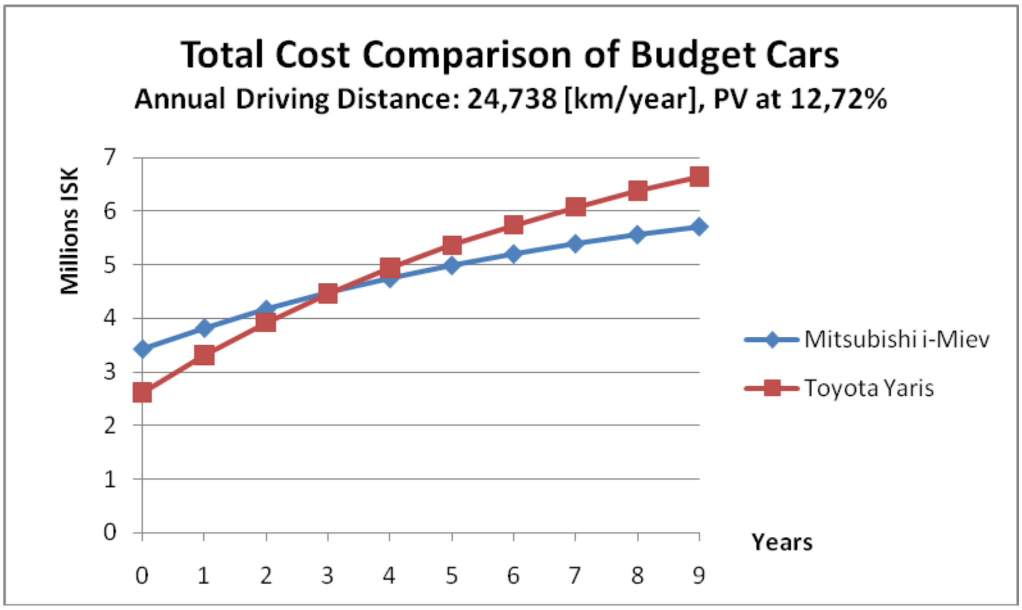

Figure 6: Total cost of budget cars, D = 24,738 km/year, Present-Valued at 12.72%

Figure 5 and Figure 6 show total cost comparison between an EV and ICE based budget car for two annual driving distances, with maintenance and refueling cost present-valued assuming yield 12.72%. Break even occurs at 7.97 and 3.07 years, respectively.

A compilation of break even points for all budget car related figures can be seen in Table 16.

Comparison	Break even point (T)
Budget Cars, D = 12,369 [km/year], PV @ 6.36%	5.96 years
Budget Cars, D = 24,738 [km/year], PV @ 6.36%	2.71 years
Budget Cars, D = 12,369 [km/year], PV @ 12.72%	7.97 years
Budget Cars, D = 24,738 [km/year], PV @ 12.72%	3.07 years

Table 16: Time of break-even for budget EVs and ICE based cars

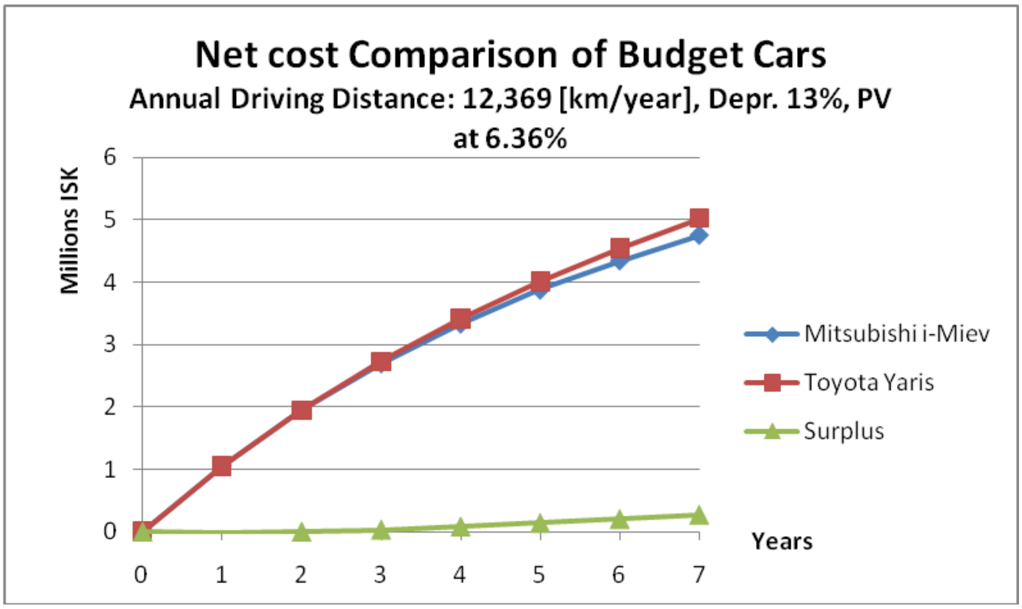

Figure 7: Net cost of budget cars, D = 12,369 km/year, Depreciation of 13%, Present-Valued at 6.36%

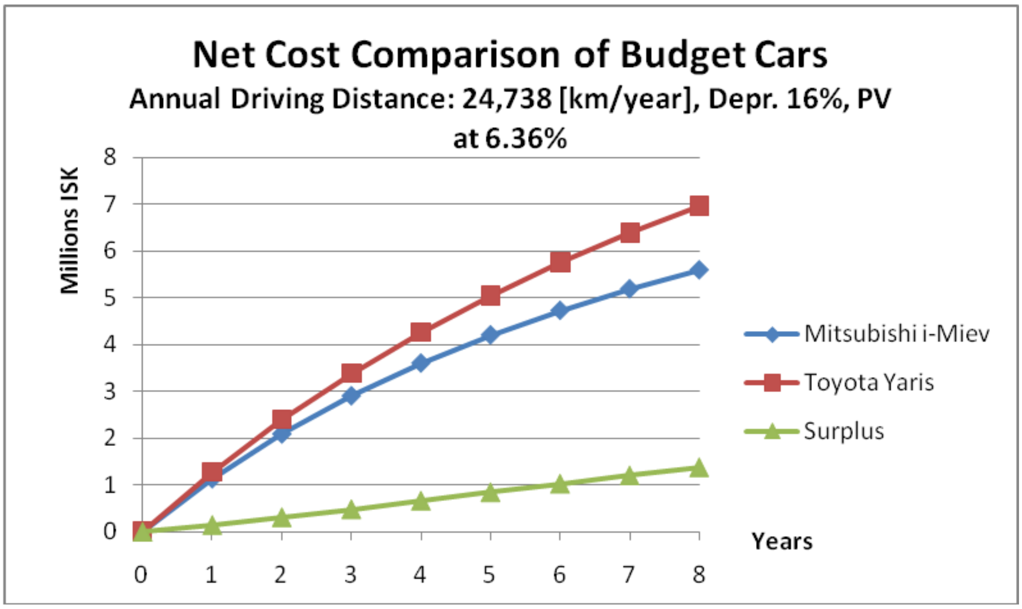

Figure 8: Net cost of budget cars, D = 24,738 km/year, Depreciation of 16%, Present-Valued at 6.36%

Figure 7 and Figure 8 show net cost comparison between an EV and ICE based budget car for two annual driving distances, with maintenance and refueling cost present-valued assuming yield 6.36%. Residual value of cars are accounted for as present valued, depreciated revenue for each year. Difference in net cost after either type of car sold at a given year is represented as Surplus (beneficial for purchaser of an EV).

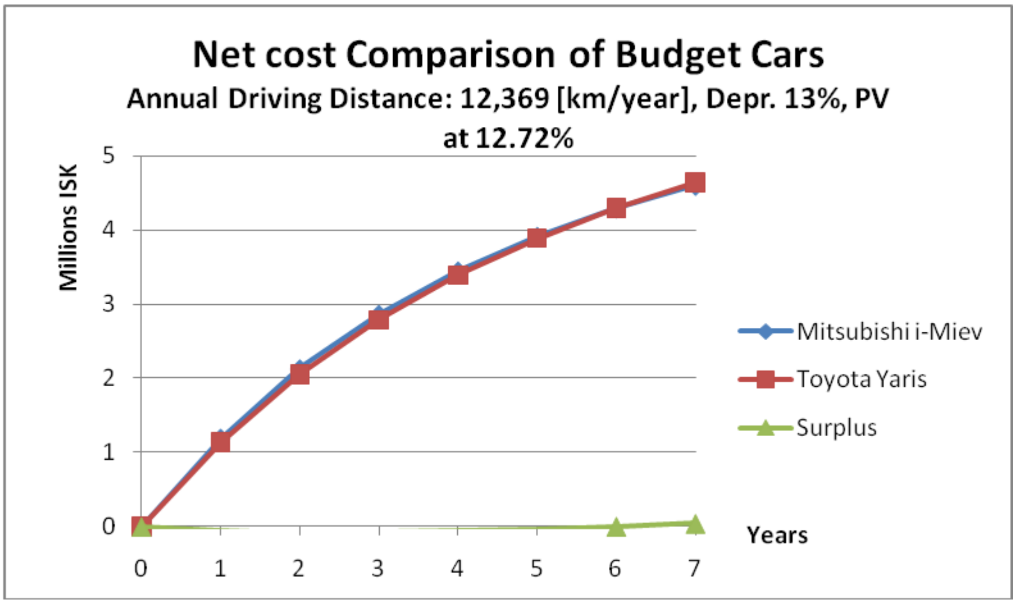

Figure 9: Net cost of budget cars, D = 12,369 km/year, Depreciation of 13%, Present-Valued at 12.72%

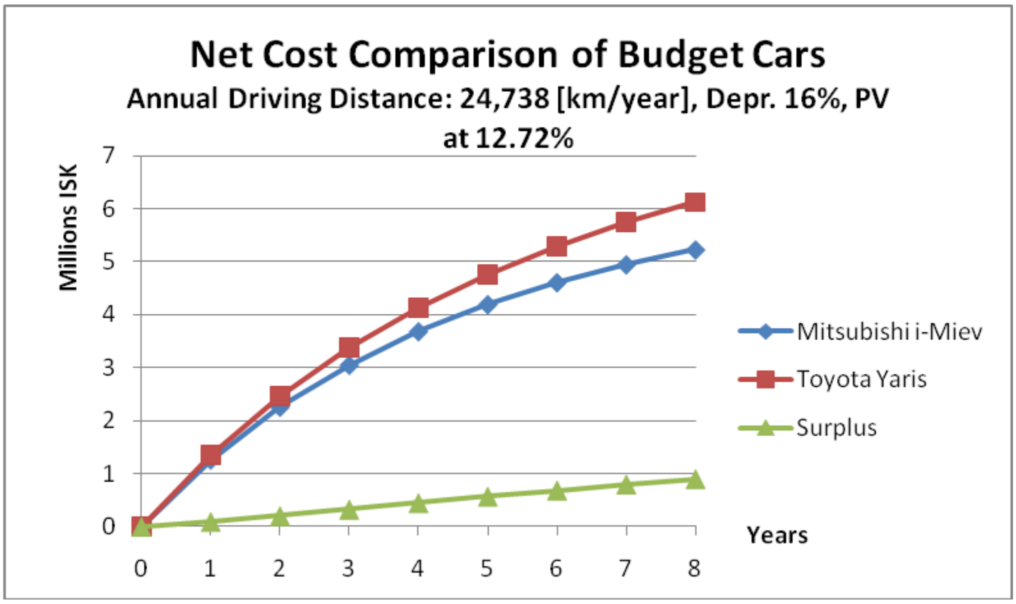

Figure 10: Net cost of budget cars, D = 24,738 km/year, Depreciation of 16%, Present-Valued at 12.72%

Figure 9 and Figure 10 show net cost comparison between an EV and ICE based budget car for two annual driving distances, with maintenance and refueling cost present-valued assuming yield 12.72%. Residual value of cars are accounted for as present valued, depreciated revenue for each year. Difference in net cost after either type of car sold at a given year is represented as Surplus (beneficial for purchaser of an EV).

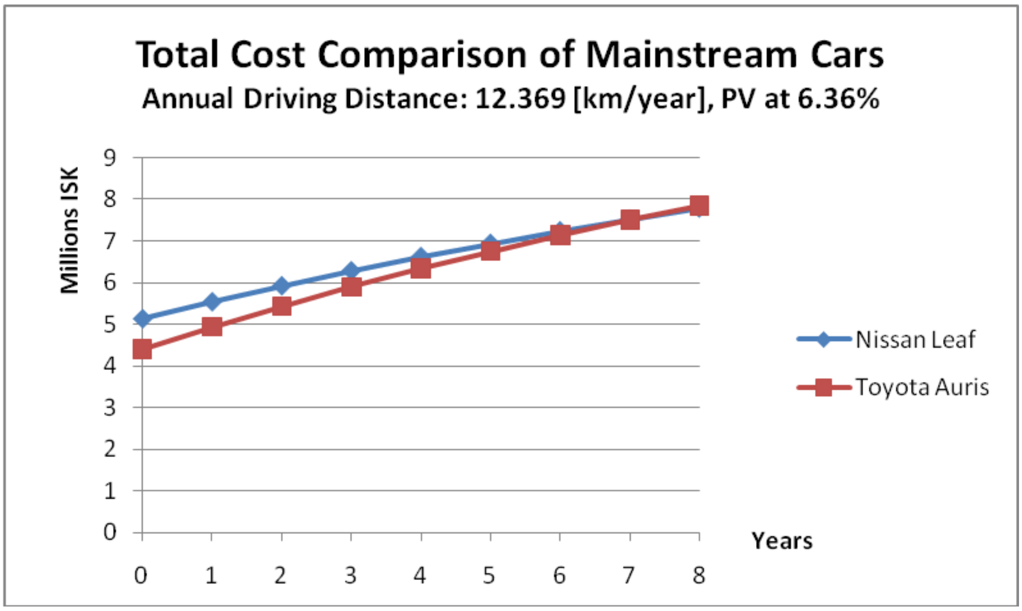

Figure 11: Total cost of mainstream cars, D = 12,369 km/year, Present-Valued at 6.36%

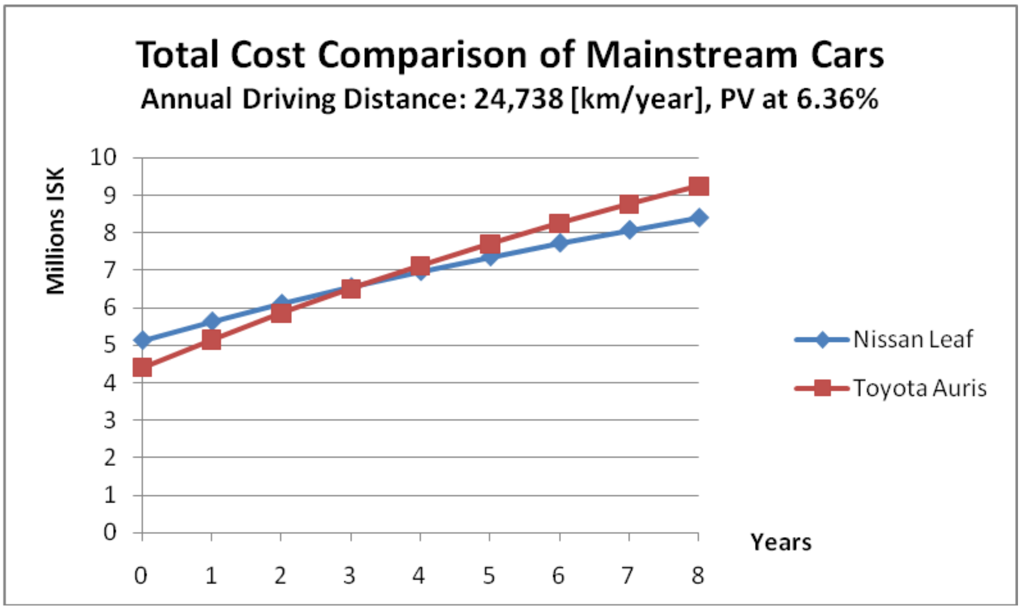

Figure 12: Total cost of mainstream cars, D = 24,738 km/year, Present-Valued at 6.36%

Figure 11 and Figure 12 show total cost comparison between an EV and ICE based mainstream car for two annual driving distances, with maintenance and refueling cost present-valued assuming yield 6.36%. Break even occurs at 7.18 and 3.20 years, respectively.

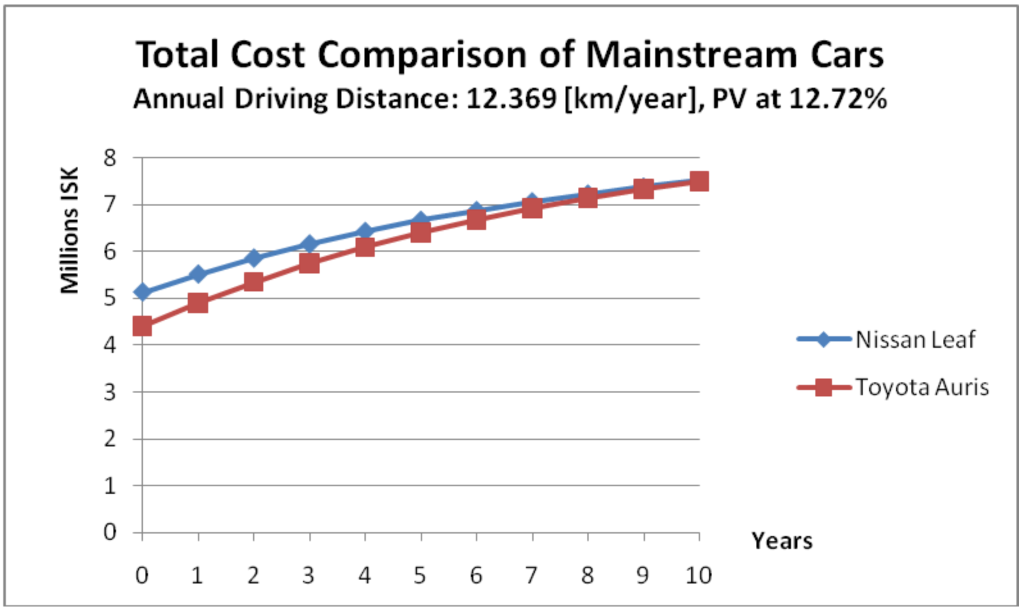

Figure 13: Total cost of mainstream cars, D = 12,369 km/year, Present-Valued at 12.72%

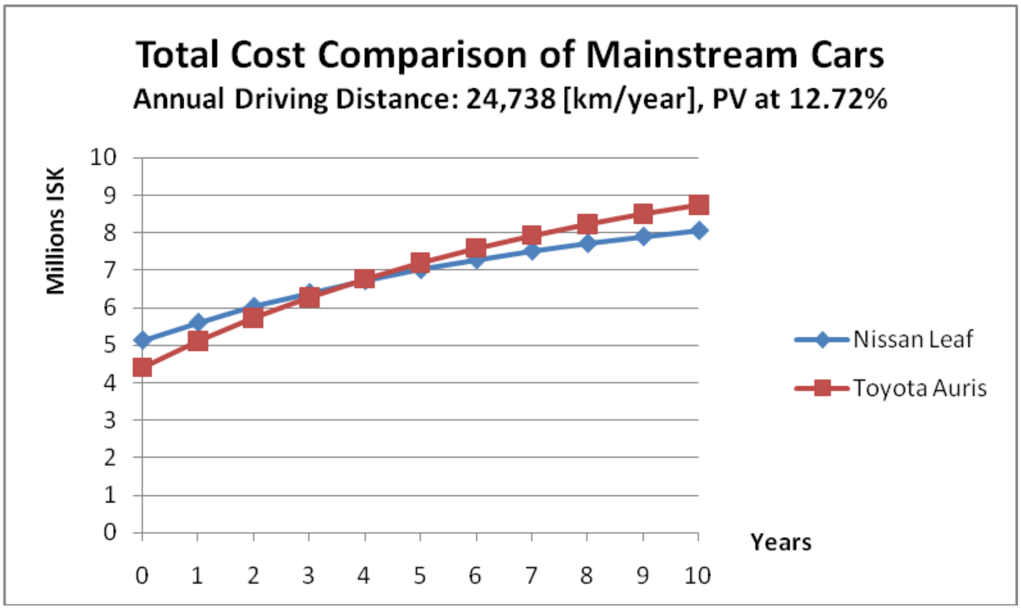

Figure 14: Total cost of mainstream cars, D = 24,738 km/year, Present-Valued at 12.72%

Figure 13 and Figure 14 show total cost comparison between an EV and ICE based mainstream car for two annual driving distances, with maintenance and refueling cost present-valued assuming yield 12.72%. Break even occurs at 10.50 and 3.70 years, respectively.

