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Plug-in Hybrid and Battery Electric Vehicles in South Africa

Market Forecasts

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Master of Commerce in Applied Economics

This paper uses diffusion modeling to forecast the sales of Plug-in Hybrid and Battery Electric Vehicles (PH/BEVs) in South Africa. First the potential benefits of PH/BEVs in South Africa are scrutinized. The global PH/BEV market is analyzed along with the goals and enticement policies of the countries that are best positioned for a widespread uptake of PH/BEVs. The supply and demand challenges facing the market for PH/BEVs in South Africa are evaluated with a review of current and proposed public policies. The total sales of PH/BEVs in South Africa are then forecast for the medium and long term using an adapted multiple technology generation Bass model with variable parameters for vehicle purchase price and running cost. Two scenarios are examined involving varying oil prices, electricity prices, government support and PH/BEV technological development.

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Acknowledgements

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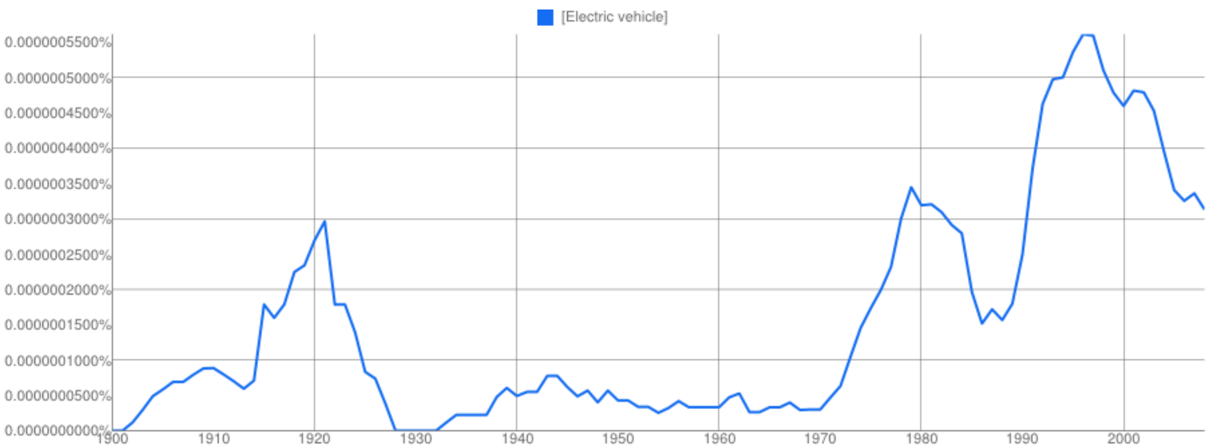
Contents

1. Introduction

Celebrated South African born entrepreneur Elon Musk splits his time evenly between his two successful companies, one of which is shaping the future of space travel while the other is building electric cars.

Electric vehicles have a much longer history than most people realise, a history of fluctuating prominence which is well represented by the Google Ngram data displayed in Figure 1. Google Ngram charts show the percentage of publications that mention a particular phrase over time. The mention of electric vehicles in publications corresponds quite well with the varying fortunes of this mode of transportation technology over the years.

Figure 1: Published Mentions of Electric Vehicles (1900 – 2008)



Source: Michel, et al. (2010)

In the year 1900 electric cars were the top selling vehicles in the United States, in 1909 the sitting US President William Taft purchased an electric car and yet by 1935 electric vehicles were no longer for sale (EVI, 2013). Since the internal combustion engine came to prominence electric vehicles have been largely ignored, although interest in electric cars have historically tended to spike when high oil prices caused concern amongst consumers, as can be seen in the spike in Figure 1 that begins to experience increasing gradient around the time of the 1973 OPEC oil embargo and peaks just before 1980 (EVI, 2013). Cheap petrol and no concern or knowledge about environmental impacts kept the electric vehicle in the shadows until legislation such as the 1990 California Zero Emission Vehicle Requirements motivated new interest in electric vehicles (Kavalec, 1996).

The 2006 documentary "Who Killed the Electric Car?" details the short life of the EV1, a battery electric vehicle from General Motors that was introduced in 1996 and mass repossessed by the manufacturer in 1999 (Paine, 2006). The EV1, which endeared itself to the few consumers who were able to drive one, is most likely responsible for the peak in published mentions of electric vehicles that can be seen around the mid to late 1990's in Figure 1. The data in Figure 1 only goes up to 2008 and so does not reflect the most recent developments in the electric vehicle industry which can more than adequately be summed up by the title chosen for the 2011 sequel to "Who Killed the Electric Car?", the ruthless sounding "Revenge of the Electric Car" (Paine, 2011).

With a new historical peak in global stock of 180 000 plug-in hybrid and battery electric vehicles being reached in 2012 the electric car has indeed emphatically returned (EVI, 2013). The latest wave of electric vehicles are provided with favourable policies from the governments of many countries, a variety of quality vehicles being supplied by respected manufacturers, the backing of influential international organisations and grass roots support from vocal groups of the public making it appear that this time electric mobility is here to stay. The latest resurgence of the electric vehicle brings with it many questions about what the impact of a large scale rollout will be, not just on greenhouse gas emissions but also on commodity prices, employment creation and public health. In order to approximate the scale of such impacts the rate that electric vehicles enter the vehicle market needs to be estimated.

Projecting how the market will react to a new innovation prior to its introduction presents specific challenges, many of which have been addressed in the extensive body of literature. For the electric vehicle market a variety of modelling methods have been used to forecast rates of adoption in a numerous countries around the world but projections tend to vary quite drastically between studies. In a single study that entailed the use of a range of forecasting models the sales of plug-in hybrid electric vehicles in the United States for the year 2035 were estimated to range from 280 000 to 6 million (McManus & Senter, 2009). Leading consulting firms differ in modelling methodology and presentation of results which perhaps disguises the large differences in projections made for the electric vehicle market. Examples of corporate projections for plug-in hybrid and battery electric vehicles globally vary from 17 and 29 million sold annually by 2030 (McKinsey&Co., 2009b), comprising 8-10% of global light vehicle sales by 2020 (RBSC, 2011) or accounting for 7%, 25% or 50% of global light vehicle sales by 2020 depending on specific scenarios (Matthies, Stricker, & Traenckner, 2010). The variations in the projections for the electric vehicle market are understandable as the industry is only in the early stages of development but such projections provide a basis for industry stakeholders to gauge expectations make more informed decisions. The first electric vehicle became commercially available in South Africa in November 2013 and with an absence of market modelled forecasts for South Africa found in the literature the development of a sales projection model is undertaken in this study.

The first step taken in this paper is to define the various types of electric vehicles. Plug-in Hybrids and Battery Electric Vehicles (PH/BEVs) are examined in this paper as they fit the criteria of vehicles primarily powered by electric drivetrains, requiring a different method of refuelling or charging than traditional Internal Combustion Engine Vehicles (ICEVs) and Hybrid Electric Vehicles (HEVs).

Not everyone is a supporter of a large scale rollout of PH/BEVs and so the pros and cons of PH/BEVs in South Africa are discussed. Even if electric vehicles do provide a range of benefit, some countries are not yet suitable for widespread electric vehicle adoption. The environment that would make PH/BEVs enticing to consumers is described in terms of a variety of factors ranging from city densities to fuel prices.

The global PH/BEV market is then examined in terms what vehicles are available to consumers and which countries are buying them. The ambitions of various countries with regards to electric vehicles are then analysed in terms of declared fleet and sales targets and the supportive public policies that have been put in place in order to achieve them.

The challenges facing the development of the South African PH/BEV industry are analysed in addition to a review of current and proposed PH/BEV friendly government policies.

The various methods used to forecast the penetration of new market innovations are reviewed with particular attention paid to studies involving the automotive industry. A diffusion forecast model is developed as a combination of the Norton-Bass multiple generation technology model and the generalised Bass model with marketing parameters. The total sales of PH/BEVs in South Africa are then forecasted for the years 2014 to 2050 with vehicle purchase price and running cost as the variable marketing effect parameters. Two scenarios are examined involving varying oil prices, electricity prices, government support and PH/BEV technological development.

2. Electric Vehicles and their applicability to South Africa

What are Electric Vehicles (EVs)?

The term "Electric Vehicles" has been used cover a range of vehicles that are either fully or partly powered by electricity. While there are numerous varieties of two and three wheeled electric vehicles, the majority have four wheels and are predominantly what is being referred to when the term "electric vehicle" is mentioned. Categorising the various electric vehicles can be tricky as the growing number of vehicle types has created a near continuous spectrum that blurs the line between fuel efficiency and electric mobility. For simplicity, this paper shall classify the vehicles that are grouped under the broadest definition of electric vehicles into 3 categories.[1]

Hybrids (HEVs)

Hybrids are referred to as electric vehicles only by the more liberal users of the term. Hybrids can be subcategorised to be micro, mild or full hybrid vehicles. What they all have in common however, is that they do not use electric power on its own to start up and move and rely solely on conventional fuels. Micro hybrids will turn off the vehicle's conventional engine when the vehicle is not moving to save fuel while electrically powering all necessary functions of the vehicle and allowing immediate acceleration when the driver wishes to move. Mild hybrids include the micro hybrid capabilities but also use the electric engine of the vehicle in conjunction with the conventional engine to power movement. Full hybrids take this a step further and actually allow the electric engine to power the vehicles movement independently for a limited time when not accelerating. The batteries that the various hybrids use do not require an external charge or to be replaced/swapped frequently as they are charged in similar ways to conventional car batteries as well as by new, more sophisticated and elegant methods such as using the friction on the brake pads to create charge.

Plug-in Hybrids and Range Extenders (PHEVs)

Plug-in hybrids (PHEV) and range extenders are essentially the same thing; hybrids whose batteries are charged by connecting to an external power source and are capable of starting and being driven for short to moderate distances without the conventional engine being engaged. For longer journeys the conventional engine will be utilised, giving the PHEV the range of conventional automobiles.

[1] Adapted from Deutsche Bank Research, (2008) , Hensley, Knupfer, & Krieger, (2011) & Matthies, Stricker, & Traenckner (2010)

Fully Electric (BEVs)

Fully electric vehicles have no conventional engine and are powered from a battery which is either plugged into an external power source to be charged or removed from the vehicle when depleted and replaced with a fully charged battery. These 2 types are known respectively as Plug-in Electric Vehicles (PEV) and Battery Exchange Electric Vehicles (BEEV) but in this paper shall be referred to collectively as Battery Electric Vehicles (BEVs)

Plug-in Hybrids and Fully Electric Vehicles (PH/BEVS) will be referred to collectively as they share many common characteristics which sceptics of their usefulness admonish and supporters of their potential benefits embrace. When necessary a distinction will be made between the two. Internal Combustion Engine (ICE) Vehicles shall be used in reference to conventional engine vehicles and any light or mild hybrid vehicles that do not qualify for full HEV status.

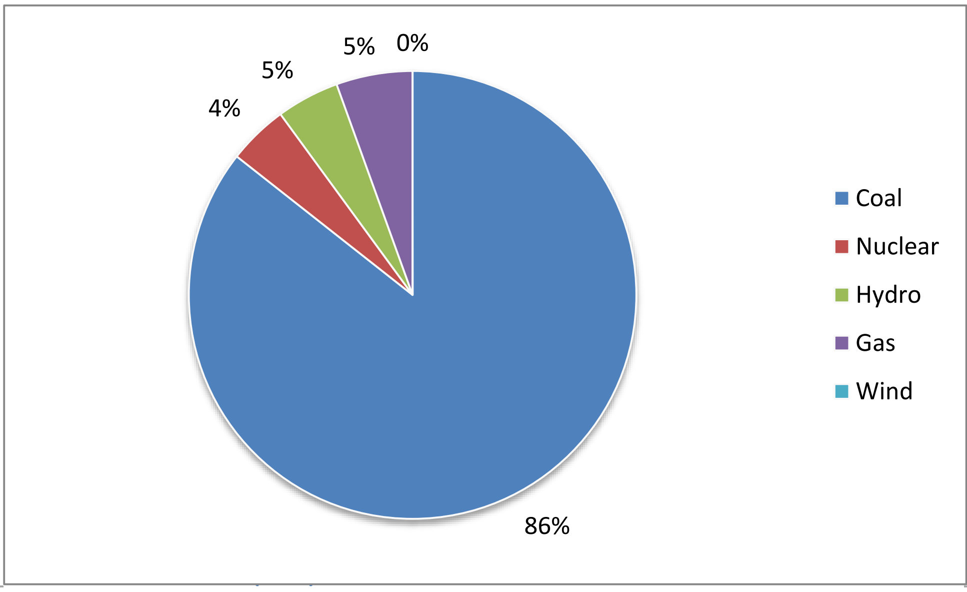
Would a widespread adoption of Electric Vehicles be good for South Africa?

PH/BEVs are generally lauded in the media and amongst the general public for their direct environmental benefits. With a call to embrace PH/BEVs coming from many sectors it is necessary to consider whether PH/BEVs offer the environmental, social and economic benefits that they seem to from the outset (IPAP, 2010).

Environmental benefits

It is assumed that a shift to PH/BEVs would be beneficial in reducing overall Green House Gas (GHG) emissions as they produce no CO_2 directly from the electric drivetrain and therefore significantly less than ICE vehicles. Liu, Hildebrandt & Glasser (2012) postulate that a more widespread use of PH/BEVs in South Africa would not have the positive impact on the environment that it might in other countries due to way South Africa generates its power. The majority of electricity in South Africa comes from coal burning power stations, as shown in Figure 2.

Figure 2: Eskom Power Generation Mix (2012)



Note: Eskom generates 95% of electricity in South Africa

With a greater number of PH/BEVs on the road, the direct carbon emissions from vehicles will decrease but there will also be an increased requirement for electricity in order to charge the PH/BEVs. If this electricity is coming predominantly from burning coal then the environmental benefits of driving PH/BEVs are seemingly lost. In a study involving BEVs being operated in 20 different countries around the world it was found that only BEVs operated in India would produce effectively more CO_2 per kilometre through dirty power generation methods than BEVs operated in South Africa (Wilson, 2013). Despite some justifiable concerns there is still support for encouraging the adoption of PH/BEVs from various South African sources such as the UCT Energy Research Centre, the Industrial Development Corporation and the Department of Trade and Industry (Dane, 2013) and several international studies such as the widely cited research of the Natural Resources Defence Council (NRDC) which gives evidence to the belief that even with a coal dominated electricity grid, PH/BEVs will reduce the production of GHGs (Electric Power Research Institute, 2007).

There is the expectation that as the level of technology for the production of electricity from renewable sources improves, the generation mix will change and PH/BEVs will become progressively more environmentally friendly to operate. The precise plans for renewable energy power generation in South Africa have been constantly evolving in recent years but the South African government has declared a strong intention to continue the early work of greening the electricity grid (Economic Development Department, 2010) with recent targets aiming for 17 800MW of new power capacity to come from solar and wind power projects by 2030 (DTI, 2013a). ICEVs also bare the potential to become greener over time but there are simply more possibilities open to generating power in a cleaner fashion than to producing ICE vehicles and fuels with perpetually reducing greenhouse gas emission levels. PH/BEVs are also more energy efficient with driving efficiencies of approximately 75% versus the 18% of ICEVs (Snyman, 2012). At current levels the well-to-wheels efficiency of PH/BEVs is 24% and considering the vast potential for improvement in this figure, PH/BEVs appear particularly more promising than comparative ICEVs with well-to-wheel efficiencies of 7% using petrol synthesized from coal and 18% using petrol refined from oil (Snyman, 2012).

The argument for the widespread rollout of PH/BEVs is also affected by how base-load power and new power generation are perceived and a point of contention is whether the power for PH/BEVs should be considered as being provided by the new power generating facilities or from the system as a whole. In more developed nations where electricity production is at a stable level it evident that power production capacity which is added to the grid has been developed in at least some extent to meet the increased need for electricity brought about by more PH/BEVs on the roads. Due to technological advancements newer power capacity is provided by renewable energy technologies and/or more environmentally friendly coal and gas facilities than existing power plants. If the additional demand for power created by the widespread adoption of PH/BEVs is directly motivating the construction of new power generation facilities then the well-to-wheel efficiency and environmental impact of the PH/BEVs should be calculated based on the efficiency of the new facilities and not on the efficiency of the power generated from the system as a whole. In developing nations such as South Africa, electricity generation capacity constantly needs to increase and so new capacity demands cannot be attributed solely to the addition of PH/BEVs to the national vehicle fleet.

This issue is further complicated when it is assumed that PH/BEVs will predominantly be charged during off-peak hours. While off-peak charging will limit any strain caused by the addition of PH/BEVs to the South African motor pool it confuses the ability to appropriately assign how the electricity powering particular vehicles is being generated. Assuming that it is possible to limit the majority of PH/BEV charging to off-peak hours using a smart electricity grid or time-gauged home charging stations, PH/BEVs would not be causing additional power generating capacity demand.

Whether or not it is appropriate to judge the GHG production of PH/BEVs on new or total power generation capacity is a key point in the debate over the impact of PH/BEVs on GHG production in South Africa and is clearly a complex issue with viewpoints being somewhat subjective. However, even if electricity produced for PH/BEVs is allocated to have come from the old 'dirty' power stations there are still industry stakeholders and concerned citizens who would cite improved economic stability, green employment and improved public health as reasons for embracing the arrival of PH/BEVs.

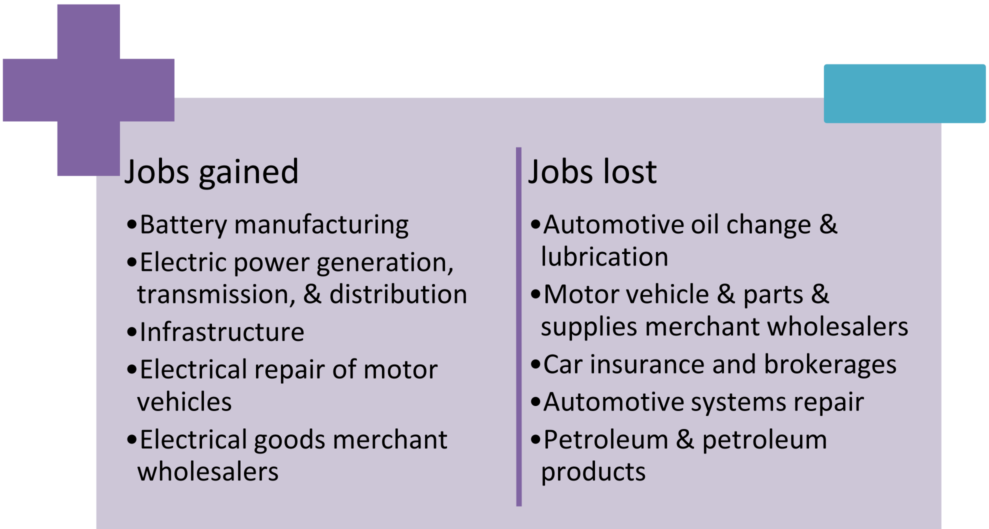
Economic stability

There is more than just the environment at stake when considering PH/BEVs. With PH/BEVs making up a significant share of the vehicles on the roads, the national economy will be less reliant on foreign oil and therefore less susceptible to oil price shocks and will also lessen fears about oil supply security. South Africa's number one commodity import for the 2012 calendar year was crude oil, with partially distilled fuel and fully refined petrol also ranking in the top ten most significant imports. These 3 fuel categories accounted for over R168.5 billion in imports during 2012 (SARS 2012), a substantial portion of which was for the transport sector. Importing less oil will also have a positive effect on South Africa's trade deficit. Admittedly South Africa is not as reliant on foreign oil to meet its transportation needs as some other countries due to liquid fuel being manufactured from local coal and natural gas reserves; however this only partially discounts the risks of relying on imported oil and comes with detrimental environmental effects from the rather emissions and energy intensive coal synthesising process (Letete, Guma, & Marquard, 2013).