A compilation of break even points for all mainstream car related figures can be seen in Table 17.

Comparison	Break even point (T)
Mainstream Cars, D = 12,369 [km/year], PV @ 6.36%	7.18 years
Mainstream Cars, D = 24,738 [km/year], PV @ 6.36%	3.20 years
Mainstream Cars, D = 12,369 [km/year], PV @ 12.72%	10.50 years
Mainstream Cars, D = 24,738 [km/year], PV @ 12.72%	3.70 years

Table 17: Time of break-even for mainstream EVs and ICE based cars

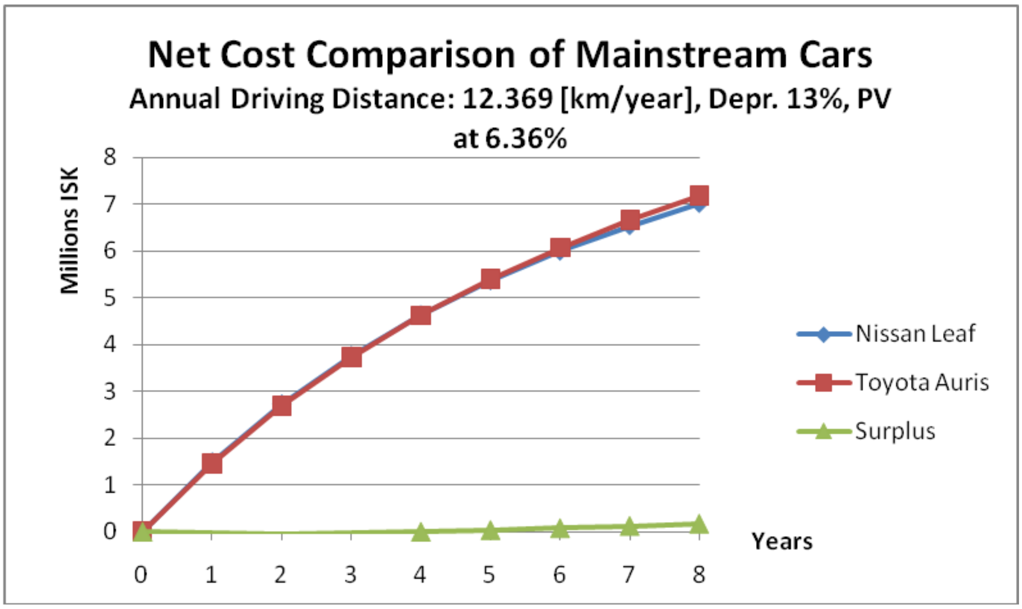

Figure 15: Net cost of mainstream cars, D = 12,369 km/year, Depreciation of 13%, Present-Valued at 6.36%

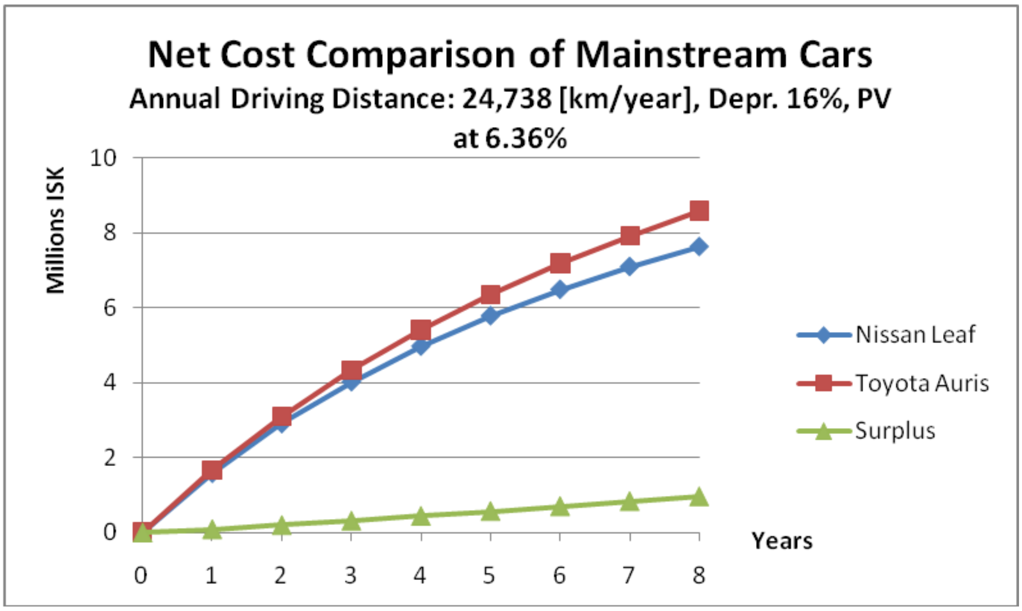

Figure 16: Net cost of mainstream cars, D = 24,738 km/year, Depreciation of 16%, Present-Valued at 6.36%

Figure 15 and Figure 16 show net cost comparison between an EV and ICE based mainstream car for two annual driving distances, with maintenance and refueling cost present-valued assuming yield 6.36%. Residual value of cars are accounted for as present valued, depreciated revenue for each year. Difference in net cost after either type of car sold at a given year is represented as Surplus (beneficial for purchaser of an EV).

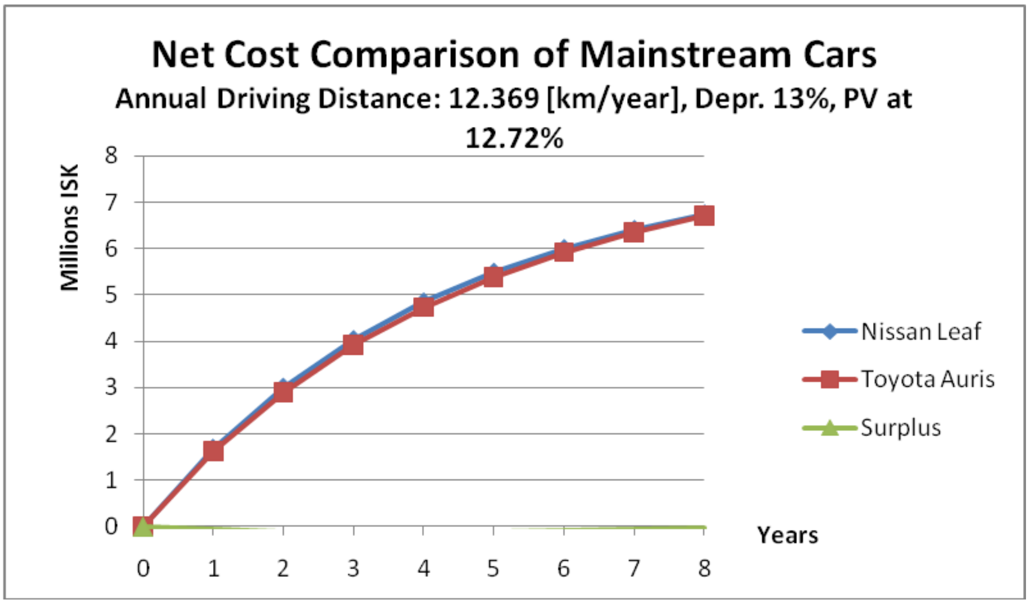

Figure 17: Net cost of mainstream cars, D = 12,369 km/year, Depreciation of 13%, Present-Valued at 12.72%

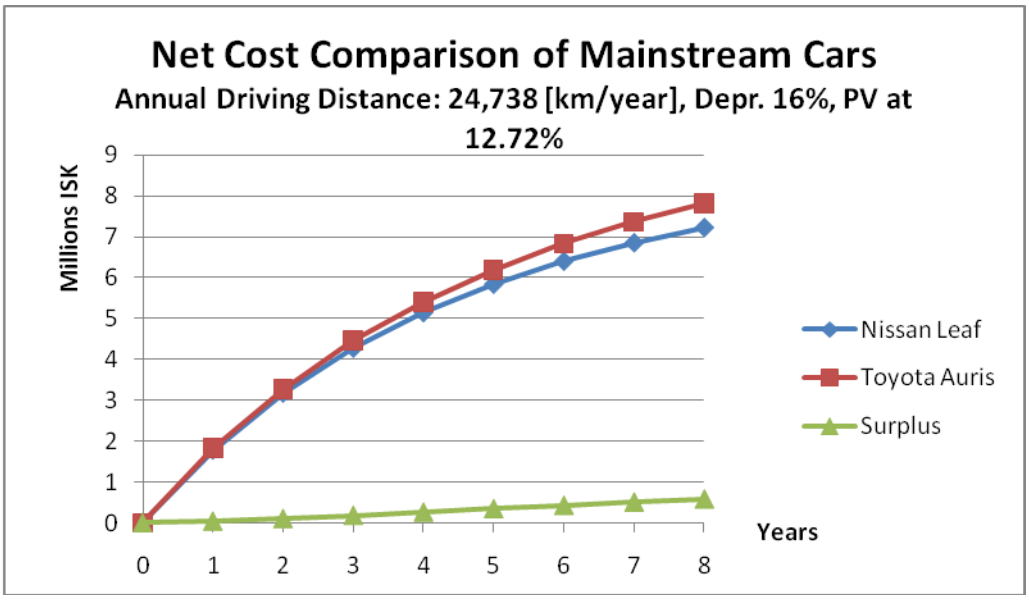

Figure 18: Net cost of mainstream cars, D = 24,738 km/year, Depreciation of 16%, Present-Valued at 12.72%

Figure 17 and Figure 18 show net cost comparison between an EV and ICE based mainstream car for two annual driving distances, with maintenance and refueling cost present-valued assuming yield 12.72%. Residual value of cars are accounted for as present valued, depreciated revenue for each year. Difference in net cost after either type of car sold at a given year is represented as Surplus (beneficial for purchaser of an EV).

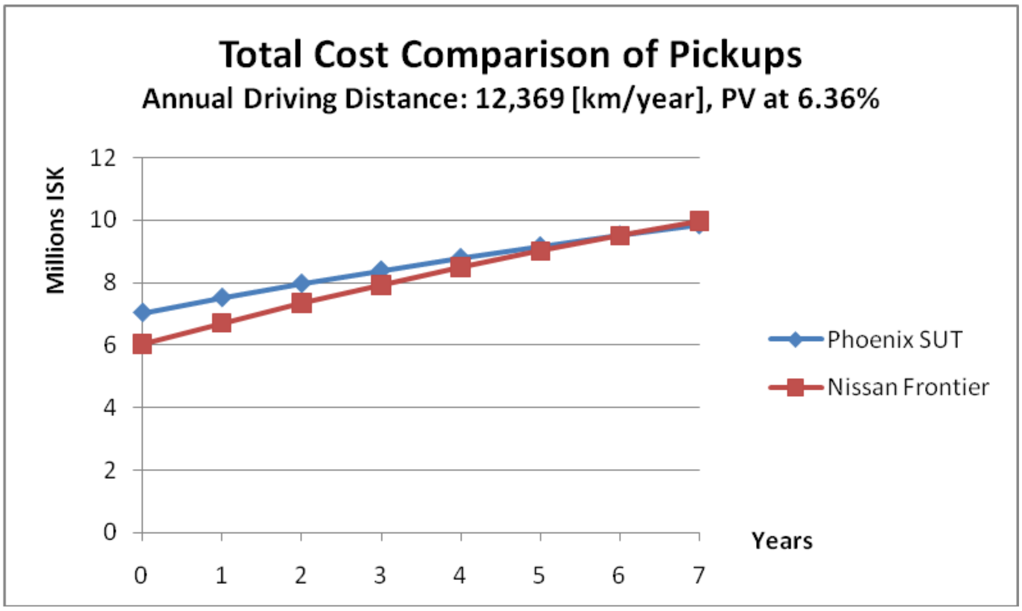

Figure 19: Total cost of pickups, D = 12,369 km/year, Present-Valued

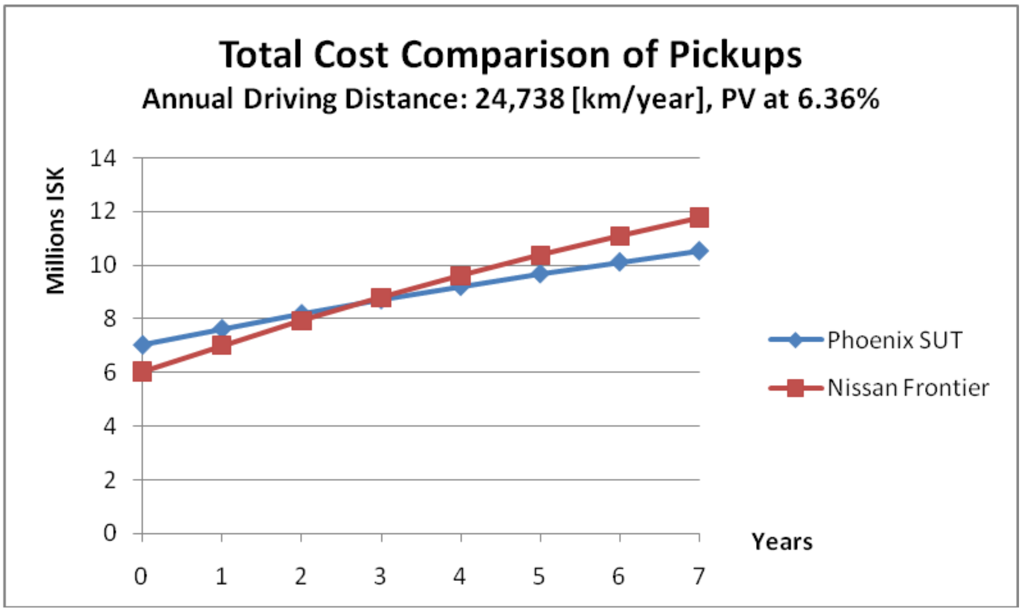

Figure 20: Total cost of pickups, D = 24,738 km/year, Present-Valued

Figure 19 and Figure 20 show total cost comparison between an EV and ICE based pickup car for two annual driving distances, with maintenance and refueling cost present-valued assuming yield 6.36%. Break even occurs 6.10 and 2.77 years, respectively.

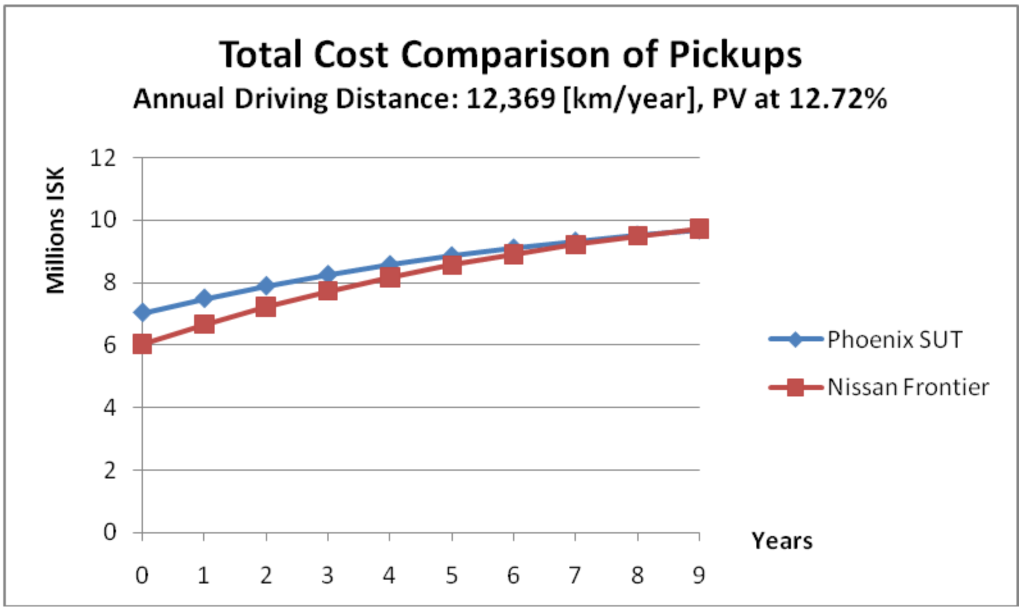

Figure 21: Total cost of pickups, D = 12,369 km/year, Present-Valued at 12.72%

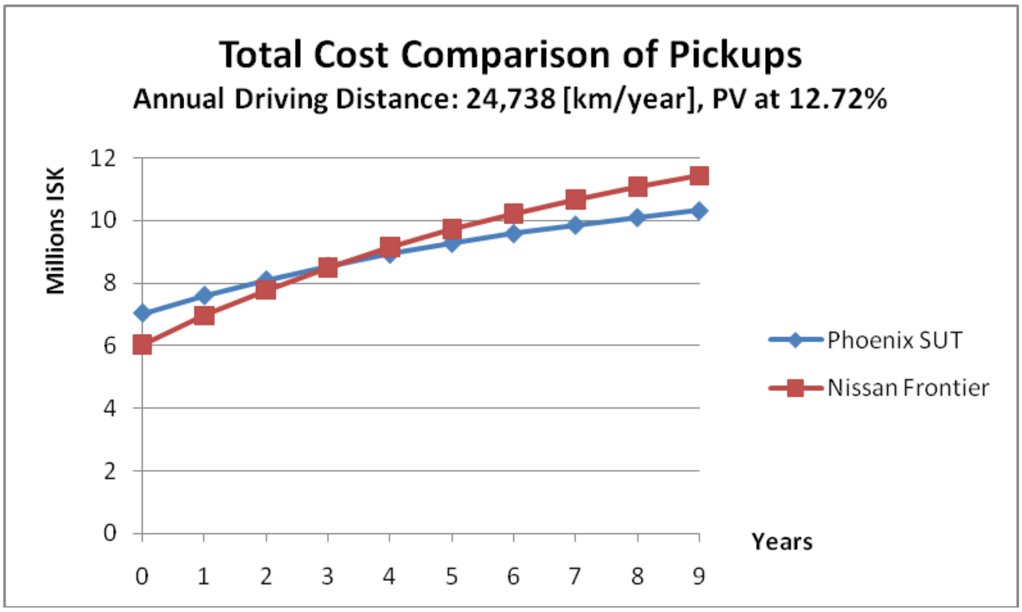

Figure 22: Total cost of pickups, D = 24,738 km/year, Present-Valued at 12.72%

Figure 21 and Figure 22 show total cost comparison between an EV and ICE based pickup car for two annual driving distances, with maintenance and refueling cost present-valued assuming yield 12.72%. Break even occurs 8.24 and 3.14 years, respectively.

A compilation of break even points for all pickup car related figures can be seen in Table 18.

Comparison	Break even point (T)
Pickup Cars, D = 12,369 [km/year], PV @ 6.36%	6.10 years
Pickup Cars, D = 24,738 [km/year], PV @ 6.36%	2.77 years
Pickup Cars, D = 12,369 [km/year], PV @ 12.72%	8.24 years
Pickup Cars, D = 24,738 [km/year], PV @ 12.72%	3.14 years

Table 18: Time of break-even for pickup EVs and ICE based cars

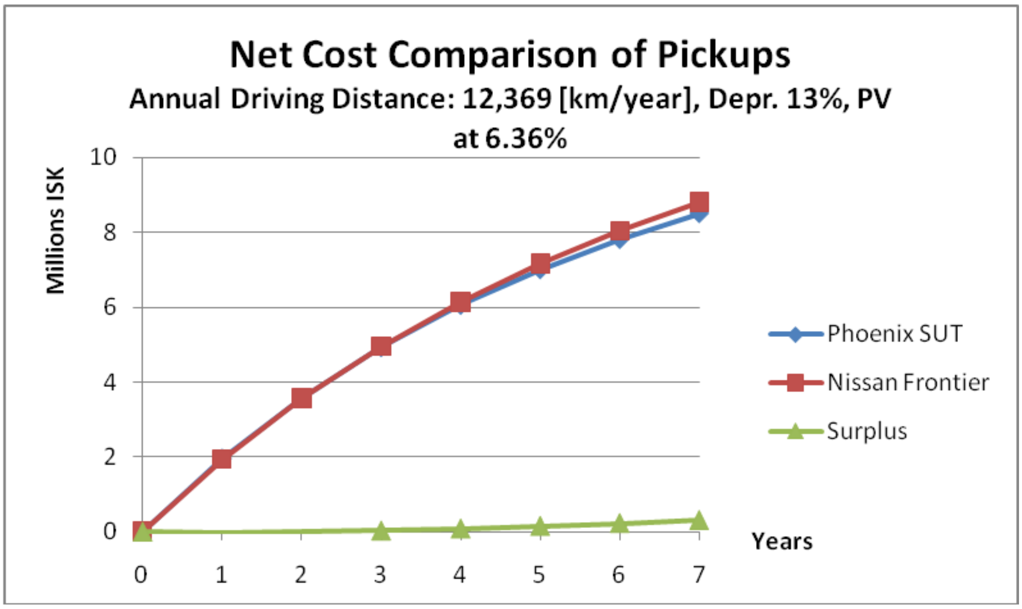

Figure 23: Net cost of pickup cars, D = 12,369 km/year, Depreciation of 13%, Present-Valued at 6.36%

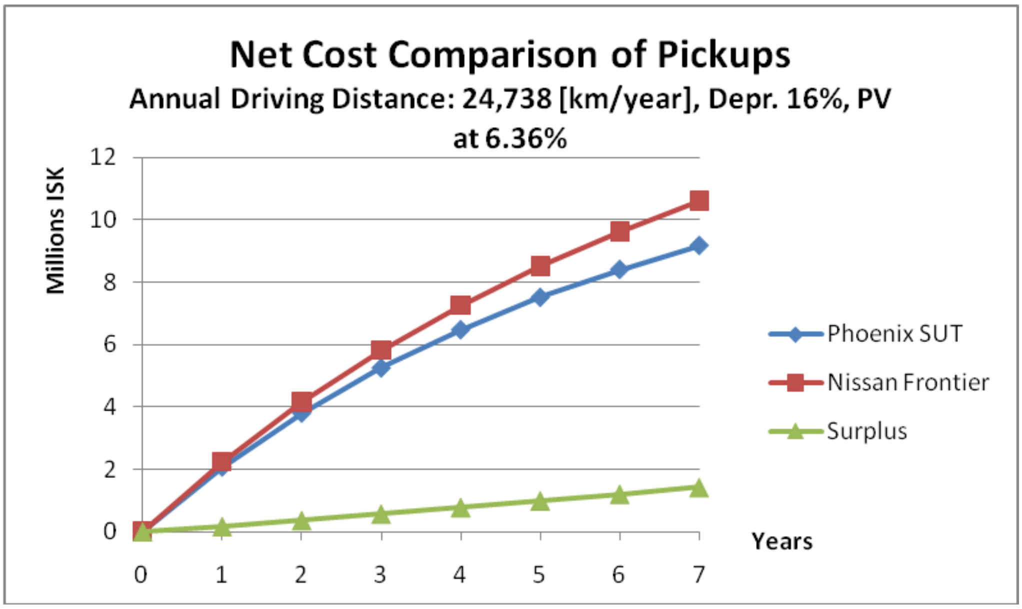

Figure 24: Net cost of pickup cars, D = 24,738 km/year, Depreciation of 16%, Present-Valued at 6.36%

Figure 23 and Figure 24 show net cost comparison between an EV and ICE based pickup car for two annual driving distances, with maintenance and refueling cost present-valued assuming yield 6.36%. Residual value of cars are accounted for as present valued, depreciated revenue for each year. Difference in net cost after either type of car sold at a given year is represented as Surplus (beneficial for purchaser of an EV).

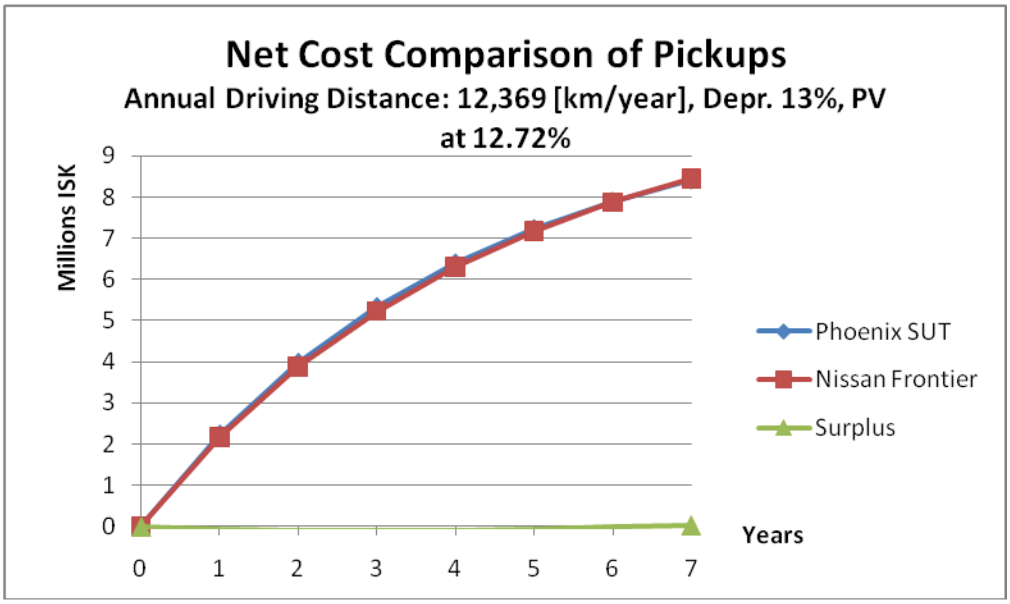

Figure 25: Net cost of pickup cars, D = 12,369 km/year, Depreciation of 13%, Present-Valued at 12.72%

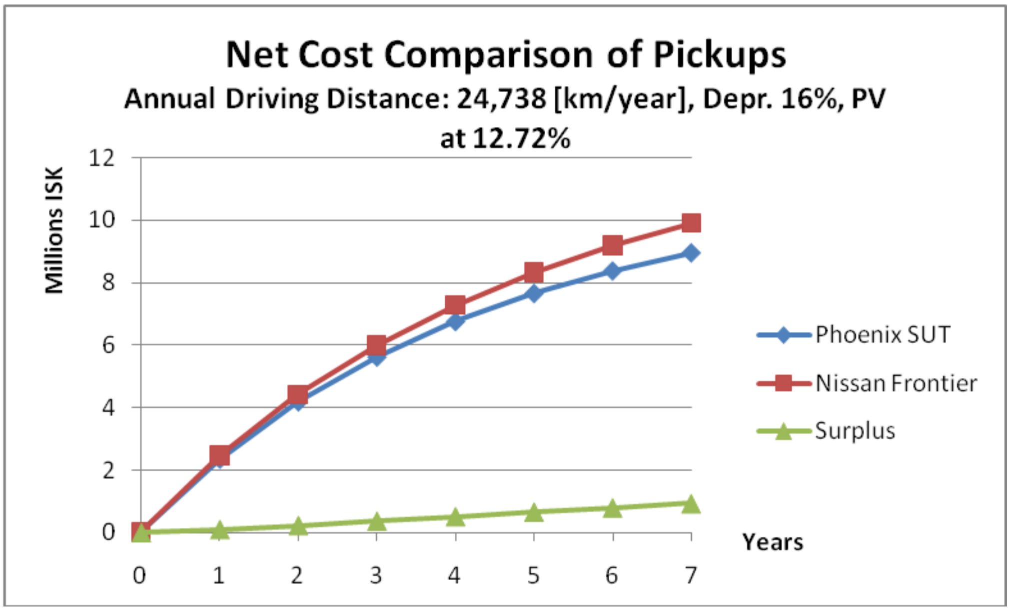

Figure 26: Net cost of pickup cars, D = 24,738 km/year, Depreciation of 16%, Present-Valued at 12.72%

Figure 25 and Figure 26 show net cost comparison between an EV and ICE based pickup car for two annual driving distances, with maintenance and refueling cost present-valued assuming yield 12.72%. Residual value of cars are accounted for as present valued, depreciated revenue for each year. Difference in net cost after either type of car sold at a given year is represented as Surplus (beneficial for purchaser of an EV).

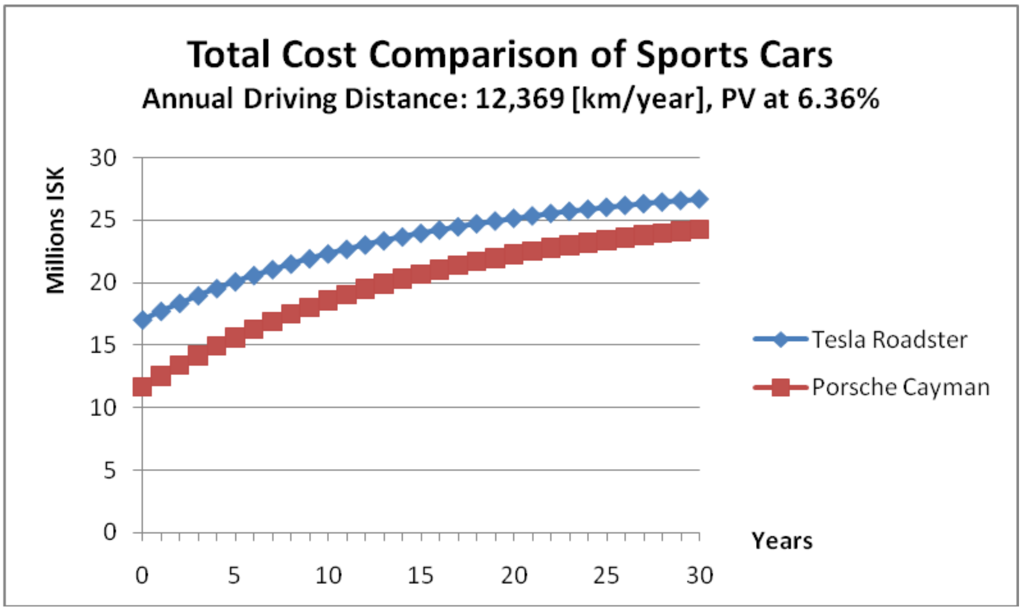

Figure 27: Total cost of sports cars, D = 12,369 km/year, Present-Valued at 6.36%

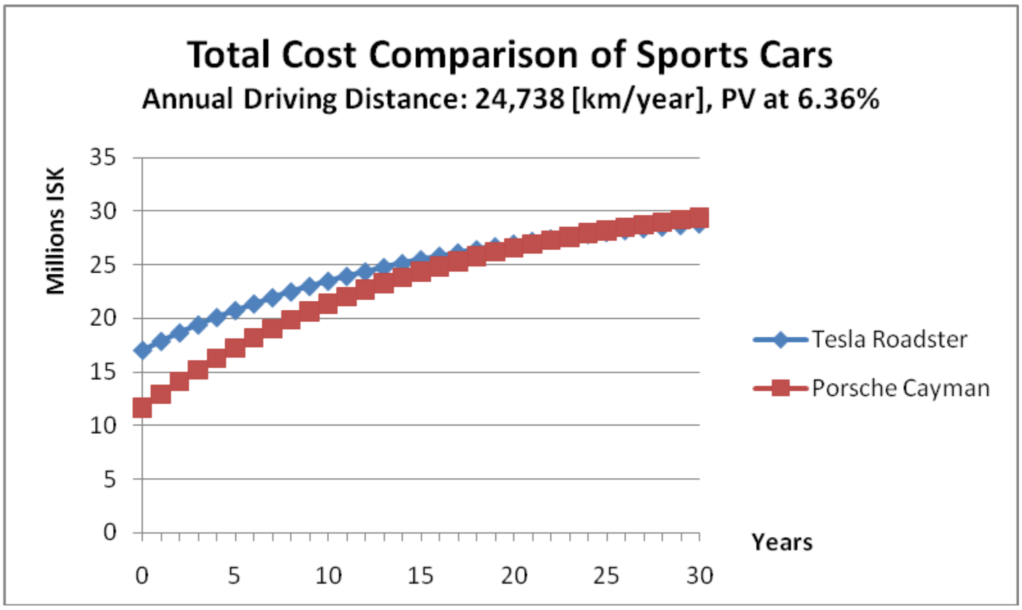

Figure 28: Total cost of sports cars, D = 24,738 km/year, Present-Valued at 6.36%

Figure 27 and Figure 28 show total cost comparison between an EV and ICE based sports car for two annual driving distances, with maintenance and refueling cost present-valued assuming yield 6.36%. Break even is impossible and occurs at 23.55 years, respectively.

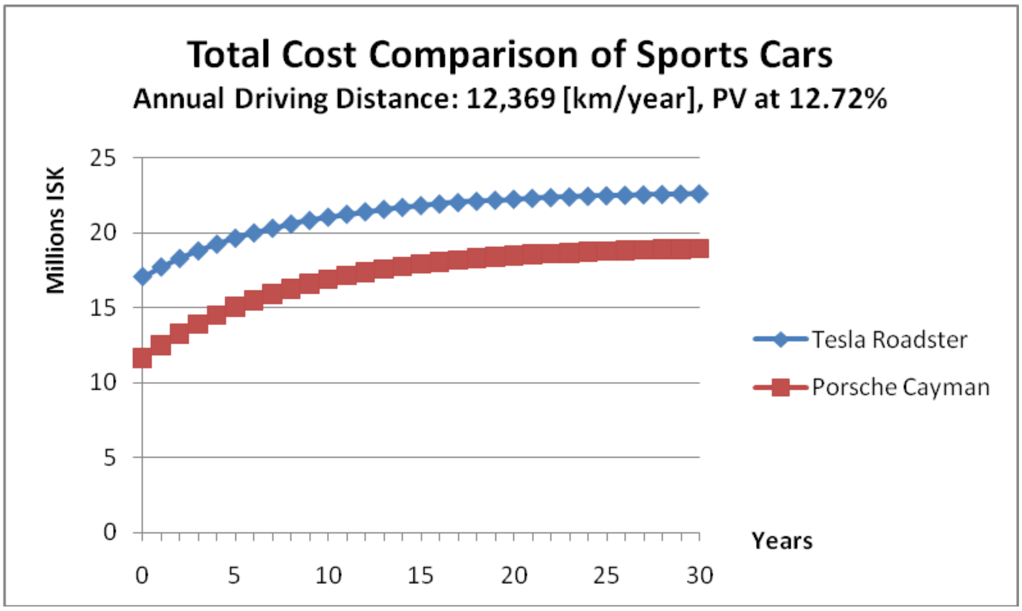

Figure 29: Total cost of sports cars, D = 12,369 km/year, Present-Valued at 12.72%

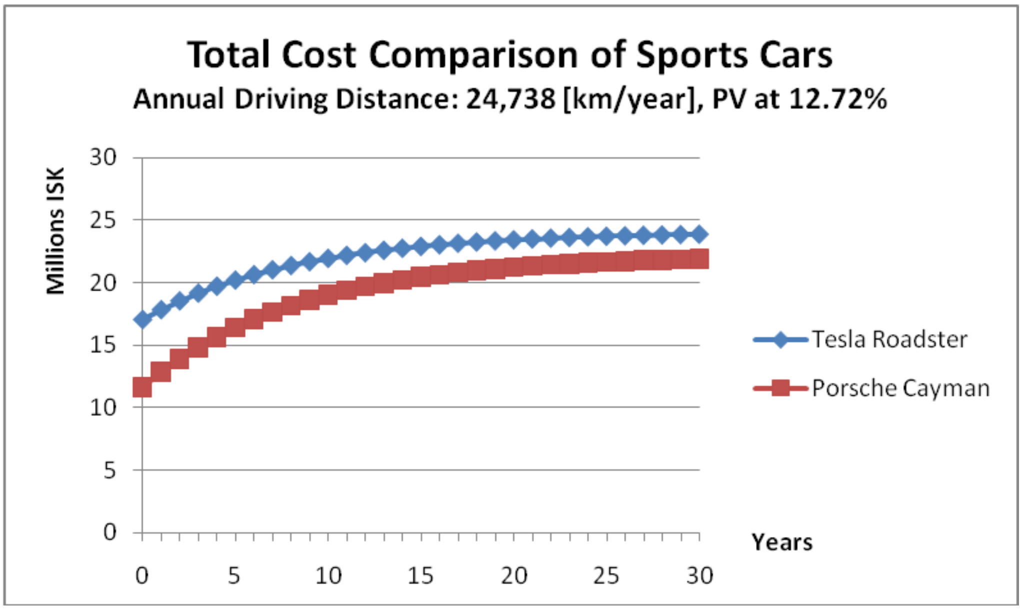

Figure 30: Total cost of sports cars, D = 24,738 km/year, Present-Valued at 12.72%

Figure 29 and Figure 30 show total cost comparison between an EV and ICE based sports car for two annual driving distances, with maintenance and refueling cost present-valued assuming yield 12.72%. Break even is mathematically impossible in either case.

A compilation of break even points for all sport car related figures can be seen in Table 19.