Employment effects

The employment effects of a wider use of PH/BEVs gives rise to an interesting debate. On one hand there will undoubtedly be jobs lost in the automotive repair and maintenance industry as PH/BEVs do not require the level of upkeep that conventional vehicles do, however on the other hand the rise of PH/BEVs is predicted to create a large number of "green collar" jobs in the sale, maintenance, public education, development and manufacture of the vehicles. The Industrial Development Corporation (IDC) released the Green Jobs Report in 2011 that predicted, perhaps optimistically, that there could be in excess of 11 000 jobs created from construction, operations and maintenance and manufacturing activities (Maia, et al., 2011). Production of PH/BEVs in South Africa will be greatly encouraged by a thriving local market for the product and if job creation in the vicinity of what is estimated by the IDC is to be achieved then being a base for exports cannot be the only major reason for manufacturing in South Africa. Figure 3 shows that the mass rollout of BEVs would create jobs but would also lead to the loss of some jobs in areas such as vehicle maintenance, parts supply and petroleum distribution.

Figure 3 : Jobs gained from mass rollout of BEVs versus Jobs lost



Source: Draper, Rodriguez, Kaminsky, Sidhu, & Tenderich (2008)

Public Health

Tied to the idea of environmental sustainability is the long term health of the population. While the environmental benefits of PH/BEVs may indeed not be tangible for the immediate future, there are direct health benefits that should be added to the list of factors in favour of mass PH/BEV adoption.

ICE vehicles release CO_2 directly out of the exhaust pipe, close to the user. The predominant use of vehicles in highly populated areas means that residents of cities and towns that are already burdened with air pollutants from many other sources are subjected to further increased levels of pollution even if they are not vehicle users. The pollutants involved in the use of PH/BEVs are produced at power plants which are set well away from large population centres. The benefits of placing some distance between the majority of the population and the source of the pollution will have positive health effects that are difficult to quantify but are significant. A healthier general public means a more productive workforce and a more vibrant economy.

PH/BEVs are beneficial

There are justifiable reasons to be sceptical about the benefits of PH/BEVs but as long as power generation methods continue to improve in efficiency and lessen their environmental impact, PH/BEVs have a future in South Africa. PH/BEVs do not come without drawbacks and yet despite the negatives that have been outlined in this section, there are enough positives to validate what might be described as cautious optimism for the environmental, economic and social benefits that PH/BEVs could provide to South Africa.

Factors impacting on PH/BEV adoption

After determining that South Africa would benefit from more PH/BEVs on the country's roads the next step is to determine if the country fits suitable criteria for PH/BEV adoption. The acceptance of PH/BEVs by the general public is not only dependant on the performance of the vehicles and their cost relative to ICE vehicles but is also reliant on a variety of local conditions. The ideal market for PH/BEVs requires that factors align to favour PH/BEV use but also skew towards discouraging continued use of ICE vehicles. For PH/BEVs to become widely used the following six factors should be met to some degree.

1. **Low electricity prices**

   The charging costs of PH/BEVs will need to be attractive to the consumer so decreasing or at least stable electricity prices would be desired with lower tariffs at night to encourage off-peak charging.

2. **High petrol prices**

   In conjunction with the previous point, fuelling costs for ICE vehicles will need to continue to escalate as the average consumer finds financial motivation a much more potent incentive than potential environmental benefits to make the transition from ICE to PH/BEV.

3. **Compact city layouts**

   PH/BEVs are most energy efficient at slow speeds whereas ICE vehicles tend to be most efficient when travelling at constant speeds of between 80 and 100km per hour. This means that PH/BEVs are most beneficial in areas where the driving patterns tend to be stop/start with high speeds rarely being reached. This would be the case in built up areas with a compact layout as typical traffic congestion, an abundance of pedestrians and traffic lights limit the speed that is achievable by vehicles.

4. **Infrastructure support**

   The specifics of the infrastructure support depend on the type of PH/BEV models that adopted but whether they are battery swap electric vehicles or plug in models there will be significant investment required. Plug-in models will require fast charge power stations while battery exchange vehicles will require stations where it is possible to swap batteries for fully charged versions. Both models would require a modern (ideally 'smart') electricity grid that allows for efficient charging of batteries from home or work.

5. **Regulatory support**

   As with most green development initiatives there is a need for funding and support that the free market will not initially provide. Governments will be required to not only aid in providing infrastructure for PH/BEVs but to create policies that entice consumers to purchase PH/BEVs. These policies could include:

   - Clean vehicle purchase incentives
   - Strict regulations on fuel economy and emission standards
   - Government fleet programs
   - Research and Manufacturing grants
   - Usage regulations such as dedicated lanes, free parking or exemption from road tolls
   - Consumer acceptance programs that educate the general public

6. **Local involvement in the industry**

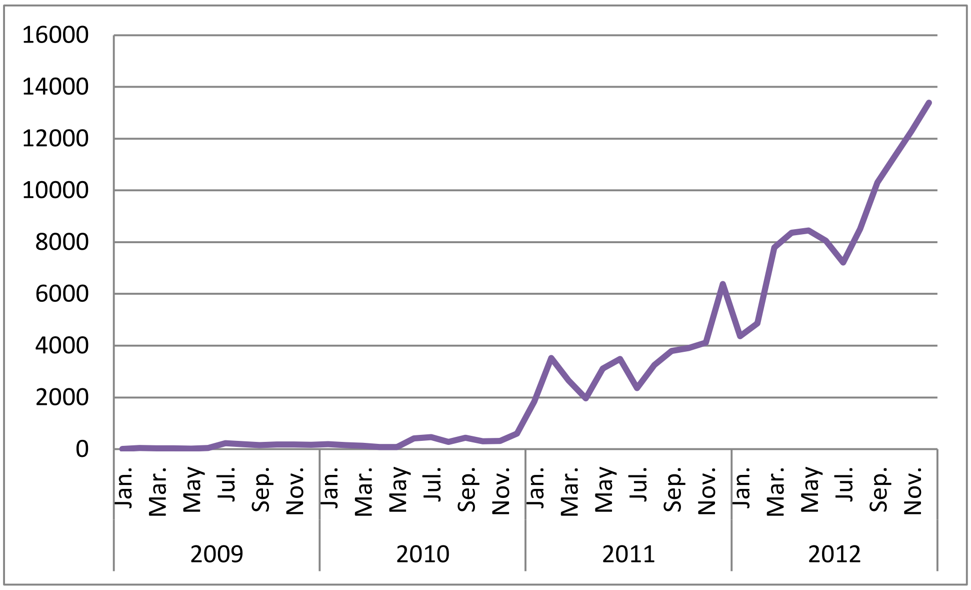
   Key research and development strides by local parties or the manufacture of PH/BEVs locally can increase domestic public awareness and acceptance of PH/BEVs. The local manufacture of PH/BEVs can also have a positive effect on their price and subsequent appeal. Local involvement would ideally be all along the value chain with research, design, production and maintenance all taking place to some extent in the country. Job creation will stimulate public support for pro-PH/BEV policy measures and result in the scaling up of regulatory support.

3. PH/BEVs in a Global Context

The World Electric Vehicle Market

The worldwide market for PH/BEVs is still developing but has experienced remarkable growth as technological advancements make PH/BEVs better and more affordable and individuals, organisations and governments in more locations do what they can to best meet the aforementioned favourable factors for PH/BEV adoption. Vehicle manufacturers are doing their part to be more environmentally friendly with the 2013 Best Green Brands report ranking automobile manufacturers very highly; Car companies took the top 3 positions with another 2 in the top 10

Figure 4: Global Monthly PH/BEV Sales



Source: Marklines Database (2013)

(Interbrand, 2013). As can be seen in Figure 4, the global sales of PH/BEVs more than doubled from 2011 to 2012. Figure 4 also shows how recent the explosion in sales is, with PH/BEV sales being all but non-existent until mid-2010. By the end of 2012 there were over 180 000 PH/BEVs in use around the world (EVI 2013). The Electric Vehicle Initiative, a multi-government policy forum of which South Africa is a member, is targeting 20 million PH/BEVs on the road by 2020 (EVI 2013). This would require vehicle sales to grow by 80% each year, a target which has been exceeded in recent years such as 2012, although admittedly off a low base.

The increases in PH/BEV sales are not only due to the improved performance and price of existing PH/BEV models but also to the wider variety of PH/BEVs that have been introduced to the market. In 2012 there were 54 different types of PH/BEVs sold around the world from 38 different brands, up from only 20 different models in 2011 (Marklines Database, 2013). There have been some recent notable launches of PH/BEVs from top vehicle manufacturers around the world, with some titans such as Nissan and General Motors placing a great deal of faith in the potential of the PH/BEV market by rolling out their respective PH/BEVs on a large scale. This faith is not unjustified but can be viewed as risky in light of some very high profile failures of companies who sought to pioneer the PH/BEV market such as the bankruptcies of the vehicle manufacturer Fisker Automotive and the battery manufacturer A123 Systems, both of which received significant financial support from the United States Department of Energy (Ingram, 2013). The staunch entry barriers in the automotive industry have traditionally made is tough for smaller companies to find a niche but with the shift in technology towards electric mobility a gap has opened for companies like California based Tesla Motors which has achieved initial success by building vehicles to compete with sports cars, high end sedans and SUVs. Some automotive industry stakeholders doubt the ability of small PH/BEV manufacturers to achieve the economies of scale that will allow them to survive in the long term but with the large brands following the example of the pioneering smaller companies and designing PH/BEVs to compete with the full spectrum of ICEVs the future of the industry appears to be in safe hands.

Even motoring enthusiasts and aficionados are starting to recognise the quality of this latest wave of PH/BEVs with the Chevrolet Volt and the Tesla Model S winning various car of the year awards in 2012 and 2013 respectively (MacKenzie, 2013 ; Squatriglia, 2012). Such acclaim from traditionally harsh critics is helping electric vehicles gain reverence in the eyes of even the more conservative and hesitant consumers.

Each of the 11 different PH/BEV models shown in Table 1 sold more than 2000 units in 2012 with the both Chevrolet Volt and Nissan Leaf selling close to 25 000 vehicles. The plug-in version of Toyota's hugely popular hybrid, the Prius, managed to sell over 20 000 cars.

Table 1: Global Electric Vehicle Sales Rankings 2012

Rank	Make	Model	Quantity
1	Chevrolet	Volt	25 400
2	Nissan	Leaf	24 135
3	Toyota	Prius	20 552
4	Opel	Ampera	4 931
5	Mitsubishi	i-MiEV	3 672
6	Chery	QQ3	3 129
7	Citroen	C-ZERO	2 678
8	Peugeot	Peugeot iOn	2 620

9	Mitsubishi	Minicab-MiEV	2 487
10	Ford	C-MAX	2 374
11	Tesla	Model S	2 120

Source: Marklines Database (2013)

Country goals for PH/BEV adoption

Various countries have declared targets for PHEV and BEV adoption. Table 2 shows the current PH/BEV stock of some selected countries along with their announced targets for 2020. Also shown in the table are the significant rates of annual growth that will need to be maintained in order for the targets to be reached. The figures for China indicated that their national PH/BEV will need to more than double in size each year in order to reach the lofty goal of 5 million vehicles by 2020.

Other nations have also set ambitious targets coming off a negligible stock in 2012. Canada is aiming for 500 000 PH/BEVs by 2020, Ireland has declared 350 000 PH/BEVs as their 2020 goal and Switzerland has targeted 145 000 PH/BEVs also by 2020 (IEA, 2011). Israel aims to introduce at least 40 000 PH/BEVs per year between 2012 and 2020 and Chile has recently proposed a target of 70 000 PH/BEVs by 2020 (Ministry of Environment of Chile, 2012).

Table 2: Existing PH/BEV stocks, stock targets and required growth rates

	2012 stock	2020 targets	Required annual growth rate
US	71 174	2 488 320	56%
Japan	44 727	800 000	43%
France	20 000	2 000 000	78%
China	11 573	5 000 000	114%
UK	8 183	1 550 000	93%
Netherlands	6 750	200 000	53%
Germany	5 555	1 000 000	91%
Denmark	1 388	50 000	57%
Sweden	1 285	600 000	116%
Spain	787	2 500 000	174%

Source: Adapted from IEA (2011) & EVI (2013)

Another notable target comes from the IEA which outlines the proposed BLUE Map scenario where by the year 2050 there will be a 30% reduction in CO_2 emissions from light vehicles due to an increased use of BEVs and PHEVs (IEA, 2011). In order for this reduction target to be reached, the world vehicle fleet in 2030 will need to comprise 33.3 million PH/BEVs and by 2050 that number will be required to increase to 106.4 million PH/BEVs (IEA, 2011).

Pro-PH/BEV Policy measures in other countries

Appropriate policy measures are required if any of the previously mentioned targets for PH/BEV adoption are to be achieved. There are several recognised ways to encourage PH/BEV adoption and these have been tested in other countries with varying levels of success but there are also some promising new ideas which could be explored.

Rating the current policies

McKinsey & Company publish a ranking of countries based on their supply and demand readiness for PH/BEVs. The demand readiness factor is determined by the PH/BEV share of car sales, the economic advantage of PH/BEVs and the additional incentives for PH/BEV drivers. The supply readiness factor is determined by the forecasted share of PH/BEVs in car production, the number of PH/BEV models available in the country and the level of government support of infrastructure and research and development. As of January 2012, Japan led the way with a score on the McKinsey Electric Vehicle Index of 2.6 out of 5. The US followed closely at 2.4. France and Germany both scored about 2.0 with China in 5th place with a score of 1.5 (Krieger, Wang, Radtke, & Malorny, 2012).

Japan

One of the policies that make Japan so suitable for PH/BEV adoption is the financial subsidy offered at a value of half the difference in price between PH/BEVs and comparable ICE vehicles. Japan also has substantially invested in researching and developing the appropriate infrastructure for PH/BEVs. One of the policies to come out of this research is offering financial support for up to half the cost of PH/BEV support equipment such as home chargers. This is a significant incentive as the more advanced fast chargers can cost up to $37 600 {¥3 million JPY} (EVI, 2013). The Japanese government has also displayed support for research concerning integrating PH/BEVs into a smart electricity grid. In addition to all the national support for PH/BEVs, in the Kanagawa Prefecture BEVs are exempt from registration tax and require no circulation tax to be paid for the first 5 years after purchase (EVI, 2012).

United States

The United States offers tax credits up to the value of $7 500 when purchasing a PH/BEV however the incentive no longer applies after 200 000 vehicles have been purchased from recognised manufacturers. The US also has policies in place to boost the development of PH/BEV supporting infrastructure such as a tax credit to the value of 30% of the cost of commercial PH/BEV support equipment and up to $1 000 for residential equipment (EVI, 2013). There has also been $360 million dollars allocated from the federal budget for infrastructure development projects and an additional

$268 million for research into PH/BEV batteries, fuel cells and vehicle systems. The city of Portland allows BEVs access to bus lanes and access to free parking. New York City has begun replacing its 26 000 public vehicle fleet with BEVs and is considering BEVs as part of the taxi fleet (Perdiguero & Jiminez, 2012). Speciality BEVs are also employed at Los Angeles International Airport in the form of e-buses and at the Port of Los Angeles in the form of all-electric drayage trucks (EVI, 2012).

France

France employs a feebate system that has provided purchasers of fuel efficient vehicles with $478 million {€450 million} worth of rebates. 90% of this money comes from charging a purchasing fee on fuel inefficient vehicles while the other 10% is government funded (ACEA, 2013). An additional $64 million {€50 million} is provided to cover up to half the cost of purchasing and installing any PH/BEV support equipment. A further $180 million {€140 million} is allocated to PH/BEV research and development (EVI, 2012).

Germany

In Germany, PH/BEVs are exempt from road taxes and there is strong financial support for research and development in the fields of electric drivetrains, creation and optimisation of PH/BEV value chains and PH/BEV batteries (ACEA, 2013). Car sharing schemes allow citizens to experience driving an PH/BEV and are then able to make an informed decision about purchasing one (Perdiguero & Jiminez, 2012).

China

China provides subsidies for the purchase of PH/BEVs up to the value of $9 500 {¥60 000 RMB} and in major cities up to an additional $6 330 {¥40 000 RMB} can be claimed (EVI, 2012). The Chinese government has also allocated $1.1 billion {¥6.95 billion RMB} for demonstration projects throughout the country (EVI, 2013).

4. PH/BEVs in a South African Context

History of PH/BEVs in SA

South Africa, while not quick to adopt PH/BEVs commercially, has played a small but fundamental role in developing the technology that has made the current wave of electromobility possible. Since the early 1980s the Council for Scientific and Industrial Research (CSIR) has aided in the development of lithium ion batteries that are the norm in PH/BEVs as well as laptops and cell phones (Forbes & Katumba, 2009). Lithium Ion batteries have revolutionised the consumer electronics industry due to their excellent energy-to-weight-ratio, slow loss of charge when not in use and high energy density. The CSIR has established a Battery Centre of Competence (BatCoC) with a focus on finding ways to produce batteries that last longer, store more energy, are cheaper to manufacture and environmentally friendly to dispose of (Forbes & Katumba, 2009). The automotive industry in South Africa has a strong history in component manufacture and whilst PH/BEV batteries tend to be highly integrated into vehicle design there is still potential for localising battery production but only with the direct backing of an international brand (Maia, et al., 2011).