Comparison	Break Even point (T)
Sport Cars, D = 12,369 [km/year], PV @ 6.36%	[Impossible]
Sport Cars, D = 24,738 [km/year], PV @ 6.36%	23.55 years
Sport Cars, D = 12,369 [km/year], PV @ 12.72%	[Impossible]
Sport Cars, D = 24,738 [km/year], PV @ 12.72%	[Impossible]

Table 19: Time of break-even for sports EVs and ICE based cars

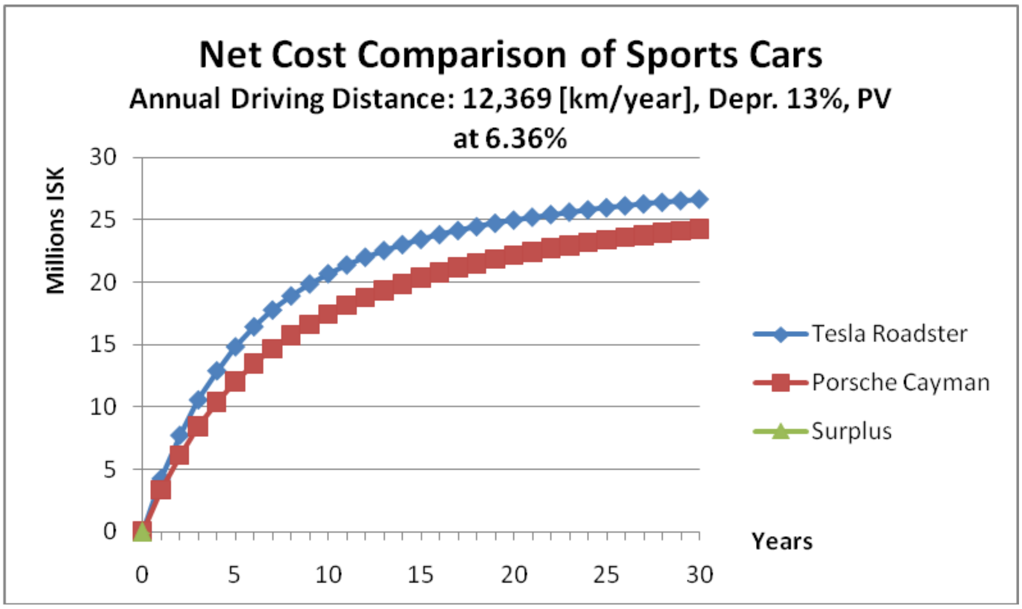

Figure 31: Net cost of sports cars, D = 12,369 km/year, Depreciation of 13%, Present-Valued at 6.36%

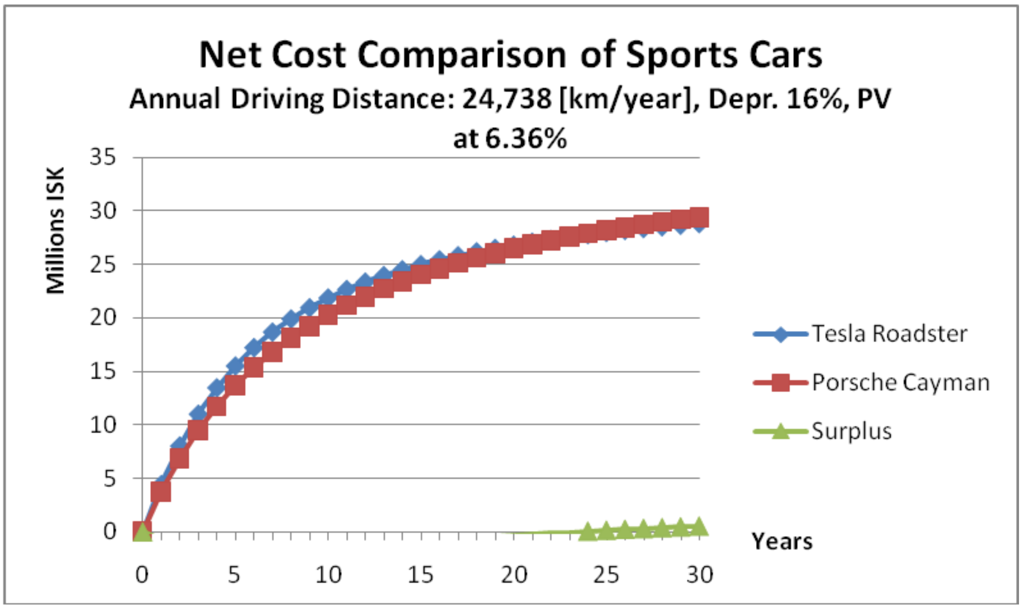

Figure 32: Net cost of sports cars, D = 24,738 km/year, Depreciation of 16%, Present-Valued at 6.36%

Figure 31 and Figure 32 show net cost comparison between an EV and ICE based sports car for two annual driving distances, with maintenance and refueling cost present-valued assuming yield 6.36%. Residual value of cars are accounted for as present valued, depreciated revenue for each year. Difference in net cost after either type of car sold at a given year is represented as Surplus (beneficial for purchaser of an EV).

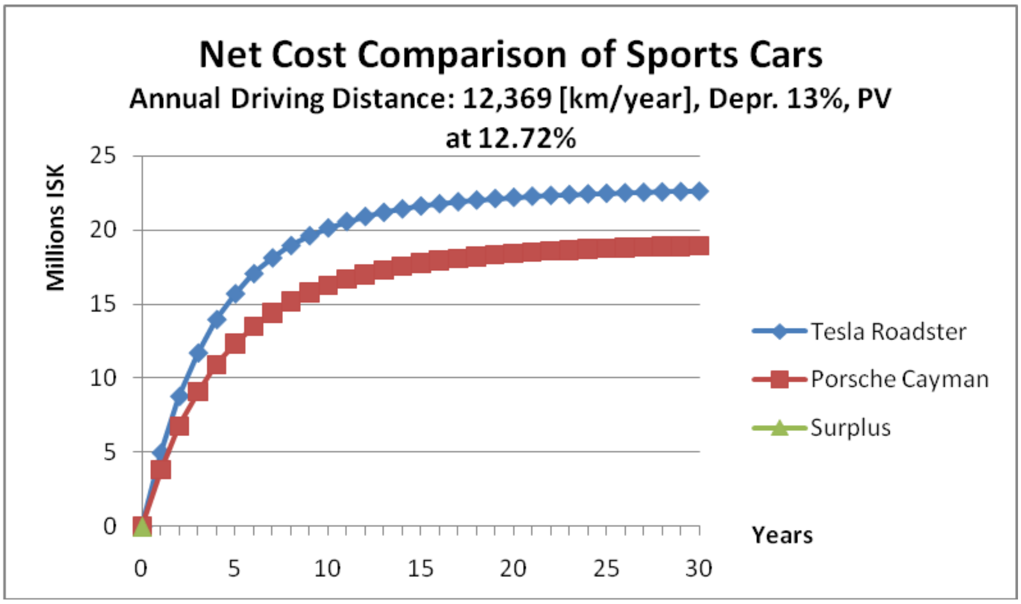

Figure 33: Net cost of sports cars, D = 12,369 km/year, Depreciation of 13%, Present-Valued at 12.72%

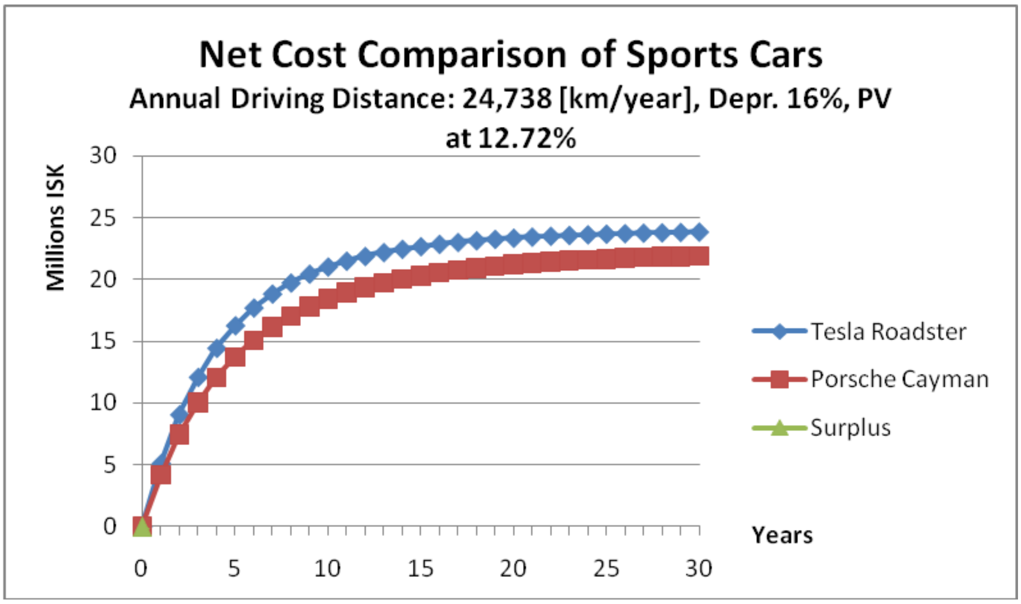

Figure 34: Net cost of sports cars, D = 24,738 km/year, Depreciation of 16%, Present-Valued at 12.72%

Figure 33 and Figure 34 show net cost comparison between an EV and ICE based sports car for two annual driving distances, with maintenance and refueling cost present-valued assuming yield 12.72%. Residual value of cars are accounted for as present valued, depreciated revenue for each year. Difference in net cost after either type of car sold at a given year is represented as Surplus (beneficial for purchaser of an EV).

Discussion

Total cost (not including car residual value) -The Figures and especially Tables of the preceding section provide interesting information. Given a choice between cars within categories of Table 11, the average Icelandic consumer would have to own and operate an EV of any category for 6-7 years (assuming a discount rate of 6.36%) before low refueling cost makes up for the initial price difference between an EV and its ICE based counterpart.

This can seem surprising on both ends of the EV enthusiast spectrum; that the low refueling costs of EVs do not contribute as much to the point of break even as initially surmised, or that the towering import price of EVs can actually be overcome by the casual driver in several years.

The exception to the aforementioned lies in the sport car category, where as seen in Table 19 an average consumer could be hard-pressed to so much as witness the time of break even in a single human lifetime, much less the EVs lifetime.

Based on the results a consumer with higher annual driving distances like D_{high} from Equation 25 is much better off driving an EV from the budget, mainstream or pickup car categories than the average driver, as seen in Table 16, Table 17, Table 18 and Figures thereof. In those cases the low refueling cost feature of EVs really shines and would make up for the initial price difference within 3 years after purchase. Again the sport car EV appears to be less than a stellar economic purchase, even for a consumer with a high annual driving distance.

Depending on the discount (i.e. uncertainty) rate used in calculations of the model stalls the point of break even further into the future for all car categories, effectively negating the possibility of ever breaking even with an EV sport car as seen in Figure 27 and Table 19. The refueling and maintenance cost cash flows simply do not possess enough counterweight to the initial purchase to really matter.

It is noteworthy how relatively little the cost slope of an EV deviates when compared to that of its ICE based counterpart. This stems from refueling costs being only a fraction of overall annual costs; refueling an EV may be cheap but its owner must still spend a hefty sum annually on maintenance. Should the maintenance cost of EVs turn out to be lower than those of ICE based cars the difference of slopes increases, yet the main bottleneck for EV implementation remains first and foremost linked to EV import prices and list prices.

Net cost (accounting for car residual value) - When accounting for the actual worth of the vehicle after initial purchase as revenue at a given year, the results are vastly different from those above. It can be seen in all Figures for Budget, Mainstream and Pickup cars that the net cost of an EV owner with average annual driving distances is strikingly similar to that of an ICE based car owner, rendering the net cost of all EVs presented in Table 11 except sports cars equal to or less than their respective ICE based counterpart at any given time.

The net cost of a driver with higher annual driving distances than the average is gradually less for EVs than that of ICE based cars. The margin increases with time.

Again, the exception to the aforementioned lies in the sport car category, where as seen in Figure 31, Figure 33 and Figure 34 the net cost for both average and a driver with higher annual driving distances are constantly higher than that of an ICE based car. Figure 32 (for higher annual driving distances and present valued at the lower rate) does show the net cost of an EV sports car eventually become lower than that of an ICE based car, however the time of intersection is deemed beyond any reasonable car lifetime.

All the numbers and figures from the compilation of Table 15 can be replaced by newer or different EV and ICE based car models and parameters for further scenarios. As more data on maintenance cost becomes available the required use of Equation 16 for linear approximation is lessened and more meaningful results, based for example on Equation 15, can be attained.

Finally, there is a weakness present in the currently used method of comparison on the subject of gasoline rates and EV import prices. Gasoline rates are assumed to stay fixed for an entire comparison when in reality gasoline rates are among the most volatile commodities in Iceland. Likewise, EV import prices are assumed to stay fixed when it is very likely that as mass production of EVs gains footing then the manufacturer suggested retail price of EVs will lower. There is however also the possibility that the two aforementioned weaknesses counterweight each other in such a way as to give the same net results as already shown.

Trade Balance

Estimating the economic effect of implementing EVs on a national scale is of great interest. EV implementations are considered favorable by many due to their lowering dependence on foreign oil imports and pollution [12, 13].

However, much of the national economic impact of implementing Electric Vehicles depends on whose view is taken. For example, substituting gasoline purchases for an increasing demand on electrical power may be profitable for consumers and power companies, but decreases government revenue from both oil imports and gasoline sales and hurts the oil and gas companies themselves [12, 24, 26, 40].

It is of interest to focus on the viewpoint of the main player in any nation's economy; the government itself. There are three major economic factors of interest to the government concerning EV implementation.

1) Trade balance - How the national trade balance is affected by EV implementation and what possible consequences that change results in.
2) Government revenue - How the gradual switch from ICE based cars to EVs by consumers is reflected in both direct and indirect tax income and how the government can compensate for lost or gained income.
3) Infrastructure – Investments and/or changes to energy infrastructure may prove necessary to facilitate the implementation process.

Car related imports

Every year certain goods related to the car industry are imported to Iceland. First and foremost are the cars themselves, imported in various numbers (N_{ICE}) at various prices (IP_*) every year. With no domestic car production present in the country, it can be assumed that for any car in the passenger car fleet that gets scrapped a new car will be imported to replenish the car fleet number. On top of maintaining the size of the car fleet a slight growth is assumed, discussed in this chapter.

Large amounts of gasoline (N_{gas}) are imported annually to the country at volatile prices (IGP_{year}) [29] intended for consumption by ICE based cars present in the country. Since no domestic oil refineries are present in the country, Iceland is wholly dependent upon imported gasoline in order to sustain its ICE based passenger car fleet.

Finally there are various ICE based car maintenance related goods (M_{ICE}) such as tires and car components, imported in order to maintain a functioning car fleet. Equation 26 shows the composition of total car related imports (TI) for any given year.

$$\mathbf{TI} = \left(\sum_{\mathbf{N_{CARS}}} \mathbf{IP_i} \right) + \mathbf{IGP_{year}} \times \mathbf{N_{gas}} + \mathbf{M_{year}}$$

Equation 26: Annual imported car related goods

Impact on Trade Balance

By considering Equation 26 the impact a single ICE based car has on national imports can be estimated. Said impact is composed of the initial import price of the car (IP_{ICE}) in ISK, the imported gasoline required during its lifetime - derived from its fuel consumption (FC_{ICE}), annual driving distance (D) and respective imported gasoline prices (IGP_{year}) for every year, and the various imported car maintenance related goods (M_{ICE}). Accounting for ongoing imports due to the presence of an ICE based car requires present-valuing (PV_t) all future import values. Equation 27 details the composition of import costs related to a single ICE based car (I_{ICE}).

$$I_{ICE} = \overbrace{IP_{ICE}}^{\text{Car Import}} + \overbrace{\sum_{t=1}^{\text{Car Lifetime}} IGP_t \times FC_{ICE} \times D \times PV_t}^{\text{Gasoline Imports}} + \overbrace{\sum_{t=1}^{\text{Car Lifetime}} (M_{ICE})_t \times PV_t}^{\text{Maintenance Imports}}$$

Equation 27: Imports due to a single ICE based car

The question attempted to answer in this chapter is what kind of an impact a hypothetical scenario where imported ICE based cars are substituted with imported EVs can have on a nation's trade balance. The net impact can be attributed to three main factors [61].

1) Changes in car imports – Substituting an imported car for another with a higher import price raises the total import, contributing to an overall trade balance deficit. The reverse is also true in that a cheaper substitute contributes to an overall trade balance surplus.
2) Changes in gasoline imports – Since an EV uses domestic energy sources whereas an ICE based car relies solely upon imported fuel, substituting an ICE based car with an EV lessens the required annually imported gasoline by the same amount an ICE based car would have otherwise required.
3) Changes in car maintenance related imports – Substituting an imported car for another with higher maintenance requirements can raise the total import of car maintenance related goods, contributing to an overall trade balance deficit. The reverse is also true in that a substitute with lower maintenance requirements can contribute to an overall trade balance surplus.

Maintenance related imports

Assertions from previous chapters state that empirical data providing conclusive results on the difference between EV and ICE based car related maintenance costs is yet to be obtained from today's manufacturers and consumers. Maintenance related imports are therefore assumed to remain unchanged for any single EV substitute. Rewriting Equation 27 for an EV therefore yields the import cost of a single EV (I_{EV}), as seen in Equation 28.

$$I_{EV} = \overbrace{IP_{EV}}^{\text{Car Import}} + \overbrace{\sum_{t=1}^{\text{Car Lifetime}} (M_{ICE})_t \times PV_t}^{\text{Maintenance Imports}}$$

Equation 28: Imports due to a single EV

As in previous chapters it is assumed that EV import prices are generally more expensive than comparable ICE based counterparts. Therefore, subtracting Equation 27 yields the net impact on trade balance (TBI) caused by the substitution; a surplus (if positive) or deficit (if negative), as seen in Equation 29.

$$TBI = \overbrace{IP_{ICE} + \sum_{t=1}^{\text{Car Lifetime}} IGP_t \times PV_t \times FC_{ICE} \times D + \sum_{t=1}^{\text{Car Lifetime}} (M_{ICE})_t \times PV_t}^{\text{ICE based car related imports}} - \overbrace{\left(IP_{EV} + \sum_{t=1}^{\text{Car Lifetime}} (M_{EV})_t \times PV_t \right)}^{\text{EV related imports}}$$

$$= (IP_{ICE} - IP_{EV}) + \sum_{t=1}^{\text{Car Lifetime}} IGP_t \times FC_{ICE} \times D \times PV_t$$

Equation 29: Net trade balance impact due to a single EV substitution

Gasoline imports

Since gasoline prices for a given year are assumed to stay fixed for every year thereafter, the imported gasoline price is independent of the sum, which in turn corresponds to a uniform series present value factor (see Equation 7 for derivation). Equation 29 may then be written as Equation 30.

$$\text{TBI} = (\text{IP}_{\text{ICE}} - \text{IP}_{\text{EV}}) + \text{IGP} \times \text{FC}_{\text{ICE}} \times \text{D} \times \frac{\mathbf{1 - (1 + r)^{-T}}}{\mathbf{r}}$$

Equation 30: Net trade balance impact due to a single EV substitution, continued

Estimating the impact of EV substitution on trade balance requires information on car related imports in Iceland. Useful statistical data is available from Statistics Iceland concerning imported vehicles, gasoline and aspects of maintenance [24], as seen in Table 20, Table 22 and Table 24 for the years 2007, 2008 and 2009 respectively.

Imported commodity 2007	Units	Import cost (CIF) [million ISK]	Average cost per unit
Other motor spirit (gasoline)	156,600 [ton]	7,188	45,900 [ISK/ton]
Diesel oil	394,300 [ton]	16,237	41,179 [ISK/ton]
New tires	4,600 [ton]	1,992	433,043 [ISK/ton]
Used tires	500 [ton]	102	204,000 [ISK/ton]
Passenger cars	18,876 cars	28,678	1,519,280 [ISK/car]
Spare parts for automobiles	2,300 [ton]	3,045	1,323,910 [ISK/ton]

Table 20: Imported car related goods in Iceland 2007 [24]

The imported commodity of motor spirit in Table 20 is assumed be consumed entirely by ICE based vehicles, albeit not necessarily by passenger cars. Interpreting the imported diesel oil is a different matter, as not only are diesel engines a minority among passenger cars in Iceland (15.5% as of 2008 according to Table 14), but ships and smaller boats use more than a quarter of all imported oil in Iceland as seen in Table 21. Airplane oil consumption is tracked separately [24].