Local PH/BEV production

In 2008 South African company Optimal Energy unveiled a fully electric locally designed and manufactured prototype vehicle named the Joule. The Joule was met with positive responses and favourable policy backing as the 2010-2013 IRP proposed the commercialisation of South Africa's electric vehicle along with all the necessary testing facilities, infrastructure, demand stimulation mechanisms and public education (IRP, 2010). Major funding for the Joule project was provided by the IDC and the Department of Science and Technology's Technology Innovation Agency but after Optimal Energy failed to gain private backers for the project the Joule was shelved in mid-2012 (CARmag, 2012). The automotive industry is infamously difficult to break into and the industry stakeholder consensus has been that the Joule would not have been able to compete with the PH/BEV products of international brands despite the entry gap created by the change in technology (Dane, 2013).

PH/BEV Availability

Various companies have acknowledged at least a modicum of domestic demand for PH/BEVs in South Africa by announcing plans to make cars locally available. As shown in Table 3, Nissan introduced the first commercially available PH/BEV to South Africa in November 2013. BMW have announced plans to introduce 2 PH/BEVs to South Africa in 2014 with the general purpose i3 set to lead the way followed by the sporty i8.

Table 3: Major PH/BEV distributor entry plans for South Africa

Manufacturer	Planned SA entry	Vehicles
Nissan	November 2013	Leaf
BMW	2014	i3 & i8
Volkswagen	2014	e-Golf

Source: Venter (2013a) ; Venter (2013b) ; Venter (2013c)

Challenges facing the South African PH/BEV Market

According to the 2010 World Development Report, South Africa "plans to be the world leader in electric vehicles" (World Bank, 2010, p. 192). For this lofty goal to be even partly realised a combination of problems specific to South Africa needs to be addressed in addition to the required advancements in the global PH/BEV industry.

PH/BEV Supply and Scale of Use

A wide range of PH/BEVs will need to be available to consumers if there is to be significant uptake. Aside from the three manufacturers listed in Table 3 there is little news on plans for other PH/BEVs to be brought into the country. This hesitation is due to uncertainty over demand levels which will need to be consistent and significant for entry to be worthwhile to the manufacturers.

Power Generation and distribution

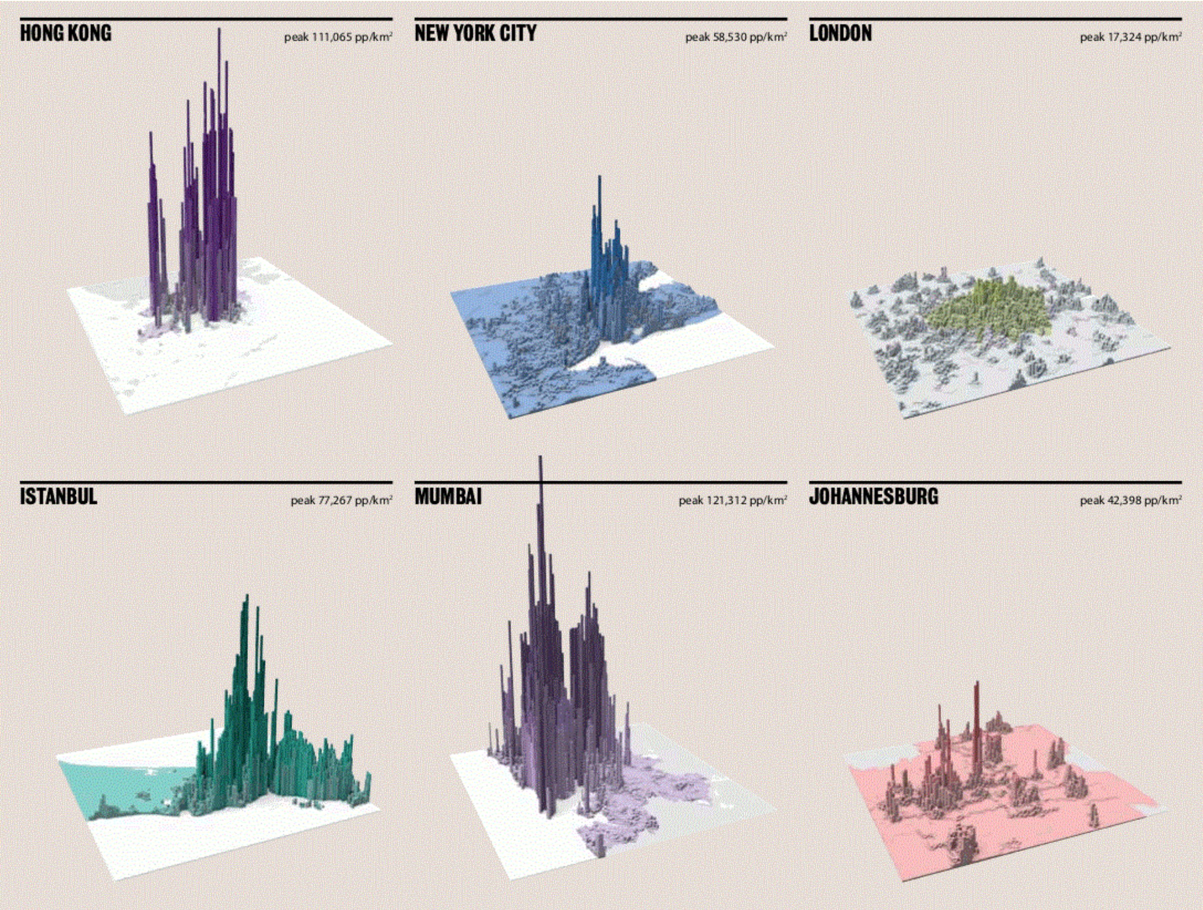
Critics of plans to introduce PH/BEVs to South Africa point out that the country has an aging and strained power grid that is not well equipped to deal with the charging of PH/BEVs. Ideally a smart grid would be in place that would allow non-peak load charging of vehicle batteries. The pricing structure used for electricity in South Africa is also not entirely suitable for the adoption of PH/BEVs with large hikes in prices scheduled for the near future (Eskom, 2013). These price increases have a negative effect on the feasibility of PH/BEVs as they obviously make running costs more expensive but they also have the further negative effect on the perception of PH/BEVs in the mind of the consumer. A persuasive factor in the decision as to what type of vehicle to buy is the climbing price of oil and if the cost of charging an PH/BEV is also set to rise, even if it is by nowhere near the same amount, then consumers will view the cost savings on fuel as potentially far less substantial than they actually would be. Since 2007 there have been electricity supply interruptions that might make potential PH/BEV adopters nervous as if the problem continues there will likely be situations where the charging of vehicles is not possible and the drivers are left stranded (DBSA, 2012).

South Africans spend an average of 4.25% of their annual income on petrol, second only to Greece in the 61 countries measured in 2013 (Bloomberg, 2013). Despite having petrol prices that rank 42nd out of the 61 countries, 6.65% of the average daily per capita income is required to purchase just one litre of fuel (Bloomberg, 2013).

City densities

Cities the most logical starting points for PH/BEV adoption in any country; however the density of South African cities does not favour PH/BEVs. Figure 5 shows the density of South Africa's largest centralised city, Johannesburg, compared to Hong Kong, New York, London, Istanbul and Mumbai. The image displays Johannesburg with relatively flat spaces between the spikes. This shows that Johannesburg is more dispersed than the other cities. Vehicles will be reaching higher speeds in between the spikes of higher density and therefore PH/BEVs will not be at their most efficient. The stop-start nature of driving in more congested cities is actually favourable to PH/BEV adoption with Hensley, Knupfer & Krieger (2011) projecting by as early as 2015, 16% of new car sales in New York, 9% in Paris and 5% in Shanghai will be PH/BEVs.

Figure 5: Population Densities of Selected Cities



Source: LSE Cities (2011)

Current SA Government Support for PH/BEVs

Electric Vehicle Industry Roadmap (EVIR)

Public policy towards PH/BEVs is still being formed but the major guide to future plans has been the broad suggestions put forward for discussion by the DTI during the announcement of the EVIR. The DTI is set to release this roadmap for the development of the PH/BEV industry by the end of 2014. This roadmap will detail demand stimulation methods, investment support, research and development support and a regulatory framework (DTI, 2013b).

Demand stimulation

The first planned step to stimulating demand for PH/BEVs appears to be consistent government procurement (Dane, 2013). The suggested target is for 3 000 – 5 000 PH/BEVs to be purchased annually. The idea is to create a consistent market for PH/BEVs that will make it possible for suppliers to provide a range of quality PH/BEVs to the public. The use of PH/BEVs by government employees will also serve to promote public awareness for the transportation mode and waylay public concerns over applicability to South African conditions. Further public education is also planned through the EV Consumer Awareness Campaigns aimed to highlight the benefits of PH/BEVs.

Tax incentive methods will probably have the most direct impact on the consumer purchase decision but the exact form is not yet decided upon. Options include, but are not limited to, rebates on personal income taxes, reduction of VAT on the vehicle Retail Selling Price and reduced vehicle registration costs (DTI, 2013b).

Investment support

Automotive manufacturing and assembly in South Africa is a powerful component of the national economy and has benefited from strong policy measures. In order to further encourage the local manufacture of automobiles the DTI replaced the long-running Motor Industry Development Programme with the Automotive Production Development Programme (APDP) in 2013. The APDP consists of duty-free allowances, import rebates, tariffs and the Automotive Investment Scheme (AIS) (DTI, 2013c).

The AIS has no direct facility to encourage the local production of PH/BEVs. The AIS provides cash grants for local vehicle manufacturers but only if more than 50 000 vehicles are produced per annum. Support is also provided for component manufacturers but only if the total annual turnover sold to vehicle manufacturers is greater than R10 million or 25% of total entity turnover (DTI, 2013d). These large output requirements do nothing to stimulate local production of PH/BEVs as the newly developing market is too small for 50 000 vehicles to be feasible in the short term. The suggested step in the Electric Vehicle Industry Roadmap is for the quota per plant to be lowered from 50 000 to 5 000 units per annum (DTI, 2013b). Even if this adjustment is made for PH/BEVs OEMs will need to focus local production on a few specific models in order to reach this 5 000 unit lower bound, a course of action that is the norm in the South African automotive industry. Duty-free allowances and/or import rebates would need to be implemented in conjunction with manufacturing subsidies in order for it to be feasible for vehicle distributors to provide consumers with the variety of PH/BEVs options necessary to stimulate demand.

Research and Development Support

Whilst OEMs will likely undertake the majority of research and development for PH/BEVs there is thought to be room for independent investigation into electric transport methods. Provision for research and development will likely be focused on components as opposed to entire vehicles. The development of improved battery technology through the CSIR is expected to continue to lead the way in South African PH/BEV related research.

Provision of Regulatory Framework

Aside from developing the necessary legislative framework for the sale and use of PH/BEVs in the country the EVIR calls for plans to develop the required urban infrastructure and refine the management of existing electricity infrastructure (DTI, 2013b).

The investment in urban infrastructure will need to initially be implemented in targeted areas. The idea put forward in the EVIR is to more fully integrate transportation, urbanisation, and enabling infrastructure that leads to economic activity in new technologies and sustainable.

As a way to combat the concerns over the lack of sophistication in South Africa's power grid it is proposed that preferential tariffs schemes and intelligent charging methods are put in place to encourage off peak charging. Public charging infrastructure will eventually need to be widely available but until then home charging systems will need to be catered for (DTI, 2013b).

Department of Environmental Affairs' Green Cars

In February 2013 the Department of Environmental Affairs (DEA) launched the Green Cars programme. The pilot programme involves a small fleet of fully electric Nissan Leaf cars whose charging needs are partially met by solar power. The solar panels are part of the DEA New Green Building Site and if successful the solar charging infrastructure will be installed in the Tshwane and Johannesburg metropolitan areas (DEA, 2013).

National Electric Vehicle Technology Innovation Programme

The Technology Innovation Agency (TIA) has also publically declared its support and stated its aim of identifying, facilitating and supporting the development of the infrastructure necessary for the widespread adoption of PH/BEVs as well as identifying areas where skills or technology levels may be insufficient (ESI-Africa, 2013). The TIA has the specific goal of finding areas of the PH/BEV value chain where South Africa might have a competitive advantage, such as battery technology and PH/BEV support components. By promoting local manufacture of PH/BEV components the hope is that South Africa will be able to become an integral stage of the value chain for the production of PH/BEVs that are tailored specifically for contexts other than highly developed and electrified North American and European cities (Dane, 2013).

Environmentally Related Taxes and Carbon Taxes

South Africa employs a variety of taxes that serve, at least in part, to make the transport industry more environmentally friendly. Transport fuels are taxed through a General Fuel Levy, Road Accident Fund levy and a Customs and Excise Levy (OECD, 2013b). The purchases of new vehicles are subject to once-off ad valorem and excise duty and the annual provincial motor vehicle licensing fees. In addition, the purchasers of new passenger cars are required to pay a CO_2 tax of R75 for each gram of CO_2 per km the vehicle produces over 120 grams of CO_2 per km (OECD, 2013a). This tax amounts to approximately R1 200 on a Mini Cooper Hatchback, R2 550 on a Ford Focus ST and R8 400 on a Lexus GS 350[2].

The purchasers of light commercial vehicles and pickup trucks are subject to a steeper CO_2 tax of R100 for every gram over 175g CO_2 per km that the vehicle produces (OECD, 2013b). The CO_2 tax on vehicle purchases is the only explicit tax on carbon emissions in South Africa at the time of writing, although an economy wide CO_2 tax is in development (National Treasury, 2013).

[2] Figures from Table 8

5. Projecting the market penetration of PHEVs and BEVs

As with any rapidly developing industry with numerous stakeholders the future uptake of PHEV and BEV is challenging to predict. The literature show many estimations about the rate of PH/BEV uptake, estimations defined through informed opinions of industry stakeholders and data driven forecast modelling. The methods for creating projections for the growth of the PH/BEV market tend to be determined by the scientific background of the research team.

Forecast Modelling for New Innovations in the Marketplace

There is an extensive body of literature that details the various methods for market forecasting and their applicability to fields such as economics, business and finance and systems engineering but the automotive vehicle fleet presents a set factors that make modelling by classical methods a challenge (Al-Alawi & Bradley, 2013). Such factors are:

1. PH/BEVs are a new technology that does not have a long sales history that could be used to extrapolate a forecast. This is especially true in South Africa.
2. Unlike HEVs, PH/BEVs require consumers to shift their behaviour away from fuelling at petrol stations and toward charging their vehicles at home and at the few public charging stations. Consumer reaction to this change is not easily quantifiable.
3. PHEVs and BEVs consume fuel differently to ICEVs and so converting energy consumption to a comparable unit of measure requires a weighting of these costs and their effect on the driving behaviour of the consumers.
4. Fuel efficient vehicles are already preferentially priced through carbon taxes and so consumer preference towards these vehicles based on fuel efficiency alone is unclear.
5. Any analysis of vehicle sales is complicated by a number of factors including the market oligopoly, the long product development cycles, the used car market and the automakers finance business units.

There are 3 categories of modelling methods that have been used in the literature to forecast new products in the automotive industry: total cost of ownership models, consumer preference models and diffusion models.

Total Cost of Ownership (TCO) Models

TCO models are common in studies from automotive industry stakeholders and consulting companies. TCO relies on data that is reasonably available data such as fuel costs, tax levels, capital depreciation and parking costs. Despite being able to handle large quantities of data, TCO models are quite flexible and it is possible to include new information without having to redesign the model.

This method relies strongly on the assumptions of rational decision making on the part of the consumer and cost being the main driver of the purchasing decision. While this simplifies the model, it is widely acknowledged that the vehicle purchase decision relies on numerous other factors such as perceived quality, brand appeal, driving requirements and safety (Ramsey Media, 2012; Choo & Mokhtarian, 2004).

The McKinsey & Company preferred method for forecasting PH/BEV adoption is as part of a global greenhouse gas cost abatement curve. All the various methods to reduce GHG emissions were ranked by their total potential and their implementation cost. The level of commitment to GHG reductions from all countries is then used to determine an estimate for total GHG reductions which is assigned to individual reduction methods based on their rankings on the curve. The McKinsey & Company (2009a) report projected 42 Million Hybrids and PH/BEVs worldwide would be sold per year by 2030; equivalent to 40% of the new car market. In a second publication released by the same company later that year the projections specifically for the PH/BEV market share were provided as three scenarios. Scenario 1 entails focusing on optimising ICEV efficiency with little to no support for HEVs and PH/BEVs, understandably leading to a negligible PH/BEV market share. Under a scenario whereby public policies favour both making ICEVs more efficient and encouraging adoption of PH/BEVs it is estimated that in the year 2030 around 16 million PHEVs and 3 million BEVs will be sold. The final scenario considered is a full embracement of HEVs and PH/BEVs by policy makers and estimates for 2030 are for about 24 million PHEVs to be sold in addition to 8 million BEVs (McKinsey&Co., 2009b).

A 2008 Deutsche Bank report used a TCO model to project that by the year 2020 nearly half of all new passenger vehicle sales in the United States would be HEV, PHEV or BEV (Deutsche Bank Research, 2008).

TCO models also suffer from the assumption that two different decision makers would make the same choice in the same situation. Correcting for this requires the inclusion of a segmentation component as is done in the most notable academic TCO based study of PH/BEV markets, Mock et al (2009). The Institute of Vehicle Concepts at the German Aerospace Centre uses this model called Vector21 to project the future German market shares of all vehicle types (Mock, Hulsebusch, Ungethum, & Schmid, 2009). The model is based on vehicle manufacturer behaviour (supply side) and customer behaviour (demand side). The supply side modelling entails defining the future prices of vehicles that will be supplied to the consumers by accounting for vehicle energy consumption, fuel costs, technology learning curves and infrastructure requirements. The demand side modelling involves mimicking the consumer choice by first filtering vehicles by size categories, then selecting the ones with the lowest total cost of ownership before finally choosing the vehicle variant with the lowest well-to-wheel CO_2 emissions. Mock et al. examines two scenarios using this model, a business as usual scenario and a government intervention scenario. The business as usual scenario represents current German policies that are set to favour a move to PH/BEVs and as such, under this scenario BEVs reach the maximum set parameter of 50% of the small vehicle market by 2030 with petrol and diesel HEVs comprising the other 50% of the market. The parameter was set to reflect concerns over range limitations. Under the government intervention scenario progressive measures are taken to reduce CO_2 emissions and the model projects that again 50% of the German light vehicle market would opt for BEVs in 2030, with Fuel Cell Hybrid Electric Vehicles gaining 40% market share and the remaining 10% belonging to petrol HEVs (Mock, Hulsebusch, Ungethum, & Schmid, 2009).

Consumer choice models

Consumer choice modelling involves using the preferences of consumers among different alternatives to construct discrete choice or logit models that describe individual and group decision making. In the automotive case the alternatives are the different types of vehicles which are defined by attributes such as price, driving range and added features. Ideally the preferences of consumers could be revealed by using the sales history of the product but in the case of new products such as PH/BEVs this is not possible and so data must be collected through stated preference surveys.

Bain & Company conducted such a survey in 2008 and based on the results created 3 scenarios to estimate 2020 global PH/BEV sales. PH/BEVs sales were estimated to be 7%, 25% or 50% of total light vehicle sales under little change, basic change and fundamental change scenarios respectively (Matthies, Stricker, & Traenckner, 2010). The conservative scenario assumes low oil prices, lenient emissions standards, little public consensus on climate change mitigation and only regionally provided subsidies for PH/BEVs. The basic scenario assumes moderate oil prices, zero emission zones in many large cities, some global action towards climate change and worldwide PH/BEV subsidies of $10-30 billion. The fundamental change scenario goes a step further and assumes high future oil prices, zero emissions zones in all major cities, fervent climate change mitigation attempts and large subsidies for PH/BEVs in the range of $50-100 billion US worldwide (Matthies, Stricker, & Traenckner, 2010).

Santini and Vyas (2005) introduced the Advanced Vehicles Introduction Decision (AVID) model. AVID utilises a multinomial logit with vehicle price, fuel cost, range, battery replacement cost, acceleration, home refuelling, maintenance cost, luggage space, fuel availability, top speed, emergency home power, use of preferential driving lanes and electric outlet for tools as explanatory variables. Consumers are divided between early adopters 15% and majority buyers (85%). The market for HEVs was analysed under 4 scenarios comprising high or low gasoline prices and high or low purchase price differentials between HEVs and ICEVs. In the scenario where gasoline prices are low and HEVs remain expensive relative to ICEVs then the model estimated that HEVs sales would reach a peak of 3% of the market within 10 years of introduction and by 2020 experience a market share of just 1%. In the counter scenario of high oil prices and relatively cheaper HEVs the AVID model estimates a HEV market share of 57% by 2020 (Santini & Vyas, 2005).

The main objection raised to consumer choice models in the literature is that stated preference surveys are tricky to implement and might not provide very accurate data (Sullivan, Salmeen, & Simon, 2009). The actual revealed preferences of consumers can be quite different to stated preferences that are declared prior to a hypothetical activity or decision. This is particularly true in cases where consumers might want to think they will chose the noblest option, such as driving a vehicle that is better for the environment, but when tested the inconvenience of factors such as driving range restrictions are shown to outweigh any environmentally gallant behaviour.

Diffusion models

Diffusion is defined as the process of acceptance of a new invention or product by the market (Al-Alawi & Bradley, 2013). Diffusion models often assume fixed saturation levels for the market potential of a new product. The vast majority of diffusion models also assume that the probability of a consumer buying a new product is a linear function of those who have previously adopted the innovation. Consumers can be characterised as either innovators or imitators with the imitators being broken down into early adopters, early majority, late majority and laggards (Bass, 2004). As the categorical breakdown suggests, the sales of a new product will start off small as only the innovators purchase. Sales will begin to grow exponentially as the early adopters and early majority enter the market. Sales will continue to increase at but at a decreasing rate once the late majority start purchasing the product and by the time the laggards enter the market sales will start to plateau. Sales over time as a new innovation enters the market forms an S-curve. This assumption is at the core of the Bass, Gompertz and Logistic models variations that populate the literature. The parameters that affect the gradient of the S-curve are calculated using historical sales data of the new product. In the case of a product being completely new to the market, the sales history of a similar product or group of products can be used (Lilien, Rangaswamy, & De Bruyn, 2007).

The Bass model was first published in Bass (1969) and despite a mistake in the title[3] has become one of the most widely used models to forecast the diffusion of new products and innovations. Whilst a review of the literature shows that variations of the Bass model have been the most common

[3] "A New Product Growth for Model Consumer Durables" was intended to read "A New Product Growth Model for Consumer Durables"

method to forecast the take up of PH/BEV there are several studies that employ Gompertz and logistic curve models. What makes the Bass model so appealing is how it allows for direct consideration of network effects.

Paixao (2010) uses logistic curves to project that BEVs will account for 14.92% of Brazil's passenger vehicle sales market by 2020 and 49.96% by 2030. This predicted growth in market share occurs even as the Brazilian passenger vehicle fleet nearly doubles in size between 2010 and 2030.

Becker, Sidhu and Tenderich (2009) used a Bass model to project that by 2030 up to 46% of the United States light vehicle stock could be comprised of electric vehicles. Using the more conservative scenario in their model still led to approximately 24% of the US light vehicle stock in 2030 being of the electric variety.

Balducci (2008) makes some interesting projections for PHEVs in the United States. Three scenarios are suggested for 2035. In the most conservative scenario, if sales of PHEVs are similar in trend to the sales of HEVs up to that period then PHEVs would account for 12% of new car sales. In the second scenario it is assumed that all research and development goals are met and PHEVs are then estimated to capture 28% of the 2035 US new car market. In the third and most aggressive scenario it is assumed that consumers will purchase all vehicles that it is possible for automotive and battery manufacturers to provide whilst not demanding more from the electricity grid than existing idle off-peak capacity allows. This scenario arrives at PHEVs comprising 68% of US new vehicle sales in 2035. While scenario 3 is extremely unlikely it does show that even with the most rapid plausible uptake of PHEVs there won't be more demand on the electricity grid than what would be manageable at current power generation levels. In fact, under scenario 3 it would take until 2045 for current off-peak power capacity to be insufficient for further PHEVs in the US.

Karplus, Paltsev & Reilly (2010) perform a cross country analysis of the US and Japan PH/BEV markets under a no new policy scenario and a PH/BEV friendly policy scenario. In a no new policy scenario it is projected that by 2030 approximately 10% of the US and 25% of the Japan vehicle fleets will be made up of PH/BEVs. Extending this scenario to 2050 and PH/BEVs in the US vehicle fleet is up to 35% while in Japan PH/BEVs comprise up to 90%. Under their PH/BEV friendly policy scenario the US is able to achieve a PH/BEV market share of around 25% by 2030 while the same scenario would supposedly lead to the entire 2030 Japan vehicle fleet being comprised of PH/BEVs.

Wansart and Schnieder (2010) analyses the adoption of a new infrastructure dependent technology in a market dominated by an established competitor by looking at the case of BEVs and ICEVs. Based on a generalised Bass model the authors come to the somewhat surprising result that public infrastructure instalment plays a fairly small role in the market adoption of BEVs. The performance capabilities of BEVs are revealed to affect the maximum size of the total potential market but not the rate at which vehicles are adopted. The results of the study also show that in such a competitive market environment, public awareness is highly influential in the diffusion of BEVs.

Cao and Mokhtarian (2004) used a Bass model to analyse the future sales of a variety of alternative fuel vehicles. Due to the various types vehicles being studied it was necessary to assume that consumers could fall into the potential market of only one vehicle type and would not opt for another powertrain later. The maximum market potential for all alternative fuel technologies was calculated at each stage as a factor of model availability, gasoline prices and the fuel price ratio but due to a lack of data this was not possible for HEVs. For this reason the maximum market potential for HEVs was assumed to be 10% of 2000 light vehicle sales. The model forecasts were used to analyse the sensitivity of the HEV market in the US to various public awareness and gasoline price scenarios. Using the two extreme scenarios of high gasoline prices with low public awareness and low gasoline prices and high public awareness it was estimated that 2025 HEV stock could range from approximately 17 million to 35 million.

Several studies in the literature compare the various diffusion modelling methods such as McManus and Senter (2009) which analyses the PHEV market in the US using a standard Bass, Generalised Bass, Gompertz and logistic diffusion models. All four models predict peak annual sales of between 340 000 and 370 000 PHEVs. The Gompertz model has a maximum market potential that, at 4.4 million, is more than double that of the other models. After expressing their concerns with the accuracy and relevance of the 4 fixed saturation models the authors adapt the Centrone, Goia and Salinelli (2007) Generalised Bass model to the PHEV market. This model generates the maximum market potential as a funtion of time with new potential customers entering the potential market and old customers leaving. Under this model annual sales of PHEVs in the US are predicted to be less than 500 000 for the first 20 years after introduction but this will grow to approximately 1 million 30 years after introduction. In the final model analysed by McManus and Senter (2009) the authors draw on Struben and Sterman (2008) and incorporate consumer preferences into the adapted Bass model, creating a combined consumer choice and diffusion model. McManus and Senter dub this model the consideration-purchase model. The consideration-purchase model has the added benefit of accounting for the dynamics of vehicle sales, stock and scrappage. PHEV adoptions are shown to be extremely sensitive to prices and based on extreme high and low price scenarios, 2035 sales vary from 380 000 to over 6 million units.

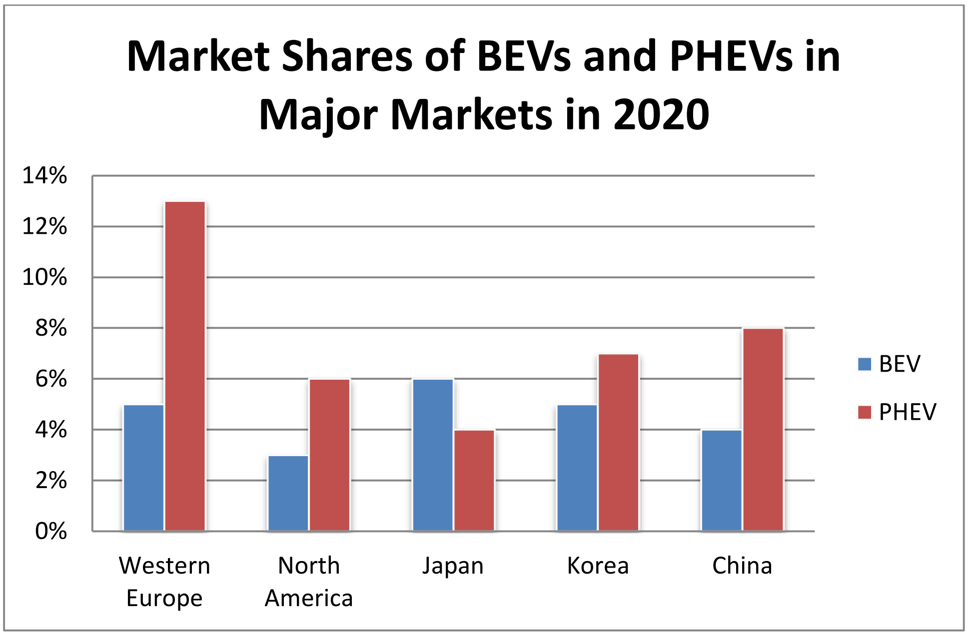
An adapted generalised Bass model was used in Jeon (2010) to forecast the HEV, PHEV and BEV markets in the United States. Vehicles were assumed to develop in successive generations and this assumption allowed the model to remove the market saturation restriction. The logic behind this assumption is that as PH/BEVs improve in funtionality there will be a larger group of consumers that will find PH/BEVs compatible to their driving requirements. The model predicts that by 2020 HEV sales could number almost 3.5 million, PHEV sales of over 200 000 and BEV sales of more than 450 000. By 2030 approximately 5 million HEVS, 1 million PHEVs and 2.1 million BEVS could be sold in the US.

Diffusion models are a popular choice for forecasting PH/BEV adoption as they are easy to implement and can be fitted the historical trend of the PH/BEV sales or to the historical sales of similar products. However the main disadvantage of these models is that the ultimate market potential for the innovation must be estimated outside the model (Al-Alawi & Bradley, 2013).

Other models

Roland Berger (2011) projected 8-10% of global passenger vehicle sales will be PH/BEVs by 2020 (RBSC, 2011). The type of model used was not disclosed. Figure 6 shows the market shares that PH/BEVs are predicted to capture in 5 major markets. Japan is anticipated to have the population most accepting of BEVs and is the only major market where BEVs are expected to outsell PHEVs. Western European is expected to have the highest percentage of PHEVs on their roads at 13% market share in 2020.

Figure 6: RBSC Estimates of PH/BEV Market Shares of New Sales in Major Markets 2020



Source: (RBSC, 2011)

After forecasting: Agent Based, General Equilibrium and Composite Models

Usually after forecasting models have created a credible prediction of the fortunes of a new market intervention other modelling takes place to determine the impact the projected penetration figures would have on a variety of concerns such as the prospects of the industry, economy or environment. General Equilibrium modelling or Agent Based Modelling are commonly used and are included as later components in several of the studies previously mentioned.

Agent Based Modelling (ABM) is a computationally intensive simulation method that uses the individual characteristics and preferences of the consumers, automakers, policymakers and fuel suppliers as decision-making agents in complex interaction modelling. This type of modelling is very useful as it allows for models to be developed based on both observed data inferences and hypothetical consumer behaviour estimations while still entertaining the possibility of exogenous shocks to the system such as policy shifts or sudden changes in fuel prices. The decisions of the agents ultimately come down to their preferences and their willingness to pay. While ABMs provide useful simulations of what is possible given the decisions of the individual agents, this approach does not produce forecasts of future markets. ABMs produce possible outcomes given sets of assumptions of how the individual agents decide and can help determine the effect that policies have on PH/BEV industry development (Sullivan, Salmeen, & Simon, 2009).

General Equilibrium analysis was conducted for economy wide modelling of South Africa for use in the examination of the Long Term Climate Mitigation Scenarios (Winkler, 2007). Under the modelling scenarios 20% of private vehicles are estimated to be HEVs by 2030. In the case of BEVs approximately 10% passenger kilometres travelled between 2008 and 2015 will be catered for by this new mode of transport. By 2030 up to 60% of passenger kilometres demanded will be BEVs with this figure assumed to stay constant between 2030 and 2050 (Winkler, 2007).

A variety of models were combined in order to project the energy demands of the South Africa transport sector, with a general equilibrium model being amongst them (Merven, Stone, Hughes, & Cohen, 2012). Assumptions for the market shares of hybrid and electric vehicles were based on the level of policy incentives for the various forms of technology up to the year 2050. A reference scenario was constructed using historical trends that were allowed to continue over the course of the examined period and so no new technologies were considered to enter the market. The alternative scenario that was considered allowed the introduction of a variety of alternative vehicles. In the event of government incentives for diesel and gasoline HEVs in addition to electric vehicles the 3 vehicle types were able to each capture 3% of the new car sales market by 2020 and a peak of 5% each by 2030 which remained consistent to 2050. Merven et al. (2012) also examined the Bus Rapid Transport (BRT) system in South Africa. In the event of infrastructure for electric and compressed natural gas vehicles being made available for the BRT system under the alternative scenario the predicted market shares of compressed natural gas and electric vehicles rose steadily with diesel vehicle market share declining from the base of 100% to 50% by 2050. Compressed natural gas and electric vehicles were predicted to each have BRT market shares of 6% by 2020, 13% by 2030, 19% by 2040 and 25% by 2050 (Merven, Stone, Hughes, & Cohen, 2012).

Dane (2013) examined the emissions reductions potential of electric vehicles in South Africa based on the assumption that 5 500 electric vehicles would be purchased in the base year and this value would rise by 10% per year till 2030 at a value of approximately 27 800.

Agent Based, General Equilibrium and the variety of composite models, such as those mentioned above, rely on usable predictions of market dynamics and either include their own forecasts or base their projections on the results of other studies. Such modelling is prominent in the analysis of the PH/BEV market but is beyond the scope of this study.

Table 4: Summary of H/PH/BEV Market Forecasting Studies

Author	Region Analysed	Forecast	Modelling method
McKinsey & Company (2009a)	World	42 Million H/PH/BEVs sold annually by 2030	TCO
McKinsey & Company (2009b)	World	3 scenarios: Between 17 and 29 Million PH/BEVs sold annually by 2030	TCO
Roland Berger Strategy Consultants (2011)	World	PH/BEVs account for 8-10% of global light vehicle sales by 2020	Undisclosed
Matthles, Stricker & Traeckner (2010)	World	3 scenarios: PH/BEVs account for 7%, 25% or 50% of global sales by 2020	Consumer choice
Becker, Sidhu & Tenderich (2008)	USA	BEVs account for 24% of light vehicle stock by 2030 (46% with aggressive estimates)	Diffusion
Deutsche Bank Research (2008)	USA	H/PH/BEVs make up 22% of car sales by 2015 and 49% by 2020	TCO
Balducci (2008)	USA	3 scenarios: PHEVs have annual market share by 2035 of 12% under basline scenario, 28% if all R&D goals are met and 68% assuming that the only thing stopping people from buying a PHEV is supply shortages	Diffusion
McManus & Senter (2009)	USA	6 models and a variety of scenarios used throughout. PHEV annual sales range between 280 000 and 6 million in 2035	Diffusion
Jeon (2010)	USA	5 million HEVs, 1 million PHEVs and 2.1 million BEVs are sold in the year 2030	Diffusion
Cao & Mokhtarian (2004)	USA	2 scenarios: HEV stock ranges from 17 - 35 million in the year 2025	Diffusion
Santini & Vyas (2005)	USA	2 scenarios: HEVs have market share of 1% or 57% by 2020	Consumer choice
Hensley, Knupfer & Krieger (2011)	Urban Areas	PH/BEVs account for 16% of sales in New York, 9% in Paris and 5% in Shanhai by 2015	Consumer choice
Karplus, Paltsev & Reilly (2009)	Japan	PH/BEVs make up between 10% and 30% of vehicle fleet by 2030 and 90%-100% by 2050	Diffusion

Mock, Hulsebusch, Ungethum & Schmid (2009)	Germany	2 Scenarios: PH/BEVs capture 15% of the market under business-as-usual scenario. BEVs capture 50% of the market under the progressive scenario by 2030 with PHEVs claiming 0%	TCO
Paixao (2010)	Brazil	BEVs capture14.92% and 49.96% of the passenger vehicle market 2020 and 2030 respectively	Diffusion
Winkler (2007)	South Africa	BEVs provide 10% of passenger kilometres travelled by 2015 and 60% by 2030	Stakeholder opinion
Merven et. Al. (2012)	South Africa	BEVs capture 3% of the new car market by 2020 and 5% by 2030	Stakeholder opinion
Dane (2012)	South Africa	5500 BEVs sold in 2014, rising by 10% p.a. until 2030	Stakeholder opinion

6. Projecting PH/BEV Demand in South Africa

With no official targets announced by the South African government there is a great deal of uncertainty over how many PH/BEVs can be expected on South African roads. A fairly believable estimate is required in order to predict the effect that PH/BEVs could have on the GHG emissions, oil prices, electricity demand, the national trade balance, employment and capital expenditures. A credible figure for PH/BEV adoption in South Africa will also give PH/BEV suppliers an indication of whether distributing or assembling their vehicles to/in South Africa will be justified. Policy makers can then use the reaction of the manufacturers to determine if their efforts to encourage PH/BEV adoption are sufficient.