Year	Oil consumption [ton]	Cars [ton]	Cars [%]	Ships [ton]	Ships [%]	Airplanes [ton]	Airplanes [%]
2007	765,000	347,000	45.4%	202,000	26.4%	169,000	22.1%
2008	702,000	328,000	46.7%	197,000	28.1%	144,000	20.5 %

Table 21: Oil consumption by cars, ships and airplanes in Iceland 2007 and 2008 [24]

In order to estimate the amount of gasoline and diesel oil imported annually for consumption by ICE based cars, several assumptions need to be made. First, based on recent price history in Iceland [29], retail price of diesel oil is assumed to be roughly the same as traditional gasoline. Second, the average fuel consumption of diesel engine cars is assumed to be the same as that of an average ICE based car. Finally, from the diesel car percentage numbers of 2007 in Table 14, the amount of diesel oil imported is assumed to be 14.1% that of imported gasoline. Therefore, 24,300 tons of diesel oil is attributed to ICE based cars for the year 2007 in Table 20.

Gasoline is better measured in units of liters than grams, and a single metric ton of gasoline is assumed to be 1,356 liters [62]. Grouping import commodities together into car, gasoline, and maintenance related terms, then repeating the above process for years 2008, 2009 and 2010 (with 15.5% diesel car ratio as of 2008) produces Table 22, with terms for all three years and cost per desired unit.

Imported 2007	Units	Import cost (CIF) [million ISK]	Cost per unit
Cars	18,876 cars	28,678	1.52 [million ISK]
Gasoline	178,600 [tons]	8,097	33.4 [ISK/liter]
Maintenance	7,400 [tons]	5,139	0.69 [million ISK/ton]

Imported 2008	Units	Import cost (CIF) [million ISK]	Cost per unit
Cars	10,703 cars	20,681	1.93 [million ISK]
Gasoline	175,500 [ton]	13,331	56.0 [ISK/0.0178]
Maintenance	5,700 [ton]	5,484	0.96 [million ISK/ton]

Imported 2009	Units	Import cost (CIF) [million ISK]	Cost per unit
Cars	2,550 cars	8,473	3.32 [million ISK]
Gasoline	180,800 [ton]	12,997	53.0 [ISK/liter]
Maintenance	3,300 [ton]	4,825	1.46 [million/ton]

Imported 2010 (until May 31st)	Units	Import cost (CIF) [million ISK]	Cost per unit
Cars	473 cars	1,418	3.00 [million ISK]
Gasoline	41,700 [ton]	3,837	67.9 [ISK/liter]
Maintenance	1,200 [ton]	1,569	1.31 [million/ton]

Table 22: Grouped car related imports in Iceland 2007, 2008, 2009 and 2010 [29]

Information from 2010 in Table 22 spans less than half the year and is not used in calculations. Table 22 contains information on average ICE based car import price (IP_{ICE}), imported gasoline price (IGP) and maintenance cost (M_{ICE}) for a given year. Without a projected curve for imported gasoline prices, the originating imported gasoline price used in a calculated scenario for a given year is assumed to stay fixed for the scenario's entire duration. The average EV import price (IP_{EV}) can be derived based on price difference in the car categories of Table 12 and Table 13. Price differences can be seen in Table 23.

Category	EV import price (IP_{EV}) [USD]	ICE import price (IP_{ICE}) [USD]	IP_{EV}/IP_{ICE} Price ratio
Budget cars	$22,000	$12,905	1.70
Mainstream cars	$32,780	$21,672	1.51
Pickup cars	$45,000	$26,620	1.69
Sport cars	$109,000 cars	$51,400	2.12
Average price difference based on all cars			**1.76**
Average price difference based on all except sports cars			**1.63**

Table 23: Average price differences between EVs and ICE based cars

Car imports

It is assumed that the import price of EVs (IP_{EV}) is the average price difference between cars of all categories from Table 12 and Table 13 except sports cars. The reason for leaving out one of the candidates is twofold: First and foremost because sports cars of similar caliber as those presented in Table 11 weigh so little within the Icelandic car fleet as to be considered a niche group [63] and also in light of the results on break even points seen in Table 19 where sports car comparisons appear as anomalies when compared to results for all other categories of Table 16, Table 17 and Table 18.

An average EV is therefore assumed to be 63% more expensive than a comparable ICE based car. This is shown in Equation 31.

$$\overline{\mathbf{IP_{EV}}} = (1 + 0.63) \times \overline{\mathbf{IP_{ICE}}}$$

Equation 31: The average EV assumed 63% more expensive than an ICE based car

Average fuel consumption of ICE based cars is needed in order to calculate hypothetical substitutions of EVs. From ICE based cars presented in Table 12 and Table 13, the fuel consumptions and their average thereof is introduced in Table 24

Car model	FC_{ICE} [liter/km]
Toyota Yaris	0.073
Toyota Auris	0.058
Nissan Frontier	0.091
Porsche Cayman	0.098
Average fuel consumption	0.080

Table 24: Average fuel consumption of ICE based cars [45, 47, 48, 58]

According to Table 24 an average ICE based car therefore requires 0.08 liters of gasoline per driven km, this is shown in

$$\overline{\mathbf{FC_{ICE}}} = \mathbf{0.08}\left[\mathbf{liter}/\mathbf{km}\right]$$

Equation 32: Average fuel consumption of ICE based cars

The only remaining parameters needed for Equation 30 are the annual distance to be driven and the car lifetime. The average life expectancy of a new car is estimated to be around 150,000 miles or 241,402 km (D_{max}) [64] which, when assuming average annual driving distances of 12,369 km per year ($D_{average}$ from Equation 25) corresponds to a number of roughly 20 years ($T_{average}$), or 10 years (T_{high}) for a driver with the higher average annual driving distance of 24,738 km per year (D_{high} from Equation 25). Equation 33 shows the relation between D_{max}, T_{max} and $D_{high,}$, the latter two of which is used in calculations for car related import scenarios with EV substitutions

$$\mathbf{T_{average}} = \frac{\mathbf{D_{max}}}{\mathbf{D_{average}}} = \frac{\mathbf{241,402\ [km]}}{\mathbf{12,369}\left[\mathbf{km}/\mathbf{year}\right]} = \mathbf{19.5} \cong \mathbf{20\ years}$$

$$\mathbf{T_{high}} = \frac{\mathbf{D_{max}}}{\mathbf{D_{high}}} = \frac{\mathbf{241,402\ [km]}}{\mathbf{24,738}\left[\mathbf{km}/\mathbf{year}\right]} = \mathbf{9.76} \cong \mathbf{10\ years}$$

Equation 33: The lifetime of a car

A compilation of all parameters necessary for Equation 30 is presented in Table 25

Parameter	2007	2008	2009	2010
IP_{ICE}	1.53 [million ISK]	1.93 [million ISK]	3.32 [million ISK]	3.00 [million ISK]
IP_{EV}	2.49 [million ISK]	3.15 [million ISK]	5.41 [million ISK]	4.89 [million ISK]
IGP	33.4 [ISK/liter]	56 [ISK/liter]	53 [ISK/liter]	67.9 [ISK/liter]
FC_{ICE}	0.08 [liter/km]	0.08 [liter/km]	0.08 [liter/km]	0.08 [liter/km]
Lifetime T	20 years 10 years	20 years 10 years	20 years 10 years	20 years 10 years
Corresponding D to Lifetime	12,369 [km/year] 24,738 [km/year]	12,369 [km/year] 24,738 [km/year]	12,369 [km/year] 24,738 [km/year]	12,369 [km/year] 24,738 [km/year]

Table 25: Parameters for calculating the impact a single EV has on trade balance

Net impact of EV substitution

Putting the parameters of Table 25 into Equation 30 yields the hypothetical impact of an EV substitution for an imported ICE based car, assuming circumstances in a given year, that imported gasoline prices remain the same as on the first year of import for the EVs entire lifetime and for discounting at 6.36% and 12.72% respectively. Results on net trade balance impact of a single EV substitute can be seen in Table 26.

Year	Net impact on trade balance, T = 10 years, PV @ 6.36%
2007	-0.48 [million ISK]
2008	-0.42 [million ISK]
2009	-1.33 [million ISK]

Year	Net impact on trade balance, T = 20 years, PV @ 6.36%
2007	-0.59 [million ISK]
2008	-0.60 [million ISK]
2009	-1.51 [million ISK]

Year	Net impact on trade balance, T = 10 years, PV @ 12.72%
2007	-0.60 [million ISK]
2008	-0.61 [million ISK]
2009	-1.51 [million ISK]

Year	Net impact on trade balance, T = 20 years, PV @ 12.72%
2007	-0.72 [million ISK]
2008	-0.82 [million ISK]
2009	-1.72 [million ISK]

Table 26: Net impact made by a single EV on trade balance

Table 26 shows how higher discount rates and/or car lifetimes impact trade balance negatively, as the decrease in future gasoline imports due to a single EV substitution weighs much less in the present compared to the EVs initial import price (see Equation 7). What Table 26 effectively shows is how much lower the import price of an EV (P_{EV}) needs to be in order for it to have zero impact on trade balance. Rewriting Equation 30 to isolate the EV import price yields Equation 34 which shows this.

$$\mathrm{TBI} = 0 = (\mathrm{IP_{ICE}} - \mathrm{IP_{EV}}) + \mathrm{IGP} \times \mathrm{FC_{ICE}} \times \mathrm{D} \times \frac{\mathbf{1} - (\mathbf{1} + \boldsymbol{r})^{-\boldsymbol{T}}}{\mathbf{r}}$$

$$\rightarrow \mathrm{IP_{EV}} = \mathrm{IP_{ICE}} + \mathrm{IGP} \times \mathrm{FC_{ICE}} \times \mathrm{D} \times \frac{\mathbf{1} - (\mathbf{1} + \boldsymbol{r})^{-\boldsymbol{T}}}{\mathbf{r}}$$

Equation 34: EV import price necessary for no trade balance impact

The corresponding values of EV import prices for the years in Table 26 are therefore as shown in Table 27.

Year	P_{EV}, T = 10 years, PV @ 6.36%
2007	2.01 [million ISK]
2008	2.73 [million ISK]
2009	4.08 [million ISK]

Year	P_{EV}, T = 20 years, PV @ 6.36%
2007	1.90 [million ISK]
2008	2.55 [million ISK]
2009	3.90 [million ISK]

Year	P_{EV}, T = 10 years, PV @ 12.72%
2007	1.89 [million ISK]
2008	2.54 [million ISK]
2009	3.90 [million ISK]

Year	P_{EV}, T = 20 years, PV @ 12.72%
2007	1.77 [million ISK]
2008	2.33 [million ISK]
2009	3.69 [million ISK]

Table 27: Corresponding EV import prices that yield no trade balance impact

What is consequently of interest is to form an image of how the trade balance is affected if a fixed percentage of imported ICE based cars is substituted for imported EVs instead, as a purchased EV can be assumed to lower gasoline imports for its entire lifetime. The total car related imports of a given year have already been formulated in Equation 26, but should be augmented to account for the presence of EVs within the car fleet, as seen in Equation 35.

$$\mathrm{TI} = \underbrace{\sum_{N_{CARS}-N_{EV}} \overline{IP_{ICE}} + \sum_{N_{EV}} \overline{IP_{EV}}}_{\text{Imported cars}} + \underbrace{IGP \times \left(N_{GAS} \times \frac{F_{ICE}}{F_{INIT}}\right)}_{\text{Imported gasoline}} + \underbrace{M_{ICE}}_{\text{Imported maintenance}}$$

Equation 35: Annual imported car related goods with EV implementation

In Equation 35 the total imports of every year remain essentially split into the same three import cost terms as before; purchased cars, gasoline imports and maintenance cost. Now purchased cars are split into two terms, one for EVs and another for ICE based cars. The amount of imported gasoline for a given year is based on the amount of gasoline imported at the originating year (N_{GAS}) factored by how much the number of ICE based cars (F_{ICE}) has grown since that very same year (F_{INIT}). As previously stated, maintenance cost is assumed to remain the same for any EV implementation.

The amount of EVs present in the car fleet (F_{EV}) in Equation 35 is initially zero, but accumulates over the years as new EVs (N_{EV}) are imported. This is demonstrated in Equation 36. The number of new EVs is a fraction of the number of ICE based cars that otherwise would have been imported (N_{CARS}), dependent upon a so-called implementation rate (IR) of EVs, assumed here to stay fixed in calculations for a particular scenario, but varying between scenarios. The derivation of N_{EV} is shown in Equation 37.

$$(F_{EV})_{now} = (F_{EV})_{last} + \sum_{N_{EV}} \overline{IP_{EV}}$$
$$(F_{ICE})_{now} = (F_{ICE})_{last} + \sum_{N_{CARS}-N_{EV}} \overline{IP_{ICE}}$$

Equation 36: Accumulation of EVs and ICE based cars within a car fleet

$$N_{EV} = IR \times N_{CARS}$$

Equation 37: Number of new EVs and the EV implementation rate

Assumptions need to be made to address certain issues found within Equation 35. It is for example assumed that every imported vehicle is a passenger car, bought and put to use immediately to replace an existing ICE based car. It is assumed that the ICE based cars already present in the passenger car fleet are written off at 90% the rate of annually imported cars, maintaining and allowing for growth within the passenger fleet by 10% of the number of cars imported annually in each scenario.

EVs are not written off, as each scenario is assumed to begin with no EVs present in the car fleet and end before the average lifetime of EVs (with high annual driving distances) has passed. The Icelandic passenger car fleet (F_{INIT}) is assumed to consist of 205,338 cars [65] at the beginning of each scenario.

Imported gasoline prices (IGP) are assumed to remain fixed from the year they originate until the defined car lifetime (10 years, see Equation 33) has passed. The given implementation rate (IR) of a scenario stays fixed for its entirety.

The resulting figures allow comparison for trade balance projections assuming that circumstances of a given year hold for ten years into the future. Each scenario is unique by a combination of prevailing circumstances from one of the three originating years, as detailed in Table 22, and four different EV implementation rates. The figures show the impact of substituting ICE based car imports with EVs over a 10 year period (T_{high}) assuming identical import characteristics every year as the originating year. It is assumed that every imported car is purchased and put to use that very same year. At the end of the estimated 10 year life cycle of an EV, it will have contributed slightly to a national trade balance deficit as per Table 26.

Results

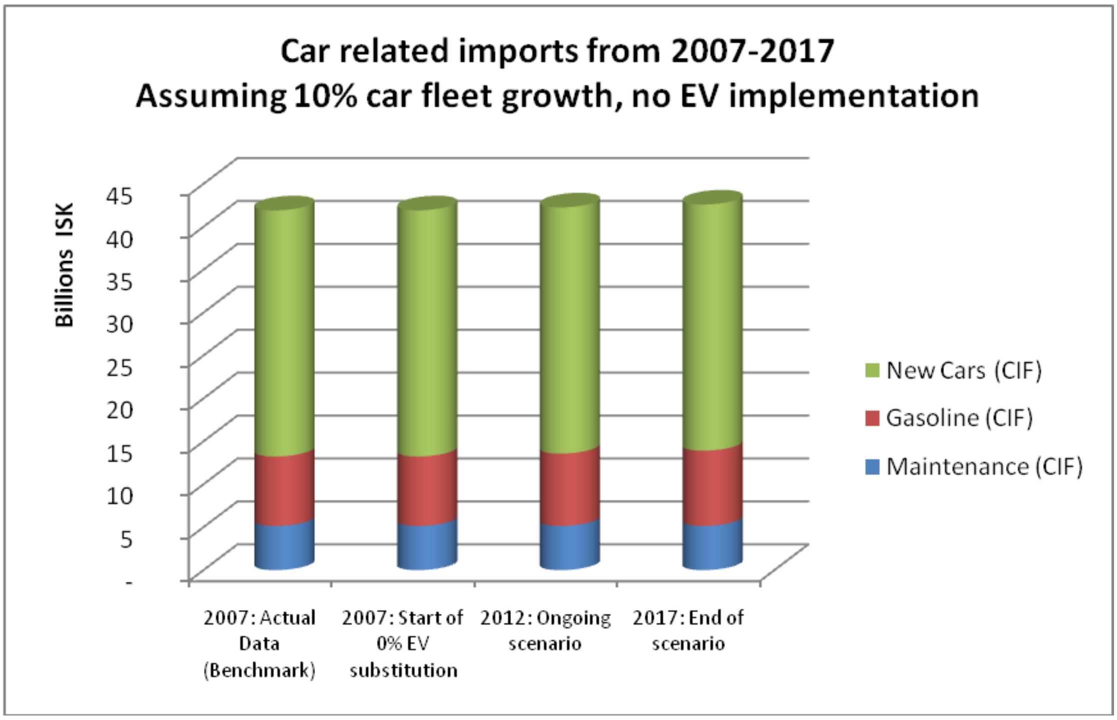

Figure 35: Car related imports based on 2007 data with no EV implementation

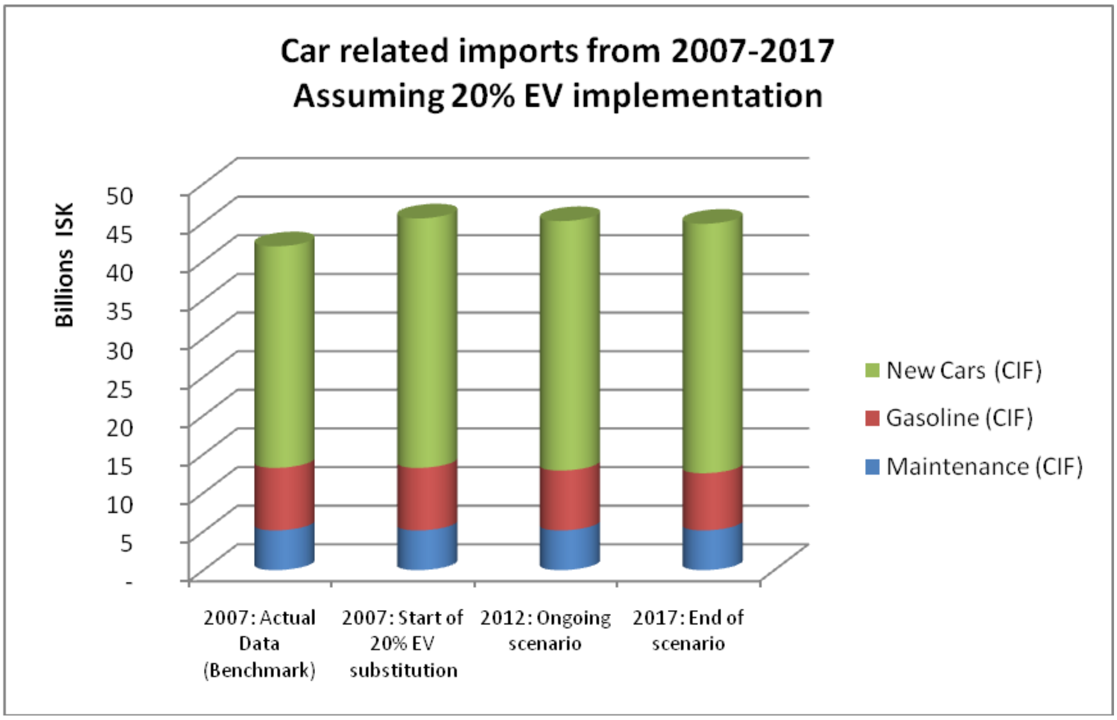

Figure 36: Car related imports based on 2007 data with 20% of imported cars as Evs

Figure 35 and Figure 36 show projected trade balance terms ten years into the future, starting from and based on import circumstances in 2007. The scenarios both assume that the passenger car fleet grows by 10% of annually imported cars, Figure 35 does without any EV substitution at all while Figure 36 assumes 20% of annually imported cars as EVs.