This section develops an adapted Bass diffusion model that is capable of estimating PH/BEV adoption in a South African scenario while also being able to account for the effects of the various policy scenarios that are under consideration by policy makers. Two specific scenarios were considered for projections to 2050. The first of these scenarios entails unfavourable conditions for PH/BEVs with technology developing slowly, only modest policy support, high electricity prices and relatively low oil prices. The second scenario considered consists of a more optimistic set of assumptions from the perspective of demand for PH/BEVs. These assumptions are technology development staying on schedule with projected rates, firm but not unrealistic policy support, limited electricity price increases and continuous escalation of oil prices.

The Bass Diffusion Model

The Bass model was chosen as the starting point for developing a PH/BEV adoption forecast model due to its prevalence in the literature, the relatively uncomplicated data requirements and the adaptability of the model. The data demands of the model are particularly important for this study as the focus is on South Africa which does not have the level of data available in the US and Europe. The adaptability of the model was also strongly considered when choosing the base model as adjustments are required for South African conditions and available data. As this model is the first of its kind in South Africa it seemed prudent to build from a structure that is well established in the literature but leaves room for localised adjustment. Future studies will be able to update the model as new data becomes available without the need to develop a fundamentally new model.

The standard Bass equation is shown below (Bass, 1969):

$$F(t) = \frac{1 - e^{-(p+q)t}}{1 + \frac{q}{p}e^{-(p+q)t}}$$

$$A(t) = m[F(t)]$$

Variables:

m	Maximum Potential Market
p	Coefficient of Innovation
q	Coefficient of Imitation
F(t)	Cumulative rate of adoption
A(t)	Cumulative number of adopters
t	Time

In this form the model is dependent on the maximum potential market (m) to determine the sales peak and on the coefficients of innovation (p) and imitation (q) to determine the rate of growth in sales until the peak is reached. The Bass model assumes that the maximum potential market for the new product is constant over the time period considered in the model. This assumption is a strong one and does not fit the case of PH/BEVs particularly well as the total vehicle market in South Africa is growing and it is also expected that improvements in PH/BEV technology and infrastructure will make the vehicles feasible for wider groups of consumers. In order to account for technological breakthroughs and increased levels of infrastructure the maximum market potential of PH/BEVs can be divided into different generations.

Generations of technology

The Norton-Bass model allows for successive generations of a technology with different maximum market potentials and altering coefficients of innovation and imitation although it is generally assumed that p and q remain constant (Norton & Bass, 1987 ; Bass, 2004).

The sales of each generation of a new market innovation are shown below for an innovation that has four technological generations:

$$S_1(t) = F_1(t)m_1[1 - F_2(t)]$$

$$S_2(t) = F_2(t)[m_2 + F_1(t)m_1][1 - F_3(t)]$$

$$S_3(t) = F_3(t)[m_3 + F_2(t)[m_2 + F_1(t)m_1]][1 - F_4(t)]$$

$$S_4(t) = F_4(t)[m_4 + F_3(t)[m_3 + F_2(t)[m_2 + F_1(t)m_1]]]$$

$$F_i(t) = 0 \quad for\ all\ t < \tau_i$$

Variables:

For *i* = 1,2,3,4

S_i(t)	Sales for generation *i*
F_i(t)	Rate of adoption for generation *i*
m_i	Incremental market potential for generation *i*
τ_i	Introduction time of generation *i*

The maximum potential market will alter for each successive generation but within each generation the rate of adoption is still determined by the coefficients of innovation and imitation. The coefficients of innovation and imitation are assumed to remain constant between generations and over the timeframe considered in the model (Norton & Bass, 1987) and so in order to account for developments in the PH/BEV industry such as changes in vehicle prices, driving costs and infrastructure investments through the introduction of a marketing effect.

Generalised Bass Model

The generalised bass model allows for the introduction of consumer decision variables into the equation (McManus & Senter, 2009).

$$A'(t) = \left(p + \frac{q}{m}[A(t)]\right)\left(m - A(t)\right)x(t)$$

$$F(t) = \frac{1 - e^{-(p+q)x(t)}}{1 + \frac{q}{p}e^{-(p+q)x(t)}}$$

The standard Bass equation is multiplied by the expression *x(t)* which is a function of the decision variables.

$$x(t) = t + \beta_1 \ln(P(t)) + \beta_2 \ln(G(t))$$

$$P(t) = \frac{P_{EV}(t)}{P_{ICE}(t)}$$

$$G(t) = \frac{G_{EV}(t)}{G_{ICE}(t)}$$

Variables:

P(t)	Purchase Price Premium %
P_{EV}(t)	Purchase Price of PH/BEV
P_{ICE}(t)	Purchase Price of ICEV
B_1	Consumer sensitivity to purchase prices
G(t)	Running Cost Premium %
G_{EV}(t)	Running Cost of PH/BEV
G_{ICE}(t)	Running Cost of ICEV
B_2	Consumer sensitivity to running costs

P(t) is the average purchase price for a PH/BEV relative to the average purchase price of an ICE vehicle. B_1 is the parameter that accounts for the sensitivity of consumers to changes in prices of PH/BEVs relative to the purchasing price of ICE vehicles.

G(t) is the average running cost of a PH/BEV per kilometre relative to the average running cost of an ICE vehicle per kilometre. β_2 is the parameter for the sensitivity of consumers to the proportionate differences in average running costs between PH/BEVs and ICEVs.

The cumulative rate of adoption can be found by the equation below

$$A(t) = M\left[\frac{1 - e^{(-(p+q)(t+\beta_1 \ln(P(t))+\beta_2 \ln(G(t))))}}{1 + \left(\frac{p}{q}\right)e^{(-(p+q)(t+\beta_1 \ln(P(t))+\beta_2 \ln(G(t))))}}\right]$$

Defining variables and parameters

Grouping BEVs and PHEVS

The decision to group BEVs and PHEVs into one category of vehicle was not taken lightly and despite the obvious differences between the two technologies the purposes of this study are better served by a singular competitor to ICEVs. Bass models make the general assumption that there are no directly competing introductory products that limit the growth of the new market innovation. BEVs and PHEVs can also not be viewed as different generations of the same technology as they are being released in South Africa concurrently.

PHEVs do provide extended range compared to BEVs but the use of both forms of drivetrain comes at a price premium that is assumed to eclipse the driving range benefits. PHEVs can cost as much as $4 000 US more than a comparative BEV (IEA, 2011). It is also assumed that PHEVs are purchased by the consumer with the intention of relying on the electric drivetrain for the majority of driving needs.

Considered Timeframe

Standard practice for Bass diffusion models and the many adaptations is to examine a time period of 30 years after the introduction of a new market innovation. There is no reason for this 30 year time period other than it is a round number which provides enough time for most single technology generation innovations to reach their maximum market potential. As no other forecast models for PH/BEV adoption in South Africa were discovered in the literature, the only figures that enable comparison are stakeholder opinions. Stakeholder opinions tend to make estimates for five or ten year intervals and so it was decided to extend the considered time period in this study to 37 years after the initial mainstream introduction of PH/BEVs, to 2050.

Defining Maximum Potential Market for each Generation of PH/BEVs

This maximum potential market share represents the portion of the vehicle buying population that have driving needs that could be met by PH/BEVs. It is assumed that if the driving needs of a consumer can be met by a PH/BEV then the only factors that would dissuade the consumer from purchasing a PH/BEV over an ICEV are financial. The maximum potential market for each generation of PH/BEVs is estimated by taking the growing South African light vehicle market at the time of introduction of each PH/BEV generation and removing the percentage of the driving population that use their vehicles for purposes which the current technological generation of PH/BEVs is ill-equipped for. Also removed is a percentage of consumers who would opt for a PH/BEV over an ICPH/BEV and would even be willing to pay a purchase price premium to do so but are simply not offered an PH/BEV in their price bracket. In each successive generation the capabilities of PH/BEVs are assumed to improve and the purchase price of the cheapest available PH/BEVs is assumed to drop.

Nearly 540 000 vehicles were sold in 2012 in South Africa according to the data displayed in Table 5. As shown in Table 5, each vehicle sold was categorised as a bus, extra heavy truck, heavy truck, medium truck, light truck or car. In this dataset the car category includes SUVs and is similar to the light passenger vehicle category found in other datasets. Considering only the light passenger vehicle market was found to be the norm in the PH/BEV forecasting literature but careful consideration was given as to whether a similar distinction is appropriate for South Africa.

Buses, extra heavy trucks, heavy trucks, medium trucks and light trucks are used for either carrying out business activities or for the transportation of people.

Most trucks are used for commercial activities such as construction, agricultural or transportation of goods. The common lack of charging infrastructure in areas where construction and agricultural activities take place presents an immediate problem for transitioning the fleet to PH/BEV alternatives which is only compounded by the raw horsepower required for these activities putting significant strain on the vehicle batteries. Speciality PH/BEVs could be used for some of these commercial activities but are a long way from being widely available (EVI, 2012). The transportation of goods entails either short trips demanding plenty of engine power or long range trips. High powered engines are difficult to power for a meaningful length of time using a battery and limits on PH/BEV driving range in addition to a lack of public charging infrastructure makes it unlikely that PH/BEVs will be able to replace the vehicles in this category in the foreseeable future.

Vehicles used to transport people are a particularly interesting category in South Africa due to the prominence of minibus taxis which are not common in the majority of the countries examined in the PH/BEV forecasting literature. Buses and Minibus taxis in urban areas are driven in a stop/start pattern and at low speeds, conditions under which PH/BEVs operate far more efficiently than ICEVs. Outside of urban areas the longer distances travelled and higher speeds make PH/BEVs less suitable for the transportation of people but still feasible. When buses are not in service they are stored at a central location making the installation of charging facilities easy and cost effective. Minibus taxis do not have this factor in their favour as drivers tend to take their vehicles to their residence when not in use. The ultimate factor that determined the placement of buses and minibus outside the scope of this study was that such vehicles are predominantly purchased in significant quantities by a single purchaser or fleet owning entity and will therefore experience different adoption patterns than regular passenger vehicles.

The value considered as the base year total light passenger vehicle market in the forecast model is equivalent to the sales of cars from 2012, shown in Table 5 to be 364 725 units.

Table 5 : 2012 Vehicle sales by class

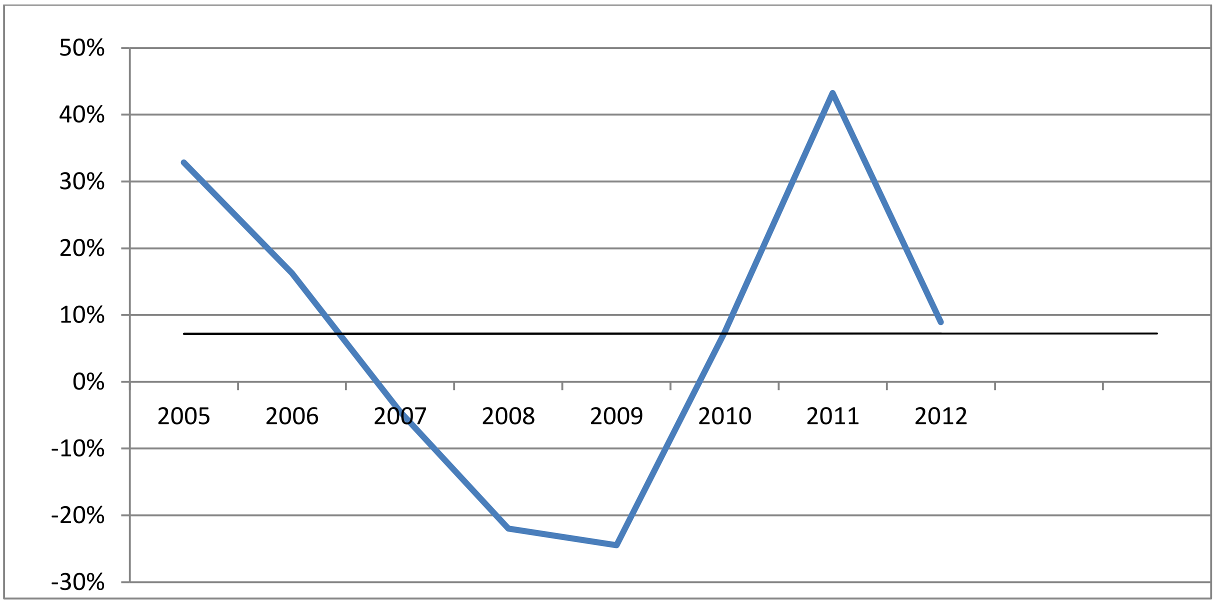
Total	**539 288**
Cars	364 725
Buses	1 134
Extra Heavy Trucks	11 621
Heavy Trucks	4 982
Medium Trucks	9 654
Light Trucks	147 172

Source: MarkLines Database (2013)

South African is a developing nation and vehicle sales are likely to grow each year. As shown in figure 7, sales of vehicles in South Africa between 2005 and 2012 experienced fluctuating growth rates. 2007, 2008 and 2009 actually experienced negative growth rates brought on by the financial crisis that began in late 2007. Over this 8 year period the new vehicles market grew on average 7.21% per year. Due to the extended time period being examined it was assumed that growth in vehicle sales would not be so consistently strong, especially in later years when alternative transportation methods are assumed to have improved. A more conservative and realistic estimate of 6.5% annual growth in vehicle sales was assumed until 2020, dropping to 3% for the remainder of the considered time period. The estimates created by the stated growth rates are approximately consistent with the estimates used in Merven, et al.(2012) of 949 000 to 1 496 000 annual car and SUV sales by 2050.

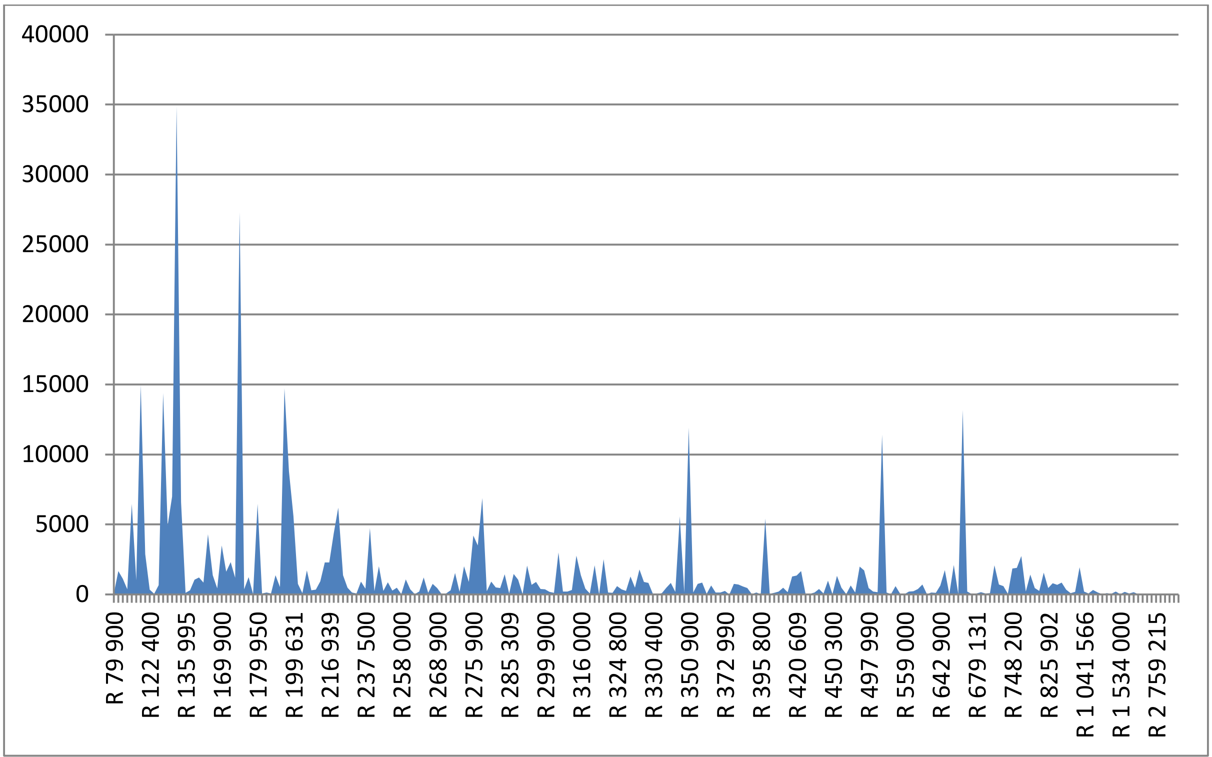
The maximum potential market for PH/BEVs is initially constrained by the budget of the average vehicle purchaser. The Nissan Leaf was introduced to the South African market at a price of R446 000 (Venter, 2013b), a rather steep price for a general purpose 4 door hatchback. Even for some South African consumers that are very eager to purchase an PH/BEV, this price is something which they are just not able to afford. Figure 8 displays the prices of vehicles relative to their 2012 sales. As shown in the figure, 69.5% of vehicles sold in 2012 had average retail starting prices of under R200 000, certainly not the portion of market that would be able to spend more than double the price to opt for an PH/BEV alternative. For this reason it is assumed that consumers will be removed from PH/BEV purchase consideration if the purchases made in 2012 indicate that that the current generation of PH/BEVs does not fall into their price bracket of ICE purchase price plus 50%. The term for this extra amount that a consumer is able to pay but chooses not to for an ICE vehicle is the consumer price bracket extension ability. There is no upper bound for the PH/BEV price bracket as vehicles like the Tesla Model S and Roadster target high income groups and have been well received in other countries. The lowest price for each generation of PH/BEVs was estimated by using the starting price of the recently introduced Nissan Leaf (R446 000) for the 1st generation and subsequent drops in price to R350 000, R200 000 and R100 000 for each of the successive generations. The low end PH/BEV prices for generations 2, 3 and 4 were chosen based on their proximity to being within the price brackets of 50%, 75% and 100% of new vehicle consumers.