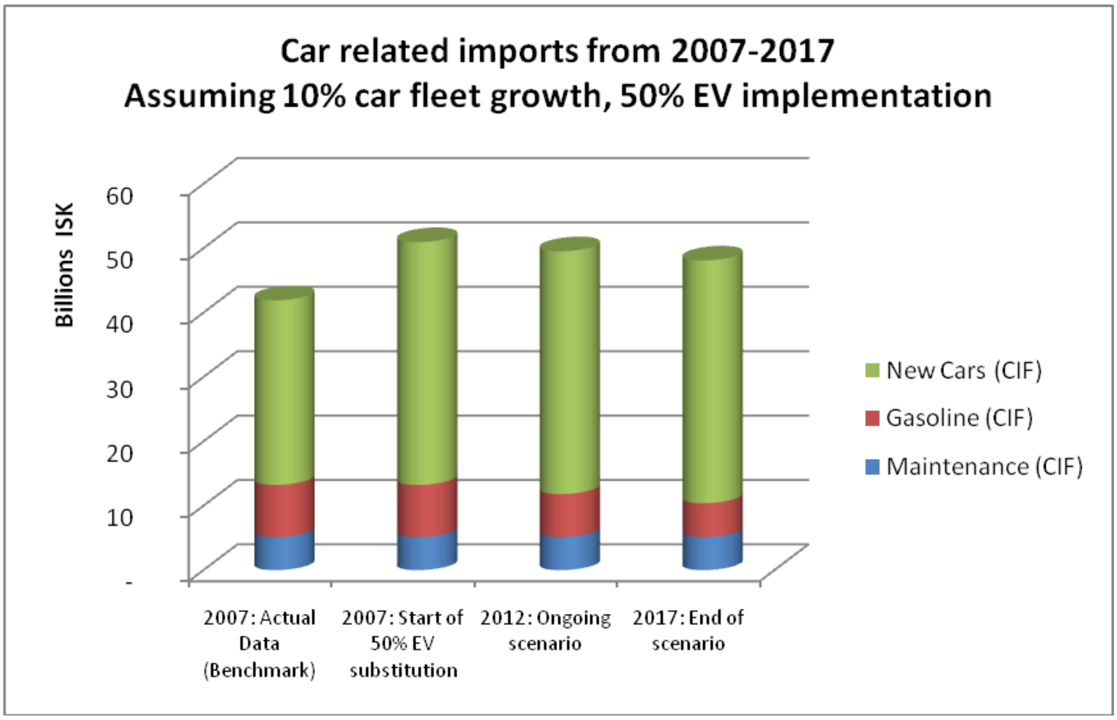

Figure 37: Car related imports based on 2007 data with 50% of imported cars as EVs

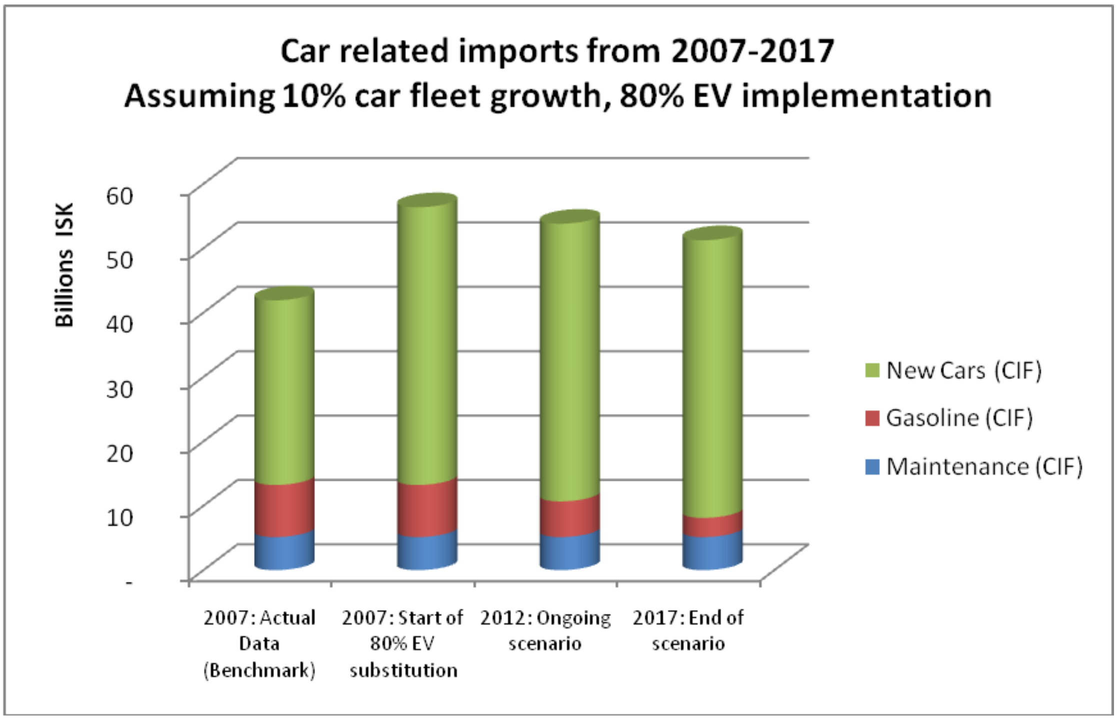

Figure 38: Car related imports based on 2007 data with 80% of imported cars as EVs

Figure 37 and Figure 38 show projected trade balance terms ten years into the future, starting from and based on import circumstances in 2007. The scenarios both assume that the passenger car fleet grows by 10% of annually imported cars, Figure 37 assumes 50% of annually imported cars as EVs while Figure 38 assumes 80% as EVs.

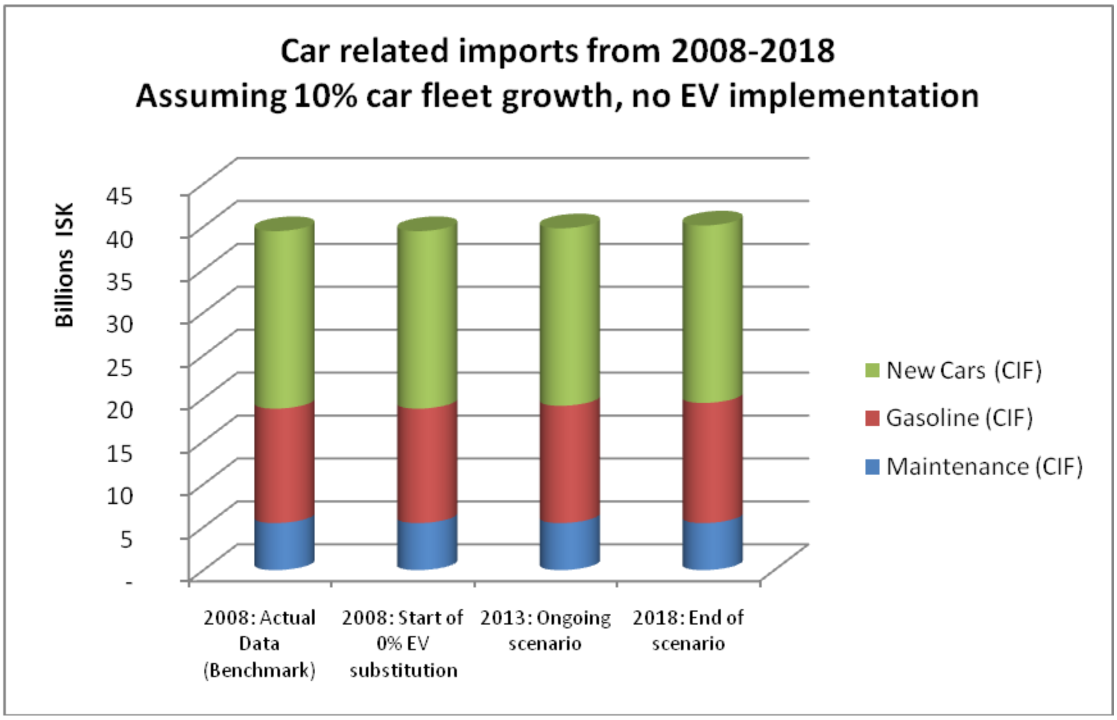

Figure 39: Car related imports based on 2008 data with no EV implementation

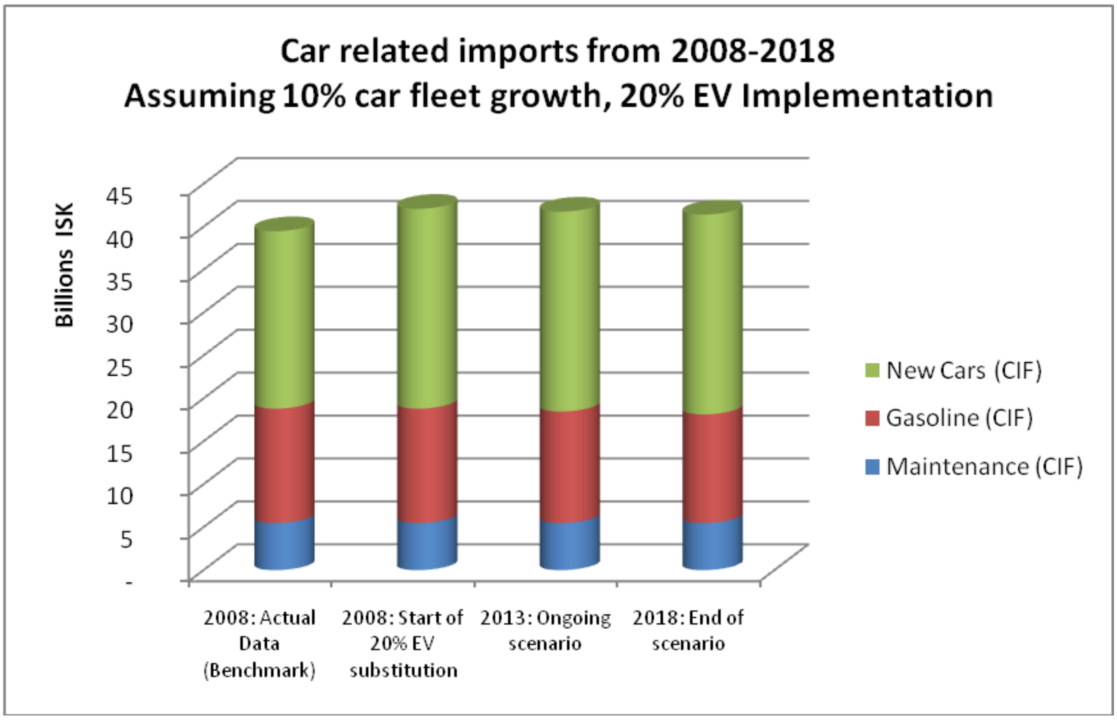

Figure 40: Car related imports based on 2008 data with 20% of imported cars as EVs

Figure 39 and Figure 40 show projected trade balance terms ten years into the future, starting from and based on import circumstances in 2008. The scenarios both assume that the passenger car fleet grows by 10% of annually imported cars, Figure 39 does without any EV substitution at all while Figure 40 assumes 20% of annually imported cars as EVs.

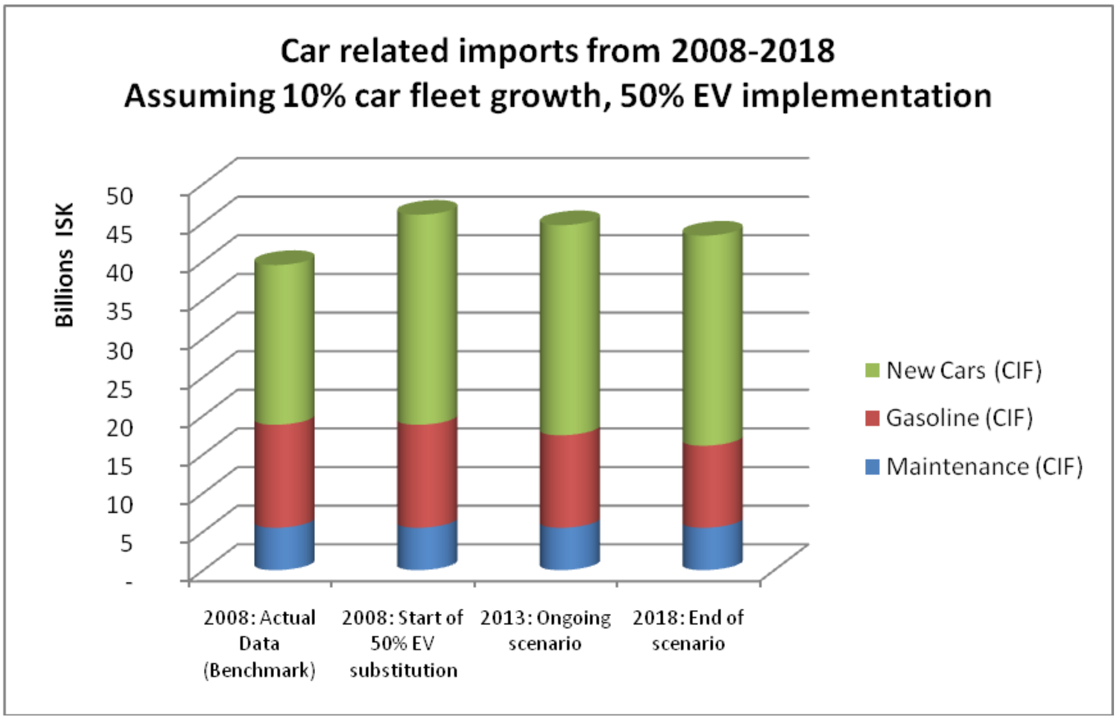

Figure 41: Car related imports based on 2008 data with 50% of imported cars as EVs

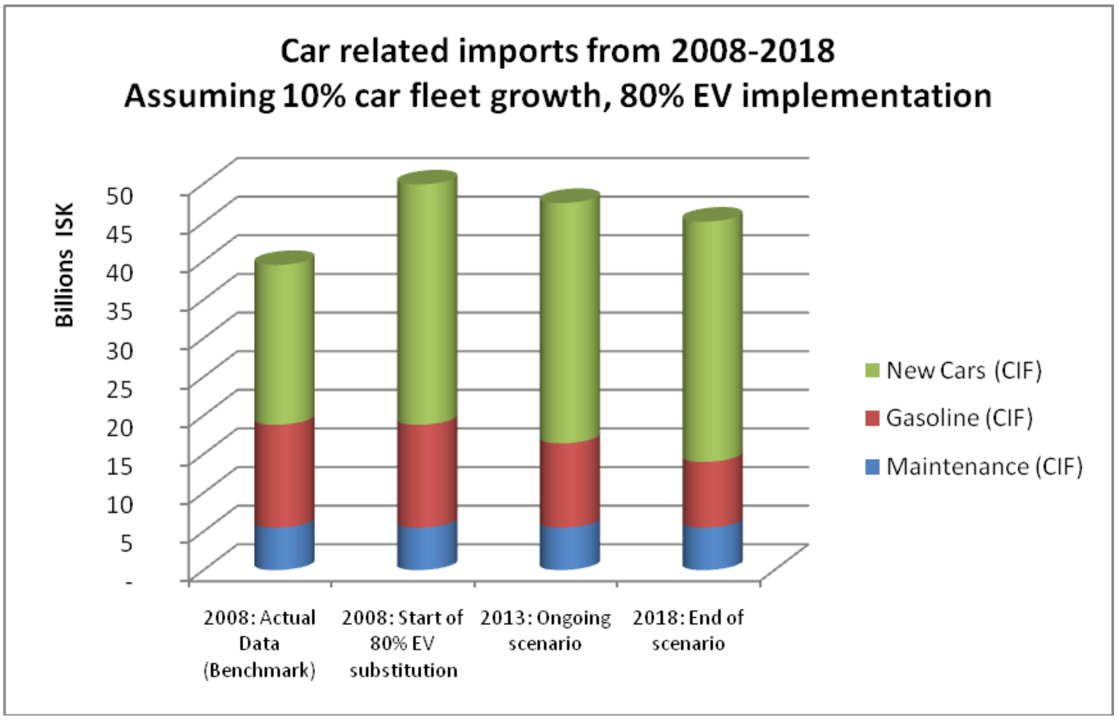

Figure 42: Car related imports based on 2008 data with 80% of imported cars as EVs

Figure 41 and Figure 42 show projected trade balance terms ten years into the future, starting from and based on import circumstances in 2008. The scenarios both assume that the passenger car fleet grows by 10% of annually imported cars, Figure 41 assumes 50% of annually imported cars as EVs while Figure 42 assumes 80% as EVs.

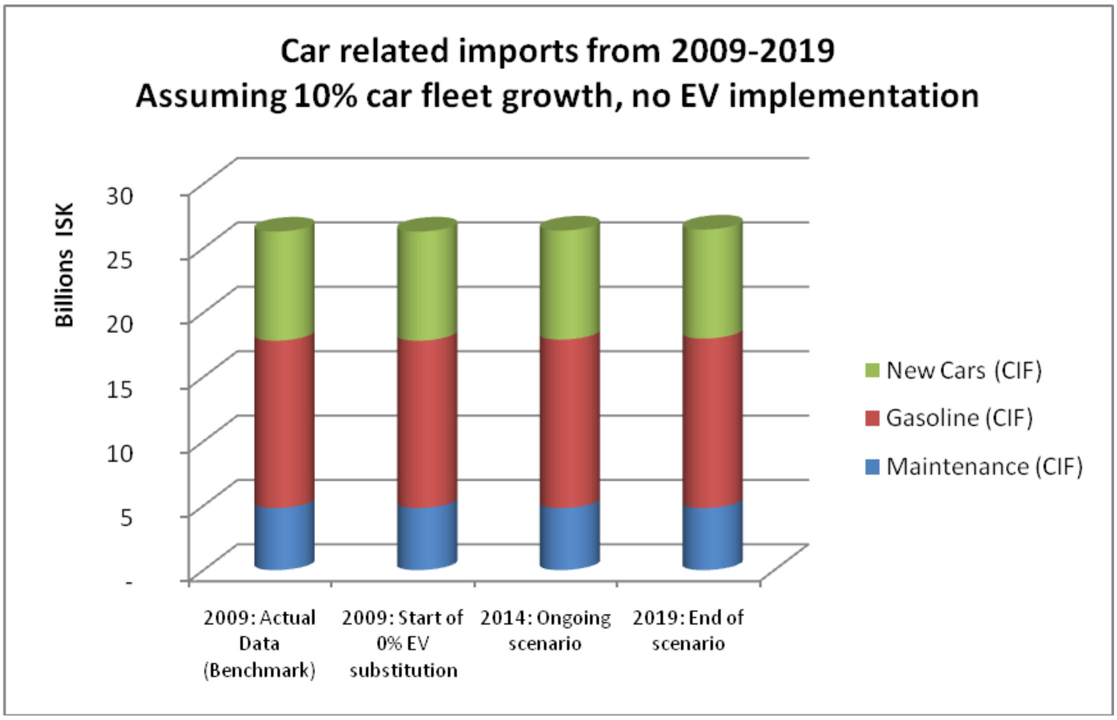

Figure 43: Car related imports based on 2009 data with no EV implementation

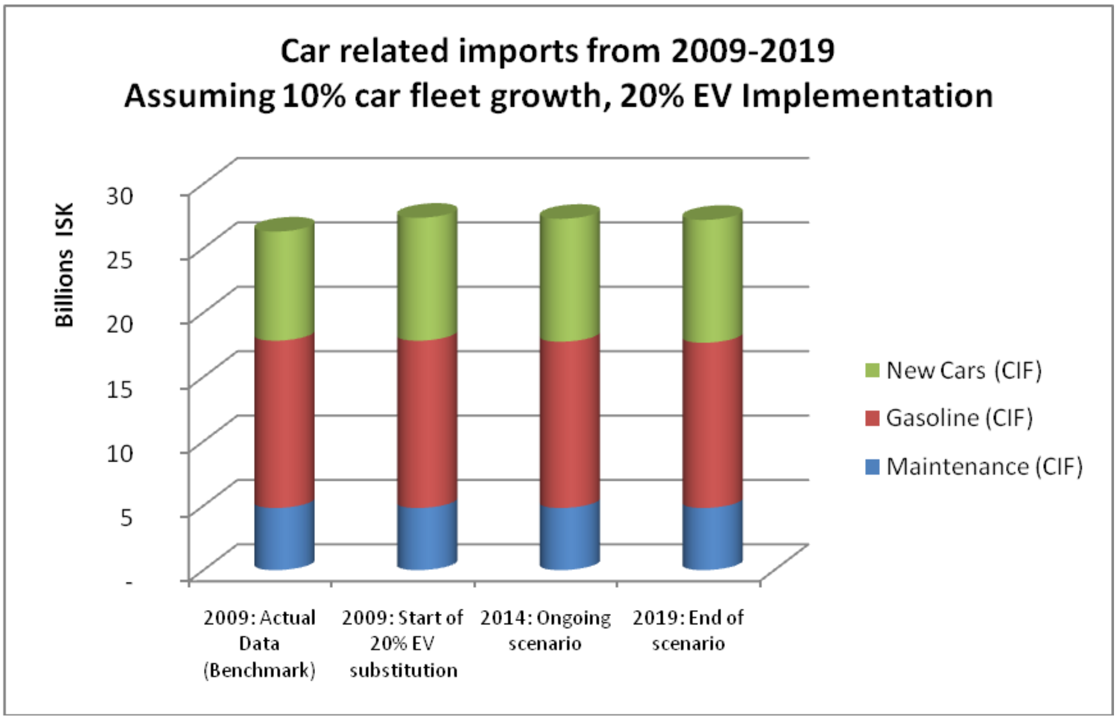

Figure 44: Car related imports based on 2009 data with 20% of imported cars as EVs

Figure 43 and Figure 44 show projected trade balance terms ten years into the future, starting from and based on import circumstances in 2009. The scenarios both assume that the passenger car fleet grows by 10% of annually imported cars, Figure 43 does without any EV substitution at all while Figure 44 assumes 20% of annually imported cars as EVs.

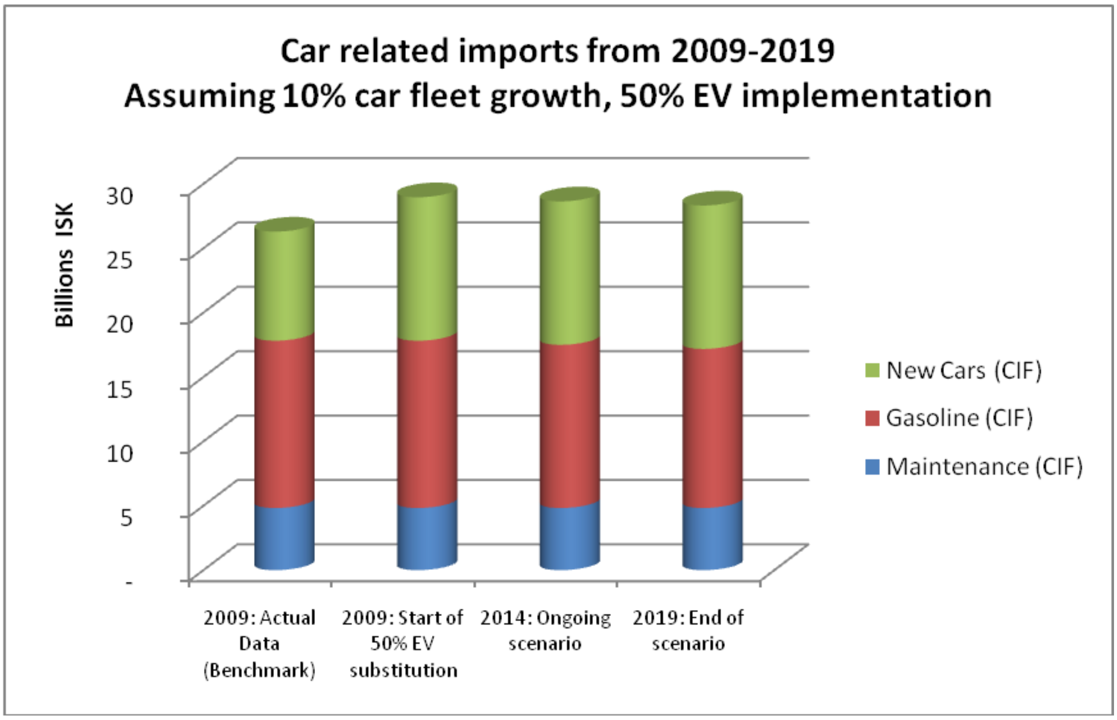

Figure 45: Car related imports based on 2009 data with 50% of imported cars as EVs

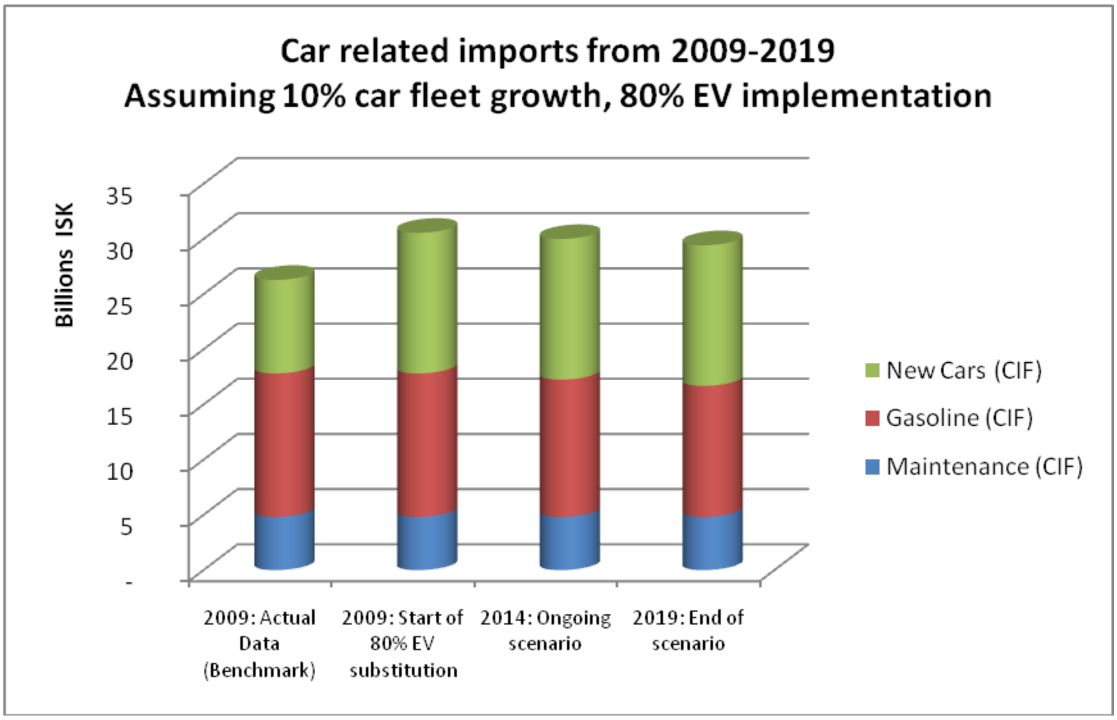

Figure 46: Car related imports based on 2009 data with 80% of imported cars as EVs

Figure 43 and Figure 44 show projected trade balance terms ten years into the future, starting from and based on import circumstances in 2009. The scenarios both assume that the passenger car fleet grows by 10% of annually imported cars, Figure 43 assumes 50% of annually imported cars as EVs while Figure 44 assumes 80% as EVs.

Discussion

In 2008 signs of an economic decline culminated in the fall of all three major Icelandic investment banks in October [66]. For the following months and years the ISK was significantly devalued and import-export ratios were substantially affected [36].

Representing car related trade balance during times of economic boom in Iceland are Figure 35, Figure 36, Figure 37 and Figure 38. The economic boom is strongly hinted at by the massive number of imported cars (18,876 cars, with a passenger car fleet of 205,338) and relatively low imported gasoline prices, both evident from the dominant car import cylinder and marginal gasoline imports seen in all figures. So high is the number of annually imported cars that by the end of scenarios with relatively high EV substitution gasoline imports have essentially been slashed in half while the monetary value of car imports has skyrocketed, as indicated by Figure 37 and Figure 38.

In 2008 car imports receded by 43% (down to 10,703 cars) while imported gasoline cost increased by almost 65%. The former perhaps a sign of sobering thought as bankruptcy loomed, and the latter possibly attributable to both world oil price volatility and devaluing of the ISK. Although by the end of scenarios in Figure 39, Figure 40, Figure 41 and Figure 42 none have contributed to as high a trade balance deficit as the figures from 2007, neither is EV implementation as robust as in 2007.

Car imports have all but stopped in 2009 (2,550 cars) when compared to numbers from both 2007 and 2008. It is the only year in which car imports are exceeded by imported gasoline, as evident by Figure 43, Figure 44, Figure 45 and Figure 46, and suggests a radical change of behavior for the average Icelandic consumer. With so few annually imported cars, the amount of imported gasoline is barely affected at all.

What all the scenarios share is the fact that any lingering effect of decreased oil demand by EVs cannot overcome the vast price difference (63%, see Table 23) between EV and ICE based car import prices. EV implementation can thus never contribute to a trade balance surplus under the current assumptions unless EV import prices get lowered over time.

Imported maintenance costs are also an assumption, as whether or not maintenance costs should be considered lower for EVs instead of equal to that of ICE based cars remains to be seen, yet could tip the scales of trade balance in either direction

Government Revenue

Contemplating what stake the government has in the currently ICE based dominated passenger car fleet environment by way of direct or indirect tax income brings back aspects of previous chapters.

Standard Excise Duties, VAT

Among underlying terms of gasoline rates introduced in Equation 13 and Table 4 is a special excise duty on imported gasoline, a gasoline fee and the value-added tax (VAT) from gasoline sales. The special excise duty is 22.94 ISK per liter of gasoline [67], the gasoline fee 37.07 ISK per liter of gasoline [68] and the VAT 25.5% of gasoline rates [69]. All provide a significant if not vital source of revenue for the government.

For every ICE based car the government levies a car excise duty upon being imported as well as a value-added tax (VAT) from retail sales, both introduced in Equation 10. The excise duty is 30% for cars with an ICE based engine of less than 2000cc and 45% for more than 2000cc. Excise duties are waived for EVs [33]. The VAT incurred at time of purchase is 25.5% Since the initial purchase makes up the biggest single cost term of owning a car, both of these government income terms are substantial [33, 69], as seen in Table 28.

Annual Driving Distance [km/year]	Car Excise Duty of NPV at 6.36% [%]	Car Retail VAT of NPV at 6.36% [%]
12,369	11.5%	11.0%
24,738	9.0%	9.6%

Table 28: Excise Duty and Car Retail VAT percentage of total cost

Standard Carbon Emissions fee

Another underlying term of gasoline rates, carbon emissions are levied as an environmental and natural resource tax. The fee is 2.60 ISK per liter of gasoline [70].

Standard Car tax

Twice a year an Icelandic car owner must pay a fee based upon the car's curb weight. For cars weighing up to a metric ton, a fee of 9.30 ISK per kg is levied. Cars weighing up to 3 metric tons are levied a fee of 12.55 ISK per kg of curb weight and the heaviest of cars pay 3,100 ISK per metric ton thereafter. The car tax may neither be lower than 4,650 ISK nor higher than 56,074 ISK for any given car during a single payment term [71]. Since EVs and ICE based cars in Table 12 and Table 13 are deemed comparable largely due to similar structure, dimensions and weight, the car tax is assumed to be the same for EVs and ICE based cars.

The weight of the average car is assumed to be 1,146 kg, based on cars in budget and mainstream car categories of Table 12. Taking into account the aforementioned rates the average car owner pays a mandatory fee of 14,382 ISK twice a year, resulting in average overall government revenue of 28,773 ISK per year per car from car taxes, which is used in calculations.

Other Standard Fees

Transportation Equalization Fees are levied as means to ensure equal prices in rural areas that require higher transportation fees than supplying urban areas. The fee is marginal, only 0.57 per liter of gasoline, but nonetheless accounted for [72].

Some other examples include VAT from car insurance and maintenance costs, both of which are assumed roughly interchangable between any two cars regardless of engine type. These are assumed to be the same for EVs and ICE based cars.

Taking together all the previously mentioned ICE based cost terms produces Table 29

Income term	Government revenue from an ICE based car
Special excise duty	22.94 [ISK/liter]
Gasoline fee	37.07 [ISK/liter]
Carbon emission fee	2.6 [ISK/liter]
Transportation eq. fee	0.57 [ISK/liter]
Gasoline VAT, assuming 204 [ISK/liter] as in 2009, Table 3	52.02 [ISK/liter]
Car excise duty, assuming average import prices from 2009, Table 22: IP_{ICE} = 3.32 [million ISK], 30% duty	996,600 [ISK]
Car retail VAT	1,100,580 [ISK]
Car tax, assuming mean weight of 1,146 kg from Budget and Mainstream cars in Table 12 and 2 payments a year	28,773 [ISK/year]

Table 29: Government revenue from a single ICE based car

The government income terms of Table 29 apply for a passenger fleet composed almost entirely of ICE based cars. The key players and income terms of such a passenger car fleet is represented in Figure 47.

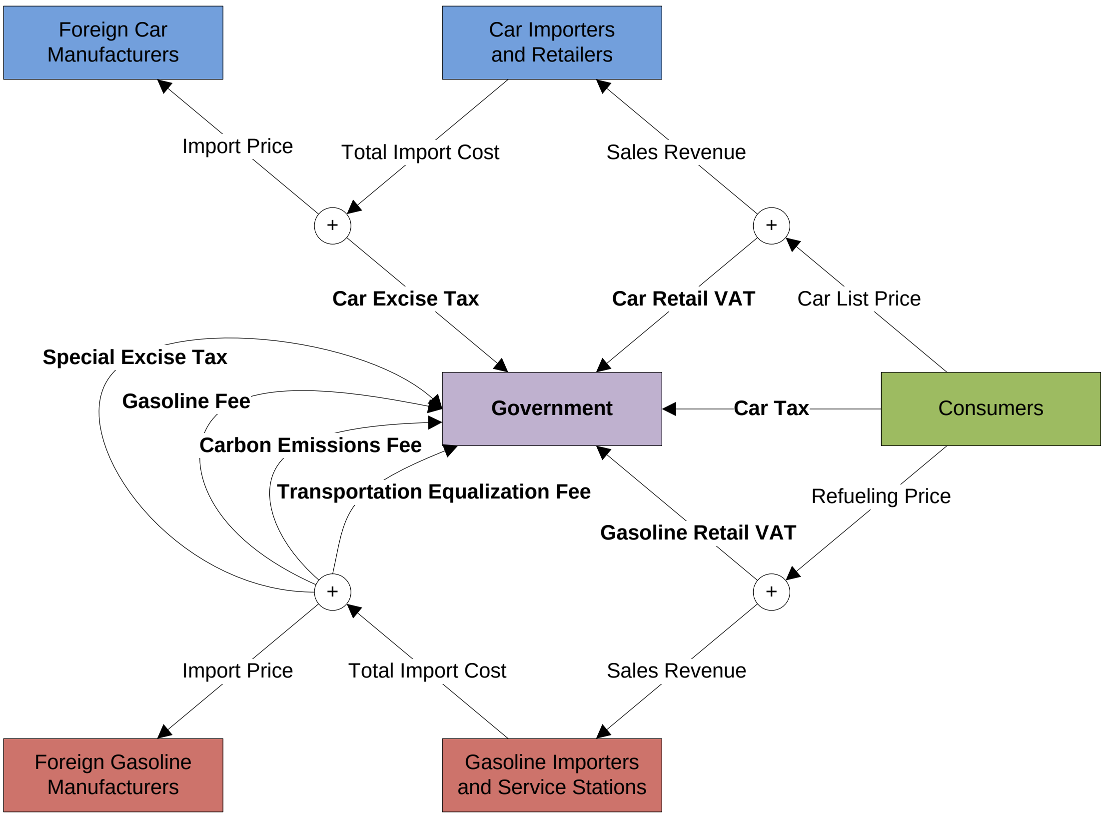

Figure 47: Contributing income terms for an all-ICE based passenger car fleet.

Figure 47 describes government revenue terms and the respective key players behind them assuming a dominant ICE based car fleet. Should the ratio of EVs within a nation's car fleet start to rise however, it is of interest to examine how the government's income would be affected.

It can be assumed that for every EV imported into the car fleet instead of an ICE based one, demand for gasoline will lower slightly, like in trade balance scenarios. However, as demand

(and therefore sales) for imported gasoline lowers, so does the government's gasoline-related revenue, whether it be in the form of any the underlying rates for gasoline per liter or VAT from sales. Therefore all government revenue from the underlying terms of gasoline rates is lost, since most EVs can recharge by plugging into a common electrical socket.[39, 43, 73]

EV Emissions Trading

The amount in tons of CO_2 that an ICE based car releases in a single year directly translates to spent units of Certified Emission Reductions (CERs) credits, which can be of significant value to countries exceeding their emission targets as per Annex B of the Kyoto Protocol [15][74].

For every gallon (3.79 liters) of gasoline that is burned by an internal combustion engine 20 pounds (9.07 kilograms) of carbon dioxide are formed. This translates to roughly 2.4 kilograms of carbon dioxide formed for every liter of gasoline consumed by an ICE based car. Assuming a higher than average driving distance and a fuel consumption of 24,738 km per year and 0.085 liters per km, respectively, the resulting average carbon emissions of a single ICE based car are roughly 5 tons per year or 5 CERs.

As all other commodities, CERs are subject to economic shocks that will ultimately affect their price. According to price history presented by J.P. Morgan Environmental Markets, the rate of CER units was 11.50 EUR on June 15th 2009 [75] or $16.16 USD [76] per ton of emitted CO_2 or CER.

The quoted rate (corresponding to 2014 ISK per CER with the proper exchange rate of Table 2) and amount emitted by the average car when multiplied together result in an average cost of 10,161 ISK per year that is used in calculations. It is assumed that accumulated CERs resulting from the absence of an ICE based car within the car fleet are automatically traded at the quoted rate and accounted for as pure government revenue.

EV Excise Duties, VAT

Imported vehicles incur either a 30% or 45% excise duty subject to having less or more ICE based engine capacity than 2000 cc respectively. EVs and other environmentally friendly automobiles are currently exempt from excise duty. Government revenue on car excise duty is therefore lost if an imported ICE based car is substituted for an EV [33, 39, 43, 73].

The price difference between the categorized cars of Table 15 is substantial, even without the excise duty for EVs. Judging from the cars in Table 15, VAT levied on the purchase of an EV is higher than that of an ICE based car, contributing to a hypothetical increase of government revenue.