Figure 7: Annual Percentage Growth in South African New Vehicle Sales (2005-2012)



Source: adapted from Marklines Database (2013)

Figure 8: Average Starting Prices of Vehicles Relative to Units Sold (2012)



Source: Compiled from Marklines Database (2013) & RGT Smart (2012)

Results from the 2012 Autobrand survey were used to estimate the percentage of consumers that would have their driving needs met by each successive generation of PH/BEV technology (Ramsey Media, 2012). The percentage of users who would consider purchasing a PH/BEV in each generation was assumed to be equal to the percentage of respondents who could afford at least the cheapest PH/BEV of that generation and cited reasons for purchasing a car which that generation of BEVs would be capable of performing. Each successive generation was assumed to be capable of all the activities of previous generations.

1st generation

The first large scale introduction of PH/BEVs takes place. The cheapest vehicles are unaffordable to approximately 67% of consumers, only 2 or 3 models are available and public infrastructure is limited. BEVs are only suitable for daily commutes to work and so 43% of consumers have their driving needs met by PH/BEVs. The maximum potential market share for PH/BEVs is 14%[4].

[4] Of the 33% of light passenger vehicle purchasers that could afford to purchase a PH/BEV only 43% would have their driving needs met and so the maximum potential market share (0.33)*(0.43)=0.1419 ≈ 14%

2nd generation

Around 5 years after the introduction of PH/BEVs to South Africa there are several models available to consumers but options are still limited. 56% of consumers are unable to afford even the cheapest PH/BEVs. The more highly developed urban areas have public charging infrastructure. BEVs are now suitable for weekend leisure activities and travel to such leisure activities, meeting 52% of consumer driving needs. The maximum potential market share for PH/BEVs in this generation is 23%.

3rd generation

15 to 20 years after PH/BEVs are fully introduced there are a wide variety of vehicles to choose from and 75% of consumers have a PH/BEV option in their price range. BEVs can now feasibly be used for travelling to holiday destinations and travelling around while at holiday destinations, meeting 64% of driving needs. The maximum potential market share for this generation is 48%.

4th generation

Between 25 and 30 years after the initial introduction, PH/BEVs are within the budget of 100% of vehicle consumers. PH/BEVs are widely available and varied with ample public charging infrastructure. 87% of consumer driving needs are met with BEVs capable of being used for the transportation of goods and passengers and long trips on a daily basis. The maximum potential market share for this generation of PH/BEV technology is 87%.

BEVs are assumed to not be able to be used to perform construction and farming activities within the timeframe of the model.

Under the optimal scenario the latest generations of technology are achieved as soon as possible while under the slow development scenario the 3rd generation of PH/BEVs is only available after 20 years and the 4th generation after 30 years

Defining rates of innovation and imitation (p's and q's)

The coefficient of innovation captures the subset of consumers who will be early adopters of PH/BEVs. The fundamental driving needs of these consumers are likely to be met by PH/BEVs and they are less concerned about paying a small purchasing premium, driving range issues or charging cost and convenience than they are with being seen as trend-setting PH/BEV driver or a supporter of environmental conservation. Alternatively a consumer could fall into this category because PH/BEVs meet their driving needs better than ICE vehicles.

The coefficient of imitation is the variable which captures consumers for whom the purchasing decisions of others is important. These are the consumers who would decide to purchase a PH/BEV once they have seen a few being driven around, they know somebody who has purchased one or they witness enough infrastructure investment to feel comfortable making the financial commitment.

The coefficient of innovation is usually quite small at values of 0.01 or less (Mahajan, Muller, & Bass, 1995). The coefficient of imitation has been found to rarely lie outside the 0.3 to 0.5 range (Mahajan, Muller, & Bass, 1995). Based on a study of 213 products Sultan et al (1990) found that coefficients of innovation have an average of approximately 0.03 and the coefficients of imitation average 0.38.

The common practice method to determining the coefficients of innovation and imitation is to use the historical sales figures for the product and using a statistical program, run an ordinary least squares regression on the data to determine values for p and q. In the study of PH/BEVs there is usually an absence of sales data, something which is particularly true in the South African case. In some studies of PH/BEV diffusion the sales data for hybrid vehicles is used as a proxy. The concern with this method is that while HEVs are greener driving alternatives to ICEVs, they do not really have all that much in common with PH/BEVs. Hybrids are more similar to fuel efficient vehicles than PH/BEVs since hybrids are fuelled in the same manner to conventional automobiles. HEVs owners may encounter battery replacement costs that are similar to PH/BEVs but both PHEVs and BEVs require changes in driving and refuelling habits that are distinct from HEVs. PH/BEVs often require charging stations to be installed at the owner's residence or place of work at significant cost. BEVs have smaller driving ranges than HEVs and ICEVs and so longer journeys require planning and a reliance on public charging or battery swap stations that are yet to be constructed in South Africa. HEVs simply need to be filled up with fuel less regularly than their conventional counterparts. Another factor that further dissuades regressing HEV sales and using the discovered coefficients in this study is the short history of hybrid vehicles sales in South Africa. The Toyota Prius was introduced to South Africa in 2005 but despite selling over 250 units over two years was not offered again until 2011 (Marklines Database, 2013). 2 HEVs from Honda, the Lexus CT and the Toyota Prius have been available since 2011 but with only 2 points of reference there is insufficient data for an accurate estimate (Marklines Database, 2013; Bass, 2004).

In the absence of usable early sales figures for PH/BEVs or even HEVs, p and q values could be constructed by using the historical data of products that have been on sale for many years and are fundamentally similar to PH/BEVs. The Bass model variables calculated from historical data for a selection of products are shown in Table 6. The obvious difficulty is finding products that are analogous to the product in question and in some cases data for the general industry that the innovation belongs to is used (Lilien, Rangaswamy, & Van den Bulte, 1999). Industry specific data is available for consumer electronics, appliances, medical equipment, pharmaceutical drugs, semiconductors, agricultural equipment and many other products (Dodson, 2010). Five base categories are usually considered in selecting similar products: regulatory environment, market structure, consumer behaviour, characteristics of the innovation and the way the public is informed about the product (Lilien, Rangaswamy, & Van den Bulte, 1999). With it being highly challenging to find a product that matches PH/BEVs in all these categories a more practical solution is to take a weighted average of some products which come closest to representing PH/BEVs.

Table 6: Historical Coefficients of Innovation and Imitation

Product	Years	p	q
Tractors	1920-1964	0.000	0.134
Clothes dryer	1948-1979	0.009	0.143
Microwave oven	1971-1990	0.002	0.357
Cable television	1980-1994	0.100	0.060
Cordless telephone	1984-1996	0.004	0.338
Electric toothbrush	1991-1996	0.110	0.548
VCR	1980-1994	0.025	0.603
	Average	**0.036**	**0.313**

Source: Lilien, Rangaswamy, & Van den Bulte (1999) p. 6)

The historical data used in table 6 is based on US sales figures and so does not give an indication of the preferences of South African consumers towards these products. Whilst a weighted average of the historical data of products similar to PH/BEV could still provide usable p and q values, comparison with other studies would be made easier by being consistent with coefficients of innovation and imitation from other studies of the diffusion of PH/BEV and allowing the consumer choice parameters introduced by the generalised form of the model to account for the local effect of purchase prices and running cost.

Table 7 shows parameter estimates for 3 PH/BEV diffusion model studies. As previously mentioned, McManus & Senter (2009) contains 4 Bass model variations with coefficients of innovation ranging from 0.00262 to 0.00075 and coefficients of imitation ranging from 0.77922 to 0.28036. These parameters were estimated by regression of HEV sales data in the US. Becker, Sidhu & Tenderich

(2009) used coefficients of 0.01 and 0.3 for a baseline oil price scenario and 0.02 and 0.4 for a high oil price scenario. Jeon (2010) used the same parameter values as the baseline oil price scenario of Becker, Sidhu & Tenderich (2009).

Table 7: H/PH/BEV Study Coefficients of Innovation and Imitation

Study	Innovation (p)	Imitation (q)
Becker, Sidhu & Tenderich (2009) (baseline oil price)	0.01	0.3
Becker, Sidhu & Tenderich (2009 (high oil price)	0.02	0.4
Jeon (2010)	0.01	0.3
McManus & Senter (2009) Generalised Bass	0.00124	0.77922
McManus & Senter (2009) Bass	0.00262	0.70935
McManus & Senter (2009) Centrone	0.0025939	0.6202921
McManus & Senter (2009) Consideration-Purchase	0.00075	0.28036

Due to the absence of historical South African sales data for PH/BEVs or homogenous products and the use of similar values in comparative studies performed in other countries, this study uses a value of 0.01 for the coefficient of innovation and a value of 0.3 for the coefficient of imitation. It is assumed that these parameter values will remain constant over successive technology generations and the variations in market adoption rates caused by oil price fluctuations and other shocks will be captured by the consumer choice variables.

Defining sensitivity to purchase prices (β_1) and running costs (β_2)

Values for consumer sensitivity towards any factor that might affect the adoption of PH/BEVs can be calculated through regression modelling of the vehicle purchase decision. The generalised Bass model in Wansart and Schnieder (2010) modelled the adoption of BEVs using 3 marketing effect parameters: price, range and infrastructure. The coefficients for these variables were drawn from the standard logit regression output of Brownstone and Train (1999). Based on stated preference survey data it was shown that the probability a consumer would purchase a vehicle would decrease as purchase price over personal income increased and would increase as vehicle driving range and refuelling infrastructure increased (Brownstone & Train, 1999). -0.185, 0.35 and 0.413 were used to reflect the sensitivity of consumers to changes in purchase prices, driving range and infrastructure availability respectively (Wansart & Schnieder, 2010).

The generalised Bass model in McManus & Senter (2009) uses values of -0.05207 and -0.32363 to reflect consumer sensitivity to changes in purchase price and running costs respectively. These values were calculated by nonlinear regression of HEV historical data and were also used in Jeon (2010) when including marketing effects in the diffusion model.

The vehicle purchase decision in South Africa was analysed by Chisasa and Dlamini (2013) by running an OLS regression of vehicle sales on variables representative of purchase prices, fuel prices, interest rates and household income. The coefficients to vehicle purchase prices and fuel costs were found to be equal to 0.0024 and 0.0988 respectively. The statistical insignificance of these variables in the Chisasa and Dlamini regression in addition to magnitudes far smaller than those found in other studies indicates that the model offers inferences of when consumers will purchase vehicles based on economic factors such as interest rates and does not provide an approximation of the sensitivity of consumers to prices and fuel costs.

Using SARB data an OLS regression model was constructed with monthly, seasonally adjusted index data for vehicle sales as the dependent variable and producer price indices for petroleum and coal products and transport manufacturing as independent indicator variables for fuel prices and vehicle purchase prices respectively.[5] After correcting for autocorrelation the coefficients on the indicators for purchase price and fuel price were found to be -0.464482 and 0.427208 respectively, with both significant at the 0.1% level. These values are similar in magnitude to the coefficients on marketing variables used in other studies.

The marketing parameters have no effect on the maximum potential market size of PH/BEVs but they do alter the rate of adoption. An overall negative effect of a marketing variable will delay the projected adoption of PH/BEVs while a positive signed marketing variable will mean earlier adoption than the base case. In the event of PH/BEV purchase prices being greater than ICE purchase prices the natural log of the price of PH/BEVs over the price of ICEVs will return a positive value, whilst PH/BEV purchase prices being less than ICEV prices will result in a negative value. These values are multiplied by β_1, and assuming consumers will be more likely to purchase the cheaper vehicles, the sign of β_1 will be negative. Similarly, the sign of β_2 will also be negative in order to account for either the delay in PH/BEV adoption brought about by ICEVs having cheaper running costs than PH/BEVs or the accelerated adoption of PH/BEVs brought about by PH/BEVs having cheaper running costs than ICEVs.

The coefficients arrived at through the regression of SARB data were used with the fuel cost coefficient adjusted to a negative value. The sensitivity of consumers to the marketing effects was set at -0.464482 for vehicle costs and -0.427208 for fuel costs.

[5] Regression output in Appendix 2

Purchase Price and running cost estimation

The generic electric vehicle

In order to approximate the price and driving costs of a PH/BEV that is representative of the variety of PH/BEVs that will soon be available in South Africa, three cars were selected that best account for the distinguishing features of the various PH/BEVs. The fully electric Nissan Leaf was chosen not only due to its recent introduction into South Africa but also because it is critically acclaimed, popular in other countries and from a well-known manufacturer that is significantly invested in the success of the vehicle. Similarly the plug-in Toyota Prius hybrid is a vehicle that has been embraced internationally, from a manufacturer that is popular in South Africa and will likely be introduced into the country in a significant fashion given the favourable reaction that the conventional hybrid Prius has received. The Leaf and the plug-in Prius are great examples of mainstream battery electric and plug-in hybrid vehicles respectively, but another category that it is vital to consider is the high end vehicle market which should be one of the earlier segments to embrace PH/BEV adoption. Manufacturers that usually cater to the high income consumer and are also producing PH/BEVs such as BMW have announced plans for slightly more modest vehicles than the rest of their product lines would suggest by opting for small hatchbacks instead of larger sedans or SUVs. For this reason the Tesla Model S was selected to represent the high price PH/BEV market. The Tesla Model S is a 4 door sedan that, as previously stated, has garnered positive reviews and has recently begun shipping into Europe.

With the Nissan Leaf the only PH/BEV available in South Africa at the time of writing, it is necessary to approximate prices in an industry where cross-border prices are known to not conform closely to exchange rate differentials (Dvir & Strasser, 2013 ; Woosey, 2012). The base starting prices were retrieved for each of the vehicles in the US and EU markets and converted into South African Rands using average 2012 exchange rates and the average price differentials for comparable ICE vehicles. The European vehicle market has been shown to have widely differing vehicle prices by country (Dvir & Strasser, 2013) but as a major vehicle producer, purchaser and South African trading partner, vehicle data is more readily available than for the Asian markets. The German Automotive market was selected to be representative of the European market due to German vehicles being popular in South Africa and around the globe and Germany being a staunch supporter of using all available methods to green their economy, including embracing electric vehicles (EVI, 2013).

For the BEV comparison the Volkswagen 1.4L Golf, the Ford Focus ST and the Mini Cooper Hatch were selected as price indicator vehicles. The Toyota Prius HEV was selected as a price indicator for the Toyota Prius PHEV due to the common manufacturer and brand. The vehicles chosen as indicators of the price of the high-end BEV were the Audi A4 3.0 Prestige, the Jaguar XF 3.0 and the Lexus GS 350. In each of the 3 categories the comparative vehicles were chosen based on the target market of each vehicle being similar to that of the respective PH/BEV. The target market was defined by the driving performance and added features demanded by the consumers. As shown in Table 8, the US and EU starting prices of the 3 categories of vehicles were converted to Rands using average 2012 exchange rates and compared to the 2012 starting prices of the matching vehicles on sale in South Africa. All prices are Manufacturer's Suggested Retail Prices (MSRP) which are required to be stated exclusive of all taxes and subsidies in the US, inclusive of VAT but exclusive of all other taxes and subsidies in Germany and inclusive of VAT and Carbon Emissions taxes but exclusive of all other taxes and subsidies in South Africa. All MSRPs and CO2 emissions data were obtained directly from the vehicle manufacturers. All taxes and subsidies were excluded from MSRPs before conversion to South African Rands and comparison. South African prices for the chosen vehicles were observed to consistently be greater than the prices obtained by converting directly using the relative exchange rates. The category averages shown at the foot of Table 8 indicate South African prices of BEVs, PHEVs and High-ends BEVs to be 111.8%, 105.4% and 112% of respective US prices and 103.8%, 114.8% and 107% of respective German prices.

Table 8: Estimating Price Differentials for Vehicle Categories

	Nissan Leaf			Toyota Prius PHEV	Tesla Model S		
	BEV comparative vehicles			PHEV Comparative vehicles	High-end BEV comparative vehicles		
Make	VW	Ford	Mini	Toyota	Audi	Jaguar	Lexus
Model	Golf 1.4L C	Focus ST	Cooper Hatch	Prius hybrid	A4 3.0 Prestige	XF 3.00	GS 350
US price in $	$ 19 995	$ 24 910	$ 19 700	$ 32 650	$ 42 600	$ 50 000	$ 47 250
$/R exchange rate	9.695	9.695	9.695	9.695	9.695	9.695	9.695
US price in R	R 193 852	R 241 502	R 190 992	R 316 542	R 413 007	R 484 750	R 458 089
EU price in € (incl. VAT)	€ 21 800	€ 22 480	€ 19 650	€ 26 800	€ 38 000	€ 52 900	€ 45 200
EU price in € (excl. VAT)	€ 17 658	€ 18 209	€ 15 917	€ 21 708	€ 30 780	€ 42 849	€ 36 612
€/R exchange rate	13.12	13.12	13.12	13.12	13.12	13.12	13.12
EU price in R	R 231 673	R 238 899	R 208 824	R 284 809	R 403 834	R 562 179	R 480 349
SA price in R (incl. VAT &CO_2tax)	R 274 900	R 318 900	R 238 000	R 388 900	R 499 500	R 743 200	R 584 900
SA price in R (excl. VAT) (incl. CO_2 tax)	R 236 414	R 274 254	R 204 680	R 334 454	R 429 570	R 639 152	R 503 014
Vehicle Emissions (g/km)	120g/km	154g/km	136g/km	94g/km	149g/km	158g/km	232g/km
Carbon Tax	R -	R 2 550	R 1 200	R -	R 2 175	R 2 850	R 8 400
SA price in R (excl. VAT & CO_2 tax)	R 236 414	R 271 704	R 203 480	R 334 454	R 427 395	R 636 302	R 494 614
US/SA differential	118.0%	111.1%	106.1%	105.4%	103.4%	123.8%	107.4%
EU/SA differential	102.0%	112.1%	97.4%	114.8%	-5.5%	111.6%	102.9%
Average US/SA differential	111.8%			105.4%	112%		
Average EU/SA differential	103.8%			114.8%	107%		

Source: EPA, 2013 ; Volkswagen, 2013 ; Ford, 2013 ; Mini, 2013 ; Toyota, 2013 ; Audi, 2013 ; Jaguar, 2013 ; Lexus, 2013

Table 9 shows the base starting prices of the Nissan Leaf, Toyota Prius PHEV and Tesla Model S in the US and Germany respectively. These prices were converted to Rands using the average 2012 exchange rates and multiplied by the average price premiums of each PH/BEV category for their respective countries. The US and German converted prices were then averaged for each category to arrive at base PH/BEV category average prices. The final base price for 1st generation PH/BEVs in South Africa was calculated as a weighted average of the 3 estimated vehicle prices. It was assumed that approximately half as many units of the High-end Model S would be sold compared to the BEV and PHEV. Similar quantities of the BEV and PHEV were assumed to be demanded. The 2-2-1 weighted average is shown in Table 9 to be R499 234.