EV Car Tax

The car tax is solely dependent upon curb weight of a car and is unaffected by engine type. As previously stated the cars in table Table 12 and Table 13 are deemed comparable based on structure, dimensions and weight, and so it is assumed that any EV substitute comparable to an ICE based car is not subject to a drastic changes regarding car taxes

EV Energy Sales

Finally, with increased electrical energy sales due to EV implementation the government is expected to sell more energy at premium prices to distributors of household electricity, and receive VAT from energy sales on top. According to a major Icelandic power company electrical energy rates are broken up into four main terms before VAT is applied; a distribution fee of 2.52 ISK per kWh, a carrier fee of 1.27 ISK per kWh and a suggested sales assessment of 3.94 ISK per kWh, followed by an energy tax of 0.12 ISK per kWh. With an added VAT the total energy price quoted is 9.85 ISK/kWh, the same amount as the quoted price of February 1st 2010 from Table 5. The Electricity VAT in ISK per kWh is therefore assumed to be 2.002 ISK per kWh.[77]

Furthermore, the distribution and carrier fees are non-negotiable while sales assessment is set by energy distributors. The distribution and carrier fee are considered to be pure government revenue terms for Electricity purchases in ISK per kWh, along with the energy tax of 0.12 ISK per kWh, netting a total of 3.91 ISK per kWh [77].

Accounting for the new income terms, Table 30 shows all government income terms for either a single ICE based car or an EV.

Income term	Government revenue from an ICE based car	Government revenue from an EV
Special excise duty	22.94 [ISK/liter]	-
Gasoline fee	37.07 [ISK/liter]	-
Carbon emission fee	2.6 [ISK/liter]	-
CERs traded	-	10,161 [ISK/year]
Transportation eq. fee	0.57 [ISK/liter]	-
Gasoline VAT, assuming 204 [ISK/liter] as in 2009, Table 3	52.02 [ISK/liter]	-
Car excise duty, assuming average import prices from 2009, Table 22: IP_{ICE} = 3.32 [million ISK], 30% duty	996,600 [ISK]	-
Car retail VAT, assuming IP_{EV} = 1.65 x IP_{ICE} from Table 23	1,100,580 [ISK]	1,396,890 [ISK]
Car tax, assuming mean weight of 1,146 kg from Budget and Mainstream cars in Table 12 and 2 payments a year	28,773 [ISK/year]	28,773 [ISK/year]
Electricity purchases	-	3.91 [ISK/kWh]-
Electricity VAT, assuming RR_{EV} = 9.85 [ISK/kWh] from Table 5	-	2.00 [ISK/kWh]-

Table 30: Government revenue from a single ICE based car and EV

Taking into account the total government revenue terms Table 30 requires that Figure 47 be augmented. Figure 48 adds a new key player; the Electrical Distributor, along with its appropriate government income terms, and thus now represents government income terms from a mixed ICE based and EV passenger car fleet.

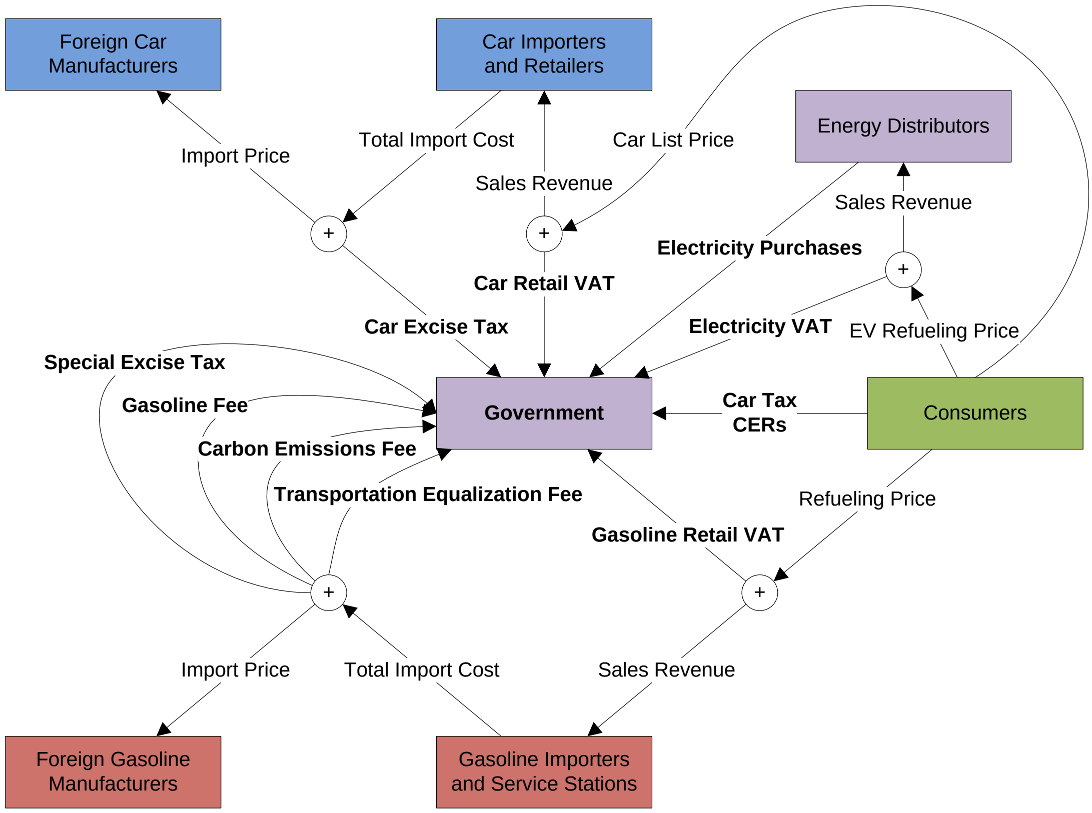

Figure 48: Contributing income terms in a mixed ICE based and EV passenger car fleet.

To assess the net effect a single EV substitute for an ICE based car has on a nation's tax income requires the use of average fuel consumption for both ICE based and EV cars, originally presented in Table 6. Multiplying the average fuel consumptions of either engine type with the average distance driven by a car during its lifetime (D_{max}), obtained from Equation 33, yields the total amount of energy an EV or ICE based car spends in its 10 year lifetime, as seen in Equation 38.

$$\overline{\mathbf{FC}_{\mathbf{EV}}} \times \mathbf{D}_{\mathbf{max}} = \mathbf{36,452\ [kWh]}$$

$$\overline{\mathbf{FC}_{\mathbf{ICE}}} \times \mathbf{D}_{\mathbf{max}} = \mathbf{20,519\ [liters]}$$

Equation 38: Total energy required by an EVs and an ICE based car

Results

It is now a simple matter to convert both the electricity purchases and underlying gasoline rates from ISK per energy unit to total average government revenue from either ICE based cars or EVs. The resulting total revenue for either engine type is presented in Table 31.

Income term	Government revenue for an ICE based car	Government revenue for an EV
Special excise duty	47,071 [ISK/year]	-
Gasoline fee	76,065 [ISK/year]	-
Carbon emission fee	5,335 [ISK/year]	-
CERs traded	-	10,161 [ISK/year]
Transportation equalization fee	1170 [ISK/year]	-
Gasoline VAT	105,622 [ISK/year]	-
Car excise duty	841,500 [ISK]	-
Car retail VAT	1,093,950 [ISK]	1,388,480 [ISK]
Electricity purchases [ISK per year]	-	7303 [ISK/year]
Electricity VAT [ISK per year]	-	3739 [ISK/year]
Car tax	28,773 [ISK/year]	28,773 [ISK/year]
NPV @ 6.36% for 10 years	**3,846,060 [ISK]**	**1,750,110 [ISK]**
NPV @ 12.72% for 10 years	**3,384,350 [ISK]**	**1,662,720 [ISK]**

Table 31: Government revenue during a single car's lifetime

According to Table 31, government revenue decreases by 2.10 and 1.72 million ISK for each EV that gets imported instead of a comparable ICE based car, present valued at 6.36% and 12.72% respectively. Income from car related taxes and fees are a crucial source of government revenue. A net loss in tax income forces the government to look elsewhere for its dues; either by trimming down existing services or by levying new taxes.

Energy Infrastructure

It is not within the scope of this paper to delve deeply into projected electricity demand in Iceland but it is of interest to get some estimation as to how the added load that follows gradual EV implementation can affect the existing energy infrastructure.

Like population, energy demand is exponential in growth. However, in order to estimate an upper value for the proportion of electricity demand due to EV implementation a linear growth is assumed for both domestic and industrial demand. As implementation of EVs progresses so will the electricity demand gradually rise. According to Statistics Iceland, the total energy demand of 2007 and 2008 was as seen in Table 32 [24, 78].

Year	Consumption by Homes [TWh]	Consumption by Heavy Industry [TWh]
2007	0.83	8.8
2008	0.86	13.1

Table 32: Electricity demand in 2007 and 2008

Maintaining the assumption that EVs are recharged in residential or commercial areas using common electrical outlets and that the average annual driving distances in Iceland are 12.366 km per year ($D_{average}$), with an average fuel consumption of EVs is 0.151 kWh per km, it can be hypothesized that a single EV would on average require 1868 kWh of electricity every year, as seen in Equation 39.

$$\overline{\mathbf{FC_{EV}}} \times \mathbf{D_{average}} = \mathbf{1868\ [kWh/year]}$$

Equation 39: Average net annual electricity requirements of an EV

Added Load

Coupling the average number of annual EV energy requirements with car import figures from Table 22 under Trade Balance an upper bound on increase in electricity demand can be estimated, as seen in Table 35.

Year	Imported Cars	20% as EVs [GWh/year]	50% as EVs [GWh/year]	80% as EVs [GWh/year]	100% as EVs [GWh/year]
2007	18,876	7.05	17.63	28.21	35.26
2008	10,703	4.00	10.00	16.00	20.00
2009	2,550	0.95	2.38	3.81	4.76

Table 33: Hypothetical increases in net energy use based on import scenarios

According to Table 33, the single most energy demanding scenario possible related to EVs and based on car imports in the year 2007 and 2009 would be an accumulated increase of roughly 35 GWh per year without accounting for loss in primary energy. Figures from the National Energy Authority suggest a loss of 0.356 TWh from a total of a total of 16.838 TWh harnessed in the year 2009, or roughly 2.11%. Scaling the figures of Table 33 yields the total increase in demand for the car import scenarios, as seen in Table 34.

Year	Imported Cars	20% as EVs [GWh/year]	50% as EVs [GWh/year]	80% as EVs [GWh/year]	100% as EVs [GWh/year]
2007	18,876	7.20	18.00	28.81	36.00
2008	10,703	4.08	10.21	16.34	20.42
2009	2,550	0.97	2.43	3.89	4.86

Table 34: Hypothetical increases in electricity demand based on import scenarios

Electricity demand in Iceland may be classified into common use and heavy industry. Table Table 35 shows figures from the National Energy Authority that indicates changes in electricity demand between the years 2008 and 2009 [79].

Electricity Usage	Year 2008 [GWh/year]	Year 2009 [GWh/year]	Weight [%]	Net change [GWh/year]
Common demand	3,231	3,163	19.7%	-68
Heavy industry	12,440	12,925	80.3%	485
Total	**15,671**	**16,088**	**100%**	**417**

Table 35: Energy demand in Iceland for 2008 and 2009

According to Table 34 and Table 35, even the most extreme implementation scenario (all 18,876 cars of 2007 as EVs) would contribute less than 8.7% of net increases from 2008 to 2009 or a gross change of 0.22%. A more modest scenario, such as 50% of imported cars in 2009 as EVs, would barely be felt at less than 0.56% of overall annual increases.

An imported EVs energy demand lingers for its entire lifetime so further analysis is of interest. As so often before, an average EV lifetime of 10 years is assumed and the most extreme implementation scenario assumed (100% of 2007's imported car numbers). While not based on actual projected data, as previously stated Figure 49 puts into perspective how relatively little the accumulated added load due to EV implementation is in 10 years time (less than 1.8% of 2019) and in the present (less than 0.3% that of 2009), having assumed a linear growth of common and heavy industry demand and the most extreme importing circumstances.

Results

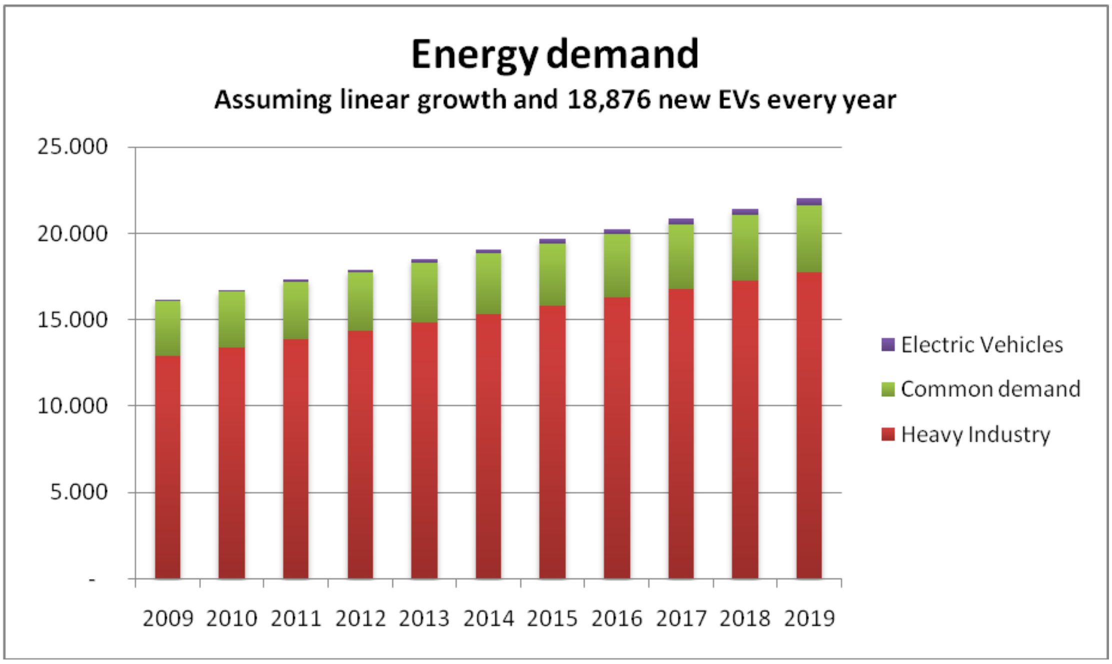

Figure 49: Hypothetical energy demand including EVs 10 years into the future

In the scenario of Figure 49 it is assumed that 18,876 EVs are imported and operated every year for 10 years, meaning a total of 188,760 EVs (or 360 GWh) present in 2019. In view of Figure 49, which shows the portion of EVs as added load to already substantial common demand and heavy industry, the added load does not appear significant enough to require specific planning and compensation in addition to that of regular projections.

Conclusion

In this project a total of four different consequences of EV implementation have been inspected; one from the view of a single consumer and three related to the government's standpoint.

Consumer interests

From results on the view of a single consumer it is concluded that there are two defining factors that judge at what point in time an EV begins to deliver on its much heralded feature of economic refueling costs; one being (unsurprisingly) the retail price of the EV itself, the other how much the prospective purchaser expects to drive it annually.

It has been shown that the closer the initial price difference is between an EV and a similarly featured ICE based car, the sooner a consumer can make up for said price difference and experience truly lower refueling with an EV, provided that the EV gets driven around. Import prices of EVs are expected to lower as manufacturer mass production gains footing yet there remain the question of availability and prices of raw materials necessary for EV production, such as Lithium. In spite of favorable pricing circumstances presented in this article such as no excise duty levied upon EVs, the initial price difference between an EV and a similarly featured ICE based car is found to be much too high to be a worthy purchase for an average consumer. Drivers with higher than average annual driving distances such as 24,738 km per year make up for the initial price difference much sooner than the average consumer or as low as under 3 years.

Results based on Equation 3 show how important it is not to neglect the resale value of an investment at any given time. Given that the vehicle can be sold at a depreciated value after the initial purchase, the net cost of owning and operating an EV is roughly the same as that of an ICE based car for an average driver due to a higher resale value. Drivers with higher annual driving distances than the average person in most cases experience a small yet widening margin of savings in net cost for EVs than that of ICE based cars.

Based on those results it is concluded that consumers with annual driving distances higher than or equal to that of the average consumer stand to benefit from purchasing EVs.

Trade Balance

Results on the effect both a single EV and numerous EV substitutions have on trade balance indicate that EV implementation will contribute to a significant trade balance deficit. The negative contribution stems entirely so to speak from much higher import prices of EVs than ICE based cars, a negative contribution so significant that its impact at the year of import weighs more than the decrease in required gasoline imports in the span of several years.

The results of trade balance scenarios for the year 2008 are noteworthy as they have the least negative impact on overall trade balance when compared with the respective scenario's starting year. This is in agreement with the net impact on balance of Table 26, in which the necessary EV import price to maintain balance is the closest to the actual EV import price of all three years.

It is concluded that the contribution of EV implementation to trade balance will always be towards a deficit until such a point as when the import price of EVs is low enough to equal the subsequent decrease in gasoline and maintenance imports, as seen in Table 27.

Government Revenue

Results from Table 31 indicate that implementing a single EV translates to a net loss of millions ISK in government revenue. This is due to the increased electrical sales and taxes thereof not amounting to the loss of tax revenue from gasoline and ICE based car imports.

Circumstances in the case of EV and ICE based car revenue comparison are not strictly fair either, in that no excise duty is (currently) levied upon EVs and there are no EV counterparts for gasoline related taxes on ICE based cars. While a mixed use of fee and rebates by the government has the potential to influence EV implementation, the government cannot readily write off millions in revenue per car in the passenger car fleet. Revenue must therefore come in another form or from a different source to retain government income levels.

Energy Infrastructure

While results from Figure 49 indicate that some portion of increased energy demand in the span of several years can be visibly linked to EV implementation under the highest import and implementation rate, its effects are nevertheless marginal or little enough to factored within overall increased residential and/or heavy industry requirements. There is little reason for construction to begin immediately on new infrastructures to accommodate immediate EV implementation.

Improvements

Several assumptions were made which affect the car comparison.

Actual maintenance cost terms can possibly tip the scales of the car comparisons presented in this article; whether by lowered overall maintenance cost for EVs resulting in earlier time of break even or by increased overall maintenance cost due to necessary battery purchases every several years prolonging time of break even and increasing net costs of EVs.

While it is not entirely illogical to apply a fixed average annual driving distance number to any year involving calculations thereof, allowing for a bit of randomness and deviations could serve to give a better sense of the results and sensitivity analysis thereof.

Another is the lack of varying numbers for imported gasoline and gasoline rates, imported cars and inflation, some of which require an in-depth analysis of consumer price indexes for the past years in Iceland and specifically accounting for turmoil caused and followed by the financial crisis of 2008 in Iceland. While it has been shown that electricity rates are relatively stable when compared to imported gasoline prices, they too have an increasing rate though nowhere near that of gasoline rates.

The average fuel consumptions and list prices are derived from a list of relatively few vehicles and results could benefit greatly with more data thereof. The Porsche Cayman originally presented in Table 11 makes for a poor comparison candidate against the Tesla Roadster, which in terms of quality outclasses the Cayman by several factors if not the import price itself. Regardless of which ICE based car may be selected for comparison with it, the Roadster is an anomaly by itself; an extremely technologically advanced electric sports car whose comparable ICE based counterparts in the Icelandic car fleet number in tens, if that many.

Growth rate in trade balance scenarios, although formulated so as to be consistent with import numbers of said scenario, is arbitrarily chosen. Further data on the structure and growth of the Icelandic fleet and application of said data to methods introduced could benefit this article in no small amount.

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