Table 9: Estimating an Average Starting Price for PH/BEVs in South Africa

	Leaf	Prius Plug-in	Model S
USA price	$ 21 300	$ 32 000	$ 62 400
Category Avg. US/SA price differential	111.8%	105.4%	112%
$/R exchange rate	9.695	9.695	9.695
Estimated R price relative to US $ price	R 230 772	R 326 855	R 674 678
Euro price (GER)	€ 23 790	€ 36 550	€ 60 000
Category Avg. Ger./SA price differential	103.8%	114.8%	107%
€/R exchange rate	13.12	13.12	13.12
Estimated R price relative to Ger. € price	R 324 040	R 550 716	R 839 800
Average price	R 277 406	R 438 786	R 757 239
Average prices (incl. VAT)	R 316 243	R 500 216	R 863 252
PH/BEV average price (incl. VAT) (Weighted 2-2-1)			**R 499 234**

The generic ICE vehicle

The average starting price for ICE vehicles was calculated as the average starting price of all 2012 cars sold weighted by the number of units of each model sold. The starting price was calculated to be R288 076. Popular vehicles with similar average starting prices include the Toyota RAV4, the Renault Megane, the Mitsubishi ASX, the Volkswagen Touran and the Alfa Romeo Giulietta. This price is inclusive of VAT and Carbon Emissions Tax. As shown in Table 10, the average CO_2 emission per kilometre for the selected ICEVs was found to be 143 grams. Estimates for CO_2 emissions were calculated from the data displayed in Table 10 instead of Table 8 data as the vehicles selected for Table 8 estimations were chosen based on their purchase price and target markets being similar to that of 3 categories of PH/BEVs and not based on their CO_2 emissions being representative of the variety of ICEVs available in the automotive market. Using 143g/km, the average carbon emissions tax was found to be R1 725 and so the average starting price for the generic ICEV, excluding emissions tax, was found to be R286 351.

Taxes and Subsidies

Dane (2013) presents a scenario for electric vehicles in South Africa that includes financial support of approximately R142 000 per vehicle in the form of infrastructure grants, rebates, carbon tax exemptions and other incentive costs. In order to improve the flexibility of the model, financial support for PH/BEVs was determined to be a tax credit equal to a percentage of the vehicle purchase price. This approach has been used in countries such as India and Spain but usually comes at with a price cap (EVI, 2013). India employs a subsidy of 20% of the vehicle cost with a cap of INR 100 000 (EVI, 2012). A tax credit of the same percentage was included in the model for the strong public support scenario. A more modest credit of 10% was put in place for the reluctant support scenario as there is still likely to be some financial incentive for PH/BEVs, even if the government is not completely enamoured with them. A cap of R50 000 was put in place for the tax credit in both scenarios.

ICEVs produce carbon just like many other economic activities and yet the vehicle purchase decision is the only economic activity to be quoted and charged an explicit price for the amount of carbon produced. As previously stated, this current rate is R75 per CO2 g/km over the threshold of 120 g/km. This current rate formed the basis for the modest policy support scenario under which the tax rate and threshold level do not change over the course of the considered time period. The current proposal for a general, economy wide carbon price is at a rate of R120 per gram of CO_2 over industry specific thresholds (National Treasury, 2013). The strong policy support scenario entails this rate being applied to the CO_2 vehicle purchase tax.

Whilst it is highly likely that the efficiency of ICEVs will improve with regards to CO_2 emissions, it was assumed that any improvement in the average carbon output would be met by a matching downward adjustment of the threshold and so a consistent level of CO_2 would be taxed throughout the considered time period.

Vehicle Price Evolution

The key to the affordability and feasibility of PH/BEVs is battery technology (IEA, 2011). The battery cost can account for 70% and 120% of the respective price premiums of PHEVs and BEVs relative to ICEVs (Jeon, 2010, p. 69). A number of issues with PH/BEV batteries need to be addressed in order to improve vehicle performance and efficiency such as battery storage capacity, battery discharge cycles and durability (IEA, 2011). With the battery being the dominant cost factor in PH/BEVs, the rate at which the cost of the battery declines is a good indicator of the rate at which the purchase prices of PH/BEVs will improve. As with all learning curves, initial cost reductions are likely to be large but will slow over time. Deutsche Bank estimated a learning rate of 5% in 2008 but adjusted that to 7.5% in 2010 as a result of the great strides in battery research and development and a decline in costs of raw materials (Deutsche Bank Research, 2008), (EVI, 2013). Hensley, Knupfer and Pinner (2009) estimated an average decline in battery costs of 6-8% annually (Hensley, Knupfer, & Pinner, 2009). Official IEA estimates place the learning rate at 9.5%, above the other previously mentioned rates, most likely due to being calculated off a much higher base battery cost (EVI, 2013).

Due to the time period being examined in this study exceeding that of any projections for PH/BEV battery costs found in the literature it was decided to use the more conservative figure of 6% annual price decline for the period between the 1st and 2nd PH/BEV generations, slowing to 2% between the 2nd and 3rd generations and to 0.5% between the 3rd and 4th generations. Using a technology generation schedule of 5 years until generation 2, 15 years until generation 3 and 25 years until generation 4 the pre tax credit price of PH/BEVs were found to be R499 234, R366 390, R299 367 and R284 731 over the 4 successive generations. The starting prices were kept constant over the different scenarios as the timing of the generation introduction accounts for varying purchasing prices at certain times between the scenarios.

The average starting prices of ICEVs are assumed to remain constant over the considered time period with the only variations in any vehicle purchase prices being due to advancements in PH/BEV technology, changes to the PH/BEV purchase tax credit and/or modifications to the carbon emissions tax rate.

Base running costs and Running cost evolution

The running costs for ICEVs and PH/BEVs were calculated by dividing the average fuel efficiency of the vehicle type by the average price for each litre or kilowatt.

PH/BEV efficiency

The efficiency of the generic PH/BEV in generation 1 was calculated as the average of the Nissan Leaf, Toyota Prius PHEV and the Tesla Model S. The efficiencies for all vehicles have been tested and estimated by the US Environmental Protection Agency (EPA) and are updated annually. In order for there to be a standardised measure for which to compare the efficiencies of vehicles the EPA converts the energy used over distance measure into Miles per Gallon equivalent (MPGe). By using the EPA conversion factors it is possible to convert MPGe into kWh per 100km. Table 10 shows the MPGe and the kWh per 100km for each of the PH/BEVs.

The Prius PHEV, which contains both electric and internal combustion drive trains, has the ability to function as a HEV with additional charging capability or as an electric vehicle with range extending capabilities. Based on US EPA tests the Prius PHEV will operate far more efficiently when the vehicle is in electric mode (EPA, 2013). In electric mode, the vehicle still utilises the combustion drive train to a small degree with the efficiency of the Prius PHEV in hybrid mode being equivalent to (29kWh + 0.2 gal)/100 miles. As shown in Table 10 the electric mode was found to be far more efficient than the hybrid mode. It was assumed that owners of the Toyota Prius will largely ignore the hybrid mode of the vehicle and that the contribution of the combustion drive train in electric mode can be converted to kWh per kilometre and attributed to the electric drivetrain. The average of the efficiencies of all 3 PH/BEVs excluding the hybrid mode of the Toyota Prius PHEV as shown in Table 10 is equivalent to 20.68 kWh per km. The efficiency of the PH/BEV was assumed to remain constant over the four technological generations.

Table 10: PH/BEV fuel efficiencies

Manufacturer	Model	MPGe	kWh/100km
Nissan	Leaf	115	18.13
Toyota	Prius PHEV (hybrid mode)	50	41.70
	Prius PHEV (electric mode)	95	21.95
Tesla	Model S (60kW)	95	21.95
Average PH/BEV efficiency			20.68

Source: (EPA, 2013)
Note: (1 litre = 0.264172052 US gallons; 1 kilometre = 0.621371192 miles; 1 US gallon = 33.56 kWh)

ICEV efficiency

Table 11: ICEV fuel efficiencies

Manufacturer	Model	MPG	L/100km	gCO2/km
Volkswagen	Golf 2.0 Comfortline	34	6.92	120
Ford	Focus ST 2.0	23	10.23	154
Mini	Cooper Hatch	32	7.35	136
Toyota	Corolla 1.8L	30	7.84	138
BMW	320i	27	8.71	144
Audi	A4 3.0 Prestige	26	9.05	149
Jaguar	XF 3.00	21	11.20	158
Lexus	GS 350	24	9.80	232
Average ICEV efficiency			8.76	143

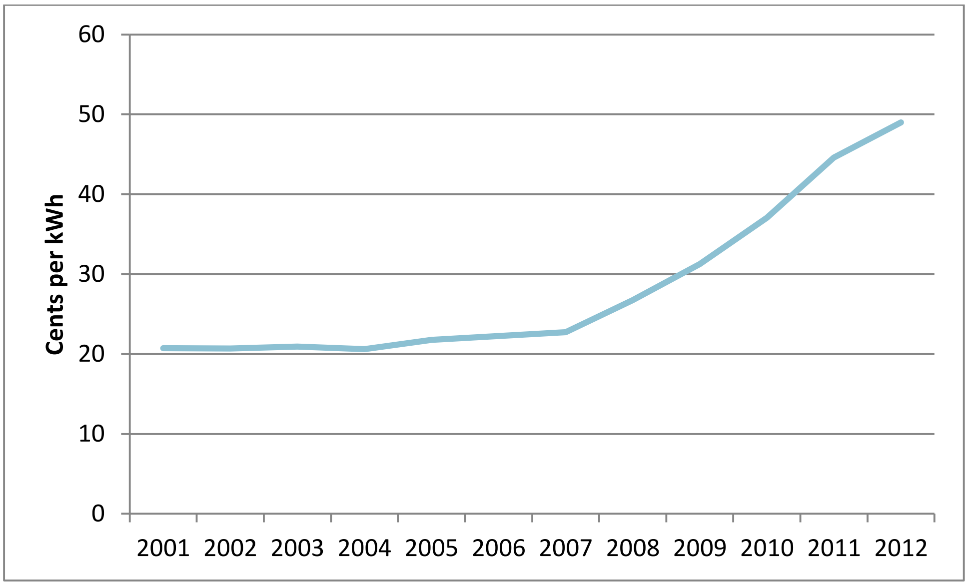
Source: (EPA, 2013)
Note: (1 litre = 0.264172052 US gallons; 1 kilometre = 0.621371192 miles; 1 US gallon = 33.56 kWh)

Table 11 shows the vehicles used in the calculation of an average ICEV fuel efficiency. The same EPA data that was used to calculate the PH/BEV average efficiency was employed, with the conversion process also being quite similar. The ICE vehicles used in the approximation of the starting price of PH/BEVs were used again due to these vehicles being representative of the range of vehicles available in the automotive market. As the Toyota Prius is an HEV and not an ICEV, it was removed and replaced with the Toyota Corolla 1.8L and the BMW 320i. All ICEV efficiencies are for manual versions of the cars. After miles per gallon was converted to litres per 100km for each of the vehicles the average ICEV efficiency was shown to be 8.76 litres per 100km. The carbon emissions of the range of selected vehicles are also shown in Table 11. The average carbon emission for these vehicles was found to be 143 grams of CO2 per kilometre. The efficiency of the ICEV was assumed to remain constant over the four technological generations.

Electricity price

Just as batteries are the dominant factor in the purchase price of a PH/BEV, electricity prices are the dominant factor affecting the cost of running a PH/BEV and the evolution of this cost over time. South Africa's main power supplier, Eskom, alters the tariffs on electricity annually. Between 1997 and 2008 the annual increase in the average price of electricity ranged between 2.5% and 8.43% but in subsequent years the new range has a low of 24.8% and a high of 31.3% (Eskom, 2013). Further price increases are scheduled in order to fund the expansion of electricity production capacity but the public response to these plans has been predominantly negative. Consumers have become accustomed to hikes in petrol prices but significant increases in the cost of charging a PH/BEV will possibly play on the minds of consumers even if the alternative of ICEVs experiences a similar problem. The outcome of the debate will have a significant impact on the appeal of PH/BEVs to South African consumers. Figure 8 shows the real average electricity prices for South Africa between 2001 and 2012 using 2008 as the base year. Even in this inflation controlled scenario the increase in electricity prices is blatantly evident.

Figure 8: Average Real Electricity Prices (2001-2013) (constant 2008 prices)



Source: OECD (2013a)

In February, 2013 the National Energy Regulator of South Africa (NERSA) approved standard electricity price increases of 8% per annum for the 2013/14 to 2017/18 financial years (NERSA, 2013). These increases will bring the standard average electricity prices up from 65.51 cents per kWh to 89.13 cents per kWh. It is the hope of Eskom that the significant investment in electricity infrastructure will result in the gap between energy demand and energy supply being closed by 2016 and paid for by the end of the NERSA approved period. If the energy gap is indeed closed then the electricity price increases in the future time periods will only need to keep pace with inflation. For this reason it is assumed that electricity prices will continue to rise in the short term before reaching a plateau where prices will remain approximately constant in real terms.

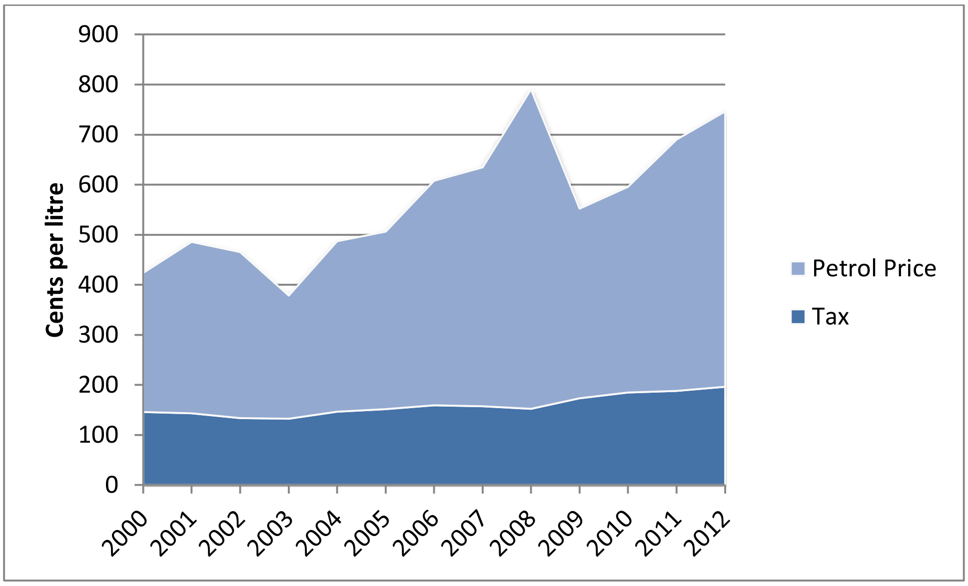
Based on the assumption that the energy gap will be closed within the Eskom timeframe, the starting price of electricity was estimated to be 65 cents per kWh. This starting price was estimated to increase at a rate of 8% per year for 5 years, 2% greater than the assumed inflation rate of 6%. After a period of increasing prices, the plateau was assumed to be reached after which prices remain constant for the remainder of the time period.

Under scenario 1, sub-optimal conditions for PH/BEV adoption, it is assumed that power supply expansion deadlines are not met and the energy gap is not closed. Under this assumption the DBSA estimates that real electricity price increases will need to persist for up to 15 years (DBSA, 2012). Under scenario 2, favourable conditions for PH/BEV adoption, it is assumed that all Eskom expansions and upgrades are met on schedule and marked electricity price increases cease after 5 years.

Petrol price

Diesel vehicles were assumed to be adequately indicated for by petrol ICEVs and petrol prices. Petrol prices have increased rapidly in recent years and since 2005 the pre-tax price of petrol has nearly tripled (Energy.gov, 2013). Figure 9 shows the evolution of petrol prices in terms of constant 2005 prices and even without inflation the rise in petrol prices has been significant. Figure 9 also shows the erratic shifts petrol prices can take with significant price drops in 2003 and 2009.

Figure 9: Historical petrol prices and taxes (constant 2005 prices)



Source: (OECD, 2013b)

OECD forecasts for world oil prices are based on three scenarios: Current policies scenario, New Policies Scenario and 450 Scenario. The current policies scenario assumes that government policies that had been enacted or adopted by mid-2012 continue unchanged. The new policies scenario assumes that existing policies are maintained and recently announced commitments and plans, including those yet to be formally adopted, are implemented in a cautious manner. Policies are adopted that put the world on a pathway that is consistent with having around a 50% chance of limiting the global increase in average temperature to 2 °C in the long term, compared with pre-industrial levels (IEA, 2012, pp. 34-36).

Under the conditions of the current policies scenario oil prices are projected to rise from $108 US in 2011 to $145 in 2035 in constant 2011 prices, an annual increase of 1.24%. In the New Policies scenario the price of a barrel of oil is projected to rise at approximately 0.6% per annum to a 2035 price of $125 in constant 2011 prices. In the 450 scenario the radical policies undermining the demand for oil drive the price from $108 in 2011 to a peak of $115 in 2015 followed by a slow decline to $100 by 2035; a net annual decline of approximately 0.3% (IEA, 2012, pp. 81-97).

The model estimates for PH/BEV adoption were calculated using high and low oil price scenarios based on the IEA current policies and new policies scenarios. The high oil price scenario entails a constant increase of petrol prices at a rate of 1.25% per annum. The low oil price scenario involves petrol prices increasing at a rate of 0.5% per annum. The post-tax Gauteng area petrol price for 4 December 2013 of 1 319 cents (South African) per litre (Energy.gov, 2013) was used as the starting petrol price.

7. Forecast Results

A summary of the two scenarios considered is contained in Table 12 with all other factors that are not mentioned assumed constant between scenarios. Of the two scenarios considered the base scenario is decidedly less supportive of the adoption of PH/BEVs but is far from a pessimistic or worst case scenario. The base case assumes smaller carbon emissions taxes and reduced PH/BEV purchase assistance than the alternative scenario but does still assume that such government support will exist. It was also assumed in the base scenario that improvements in PH/BEV technology would place the price, performance and functionality of PH/BEVs on par with ICEVs within the considered timeframe, something which industry stakeholders would be reluctant to guarantee. The base case also makes the slightly pro-PH/BEV assumption that electricity prices will eventually stop increasing.

Table 12: Summary of Key Scenario Parameters

	Scenario 1 (Base)	Scenario 2 (Pro-PH/BEV)
Generation introduction years	1,5,20,30	1,5,15,25
Coefficient of innovation (p)	0.01	0.01
Coefficient of imitation (q)	0.3	0.3
Sensitivity to purchase prices (β_1)	-0.464482	-0.464482
Sensitivity to running costs (β_2)	-0.427208	-0.427208
PH/BEV Tax incentives	10% with R50 000 cap	20% with R50 000 cap
CO_2 Vehicle Purchase Tax	R 75 per g/km	R 120 per g/km
(ICEVs average 23 g over limit)		
Electricity price increases	2% p.a. for 15 years	2% p.a. for 5 years
Petrol price increases	0.5% p.a.	1.25% p.a.

Figure 10 shows the market development of PH/BEVs under scenario 1, the base scenario with sub-optimal conditions for PH/BEV adoption. As shown in Figure 10, the 1st generation of PH/BEVs rises to a sales peak around 13 years after their introduction with approximately 36 871 being sold. The 2nd generation then accounts for the majority of sales until peaking in the year 2037 with 158 538 vehicles sold. Sales of the 3rd generation of PH/BEVs are then projected to increase until the year 2048 and peak sales of 390 119. The 4th generation of PH/BEVs is projected to still be experiencing increasing sales volumes by the year 2050.

Under this scenario it is projected that a total of 129 693 PH/BEVs will be sold in the year 2030, 285 483 in the year 2040 and 724 373 by the year 2050. Over the course of the considered time period up to the year 2050 approximately 459 041 1st generation vehicles, 2 593 321 2nd generation vehicles, 3 676 553 3rd generation vehicles and 1 093 401 4th generation are projected to be sold for a grand total of 7 822 315.

Figure 10: PH/BEV Annual Sales Scenario 1 (Sub-Optimal Conditions for PH/BEV Adoption)

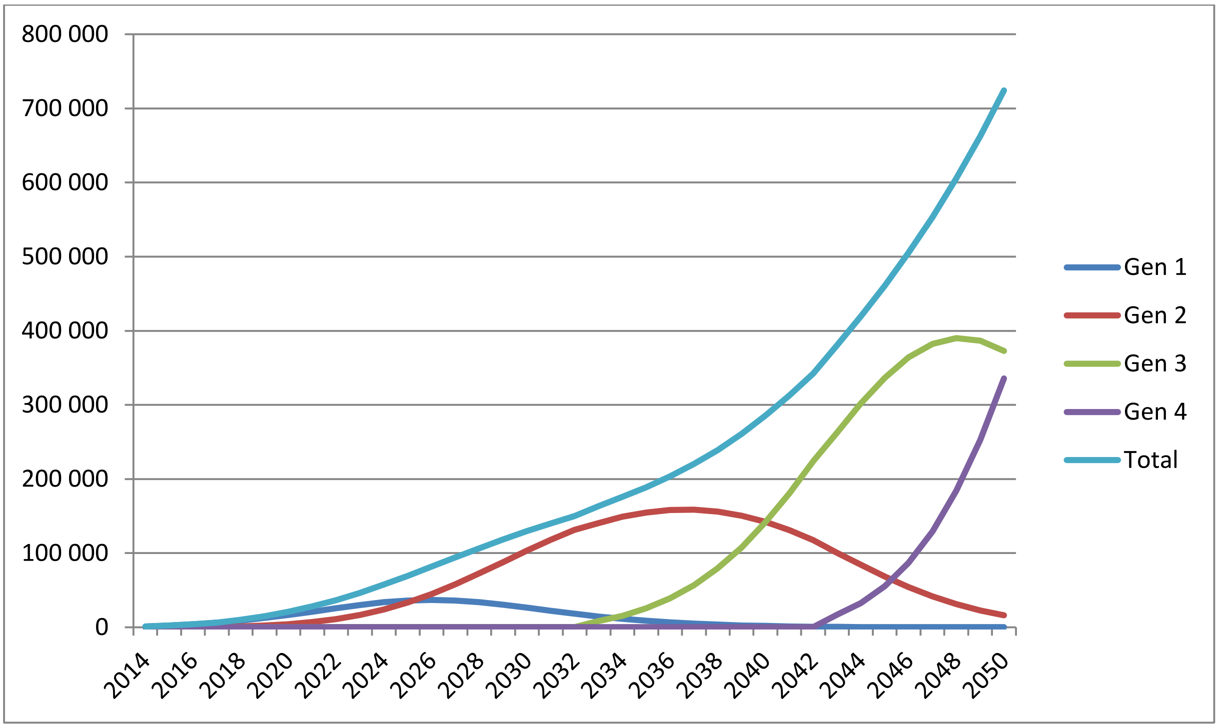


Figure 11: PH/BEV Annual Sales Scenario 2 (Favourable Conditions for PH/BEV Adoption)

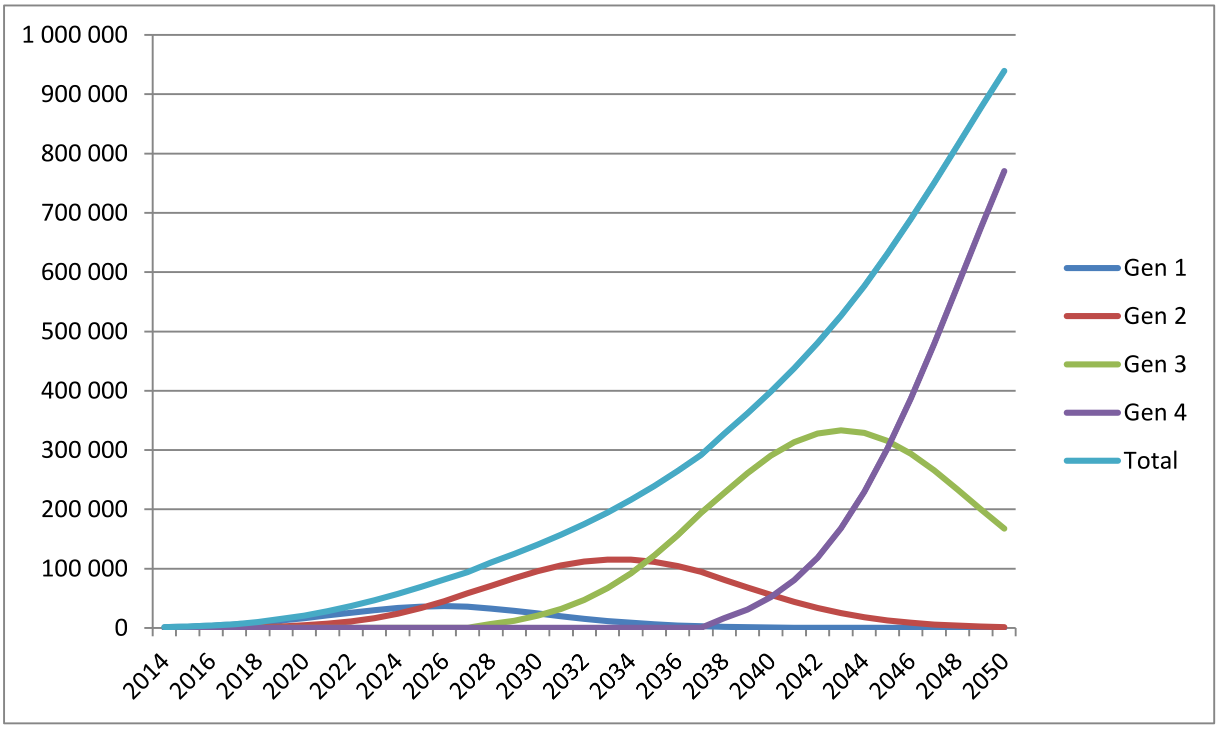


Figure 11 shows the market development of PH/BEVs under Scenario 2, favourable conditions for PH/BEV adoption. Figure 11 shows sales of the 1st generation of PH/BEVs to peak around 13 years after their initial introduction. The 2nd generation then brings in most new sales and eventually peaks in 2033 with 115 379 vehicles sold. The model then forecasts that 3rd generation PH/BEVs will experience increasing sales until the year 2043 at a peak of 333 134 units. By the year 2050, the end of the considered time period, the 4th generation of PH/BEVs is projected to still be experiencing increasing sales volumes.

Under this scenario it is projected that a total of 140 761 PH/BEVs will be sold in the year 2030, 398 654 in the year 2040 and 939 473 by the year 2050. Over the 37 year period that the scenario considers approximately 429 433 1st generation vehicles, 1 575 510 2nd generation vehicles, 4 308 575 3rd generation vehicles and 3 886 751 4th generation vehicles are projected to be sold, equating to a sum total of 10 200 279.

Table 13 shows a comparison of the two scenarios for selected years. The initial market reaction to PH/BEVs is not remarkably different between the two scenarios and the results indicate that in 2025 only approximately 150 more vehicles will be sold in the pro-PH/BEV scenario as opposed to the base scenario. This result does fit the assumptions made as the second generation of PH/BEVs was set to enter the market after 5 years in both scenarios and the 3rd generation will not have entered the market in either scenario by 2025. The lack of a major difference between the two scenarios is also indicative of early adopters being less interested in the economics of their vehicles and more concerned with environmental benefits and social factors. This consistency in purchases between the two scenarios in the formative years of the PH/BEV market can also be attributed in part to government procurement programmes. In later years the differences between the two scenarios are more evident and by 2030 over 10 000 more PH/BEVs are sold per annum in the PH/BEV friendly scenario than in the base scenario. By 2040 the difference in annual PH/BEV sales between the two scenarios is projected to be approaching 115 000 and by 2050 the difference is over 200 000 vehicles per annum. The differences in sales between scenarios in the later years considered in the model can be attributed to the delay in the introduction of the 3rd and 4th generations of PH/BEVs, higher electricity prices, lower oil prices, lower carbon emissions taxes and lower PH/BEV purchasing support.

Table 13: PH/BEV Sales and Market Shares in Selected Years

	2014	2020	2025	2030	2035	2040	2045	2050
Scenario 1	1 152	20 908	69 347	129 693	188 962	285 483	460 749	724 373
	<1%	4%	12%	19%	24%	31%	43%	58%
Scenario 2	1 154	20 963	69 496	140 761	239 414	398 654	630 976	939 473
	<1%	4%	12%	20%	30%	43%	59%	75%

Comparison of results with other forecasts

Before any comparison is made it is important to reemphasise that the forecasts for the two scenarios in this study are for annual sales in South Africa of PHEVs and BEVs collectively. Throughout the literature there was found to be little consensus between whether the term "electric vehicle" refers to BEVs, PHEVs or a combination of the two. For instance the Electric Vehicle Initiative groups the various vehicles under the blanket term of "Electric vehicles" (EVI, 2013) whereas Dane (2013) uses the same term in specific reference to BEVs. As has been stated earlier the view taken in this paper is that PH/BEVs should be grouped together for the purposes of forecasting vehicle adoption in South Africa. Nevertheless a concerted attempt has been made to be explicit when discussing the various forms of electric vehicles.

In both scenarios approximately 4% of the 2020 South African light passenger vehicle sales market was projected to consist of PH/BEVs; this figure falls short of the 14.92% for just BEVs projected to be sold in Brazil in the same year (Paixao, 2010). Predictions for 2030 also fall short of those projected for Brazil with 19 to 20% annual PH/BEV sales compared to 50% BEV sales.

Projections of 8 to 10% of the 2020 global car market comprising of PH/BEVs (RBSC, 2011) fits the projections made in this study as earlier sections have shown how South Africa is not as well set up to encourage PH/BEV adoption as countries such as China, Germany, France and the United States.

The near and medium term predictions for PH/BEVs do compare well with the figures put forward for South Africa in Merven et al. (2012). BEVs were estimated to capture 3% of the market in 2020 and 5% by 2030 and with the addition of PHEVs these figures could be quite close to the 4% and 19 to 20% shares projected. Longer term predictions in Merven et al. (2012) assumed no further growth in PH/BEV market share after 2030 and so there is substantial variation between the estimated market shares for 2050 and the long term projections of this paper.

Dane (2013) estimated that 9744 BEVs would be sold annually by 2020 in South Africa, compared with the 20 908 to 20 963 PH/BEVs projected for the same year in this study. PHEV sales would presumably make up a fair portion of the difference between these two figures.

8. Conclusion

This paper examined the potential development of a market for PH/BEVs in South Africa by first investigating the ways PH/BEVs might be beneficial to the country specifically through improvements in employment levels, economic stability and public health and in limiting greenhouse gas emissions. With the evidence indicating that PH/BEVs would offer many advantages, the next step was to investigate developments in the global PH/BEV industry. The market for PH/BEVs has experienced significant growth in recent years, most notably in countries that have put a variety of supportive public policies in place. The infrastructure, geography, political backing and policy proposals relating to PH/BEVs were examined for the South African context to enable comparison with other, more prepared nations. With the degree of readiness of South Africa for the commercial scale introduction of PH/BEVs established, the focus of the remainder of the paper turned to forecasting the levels of market penetration that PH/BEVs might achieve.

After reviewing the literature for modelling the future rates of market penetration for a new market innovation, paying particular attention to studies involving the automotive industry, a model was adapted to forecast the future market for PH/BEVs in South Africa. Two scenarios were considered to allow for future variations in fuel prices, electricity prices, policy support and rate of technological advancement. While defining the parameters for the model an effort was made to use methods and values that would enable easy and direct comparison of the forecasts produced by the model with the forecasts in other studies found in the literature.

The results of the modelling process estimated that PH/BEVs would account for approximately 4% of the car sales market by 2020, a value of around 20 908 to 20 963 units. By 2030 this figure was projected to increase to between 19% and 20% of the market, or actual sales of approximately 130 000 to 140 000 vehicles. Given time and the assumption of continuous PH/BEV technological advances, the model's long term projections for PH/BEVs are for a market share of 58% to 75% by 2050, or between 724 373 and 939 473 units.

The varied modelling techniques and reporting methods found in the literature make comparing figures across international studies a challenge but the forecasts of this study do appear to not stray too far from near and medium term projections made for comparable countries like Brazil and fit the expectations of being smaller than the majority of projections made for countries that were analysed and revealed to be well prepared for the development of their national PH/BEV markets.

Despite these pleasing results, the model used in this study has several weaknesses that must be acknowledged. The first of these issues is the time frame considered being longer than in most other studies found in the literature. As the time frame increases, the validity of the assumptions made becomes more tenuous resulting in long term projections with less credibility than the near and medium term predictions. All forecasting models rely on a set of assumptions based on the data available at the time. As new information becomes available the parameters of the model may be updated and the accuracy of the projections improved. An example of such an improvement would be to use the sales history of PH/BEVs in South Africa, once it becomes available, to directly estimate the coefficients of innovation and imitation by regression modelling methods. Other assumptions that have been made in this study could be altered using current information such as allowing the efficiency of ICEVs to improve over time or introducing more PH/BEV purchase incentives than just the single tax credit. In cases such as these, the assumptions were made to prevent the model from becoming unnecessarily complicated.

Models such as the one presented in this paper are built to be refined over time but also to serve as a basis for general equilibrium, agent based and other modelling studies that examine the magnitude of the impact that the projected levels of PH/BEV market penetration will have. This will strengthen studies similar to those by Becker, Sidhu and Tenderich (2009) and Mock et al. (2009) in the South African context and will enable better quantitative projections of the scale of the impacts that PH/BEVs will have on greenhouse gas emissions, commodity prices, employment creation, public health and the economy in general.

9. References

ACEA. (2013). *Overview of Purchase and Tax Incentives for Electric Vehicles in the EU.* European Automotive Manufacturers' Association.

Al-Alawi, B. M., & Bradley, T. H. (2013). Review of hybrid, plug-in hybrid,and electric vehicle market modeling Studies. *Renewable and Sustainable Energy Reviews 21*, 190-203.

Audi. (2013). *Audi*. Retrieved July 1, 2013, from http://www.audiusa.com/

Axsen, J., & Kurani, K. S. (2010). Anticipating plug-in hybrid vehicle energy impacts in California: Constructing consumer-informed recharge profiles. *Transportation Research Part D 15*, 212–219.

Balducci, P. J. (2008). *Plug-in Hybrid Electric Vehicle Market Penetration Scenarios.* Pacific Northwest National Laboratory: U.S. Department of Energy.

Bass, F. M. (1969). A New Product Growth for Model Consumer Durables. *Management Science Vol. 15 No. 5*, 216-227.

Bass, F. M. (2004). Comments on "A New Product Growth for Model Consumer Durables": The Bass Model. *Management Science, Vol. 50, No. 12, Ten Most Influential Titles of "ManagementScience's" First Fifty Years*, 1833-1840.

Becker, T. A., Sidhu, I., & Tenderich, B. (2009). *Electric Vehicles in the United States - A New Model with Forecasts to 2030.* University of California, Berkeley: Center for Entrepreneurship & Technology.

Bloomberg. (2013). *Pain at the Pump: Gasoline Prices by Country.* Retrieved October 3, 2013, from Bloomberg Visual Data: http://www.bloomberg.com/visual-data/gas-prices/20131:South%20Africa:ZAR:l

Bosshardt, M., Ulli-Beer, S., Gassmann, F., & Wokaun, A. (2007). *Developing a diffusion model of competing alternative drive-train technologies (cadt-model).* Switzerland: Paul Scherrer Institute.

Brownstone, D., & Train, K. (1999). Forecasting new product penetration with flexible substitution patterns. *Journal of Econometrics 89*, 109-129.

Cao, X., & Mokhtarian, P. L. (2004). *The Future Demand for Alternative Fuel Passenger Vehicles: A Diffusion of Innovation Approach.* University of California: Davis.

CARmag. (2012, 06 22). *Optimal Energy Shutting Down.* Retrieved November 8, 2013, from Car Magazine: http://www.carmag.co.za/news/optimal-energy-shutting-down/

Centrone, F., Goia, A., & Salinelli, E. (2007). Demographic processes in a model of innovation diffusion with a dynamic market. *Technological Forecasting & Social Change 74*, 247-266.

Chisasa, J., & Dlamini, W. (2013). An Empirical Analysis of the Interest Rate-Vehicle Purchase Decision Nexus in South Africa. *International Business & Economics Research Journal Vol.12 No.5*, 477-488.

Choo, S., & Mokhtarian, P. L. (2004). What type of vehicle do people drive? The role of attitude and lifestyle in influencing vehicle type choice. *Transportation Research Part A 38*, 201–222.

Dane, A. (2013). *The potential of electric vehicles to contribute to South Africa's greenhouse gas emissions targets and other developmental objectives.* University of Cape Town Energy Research Centre.

DBSA. (2012). *The State of South Africa's Economic Infrastructure: Opportunities and challenges to 2020.* Development Bank of Southern Africa: Development Planning Devision.

DEA. (2013). *Green Cars.* Retrieved November 20, 2013, from Department of Environmental Affairs: https://www.environment.gov.za/projectsprogrammes/greencars

Deutsche Bank Research. (2008). *Electric Cars: Plugged in.* Deutsche Securities (Pty) Ltd.

Diamond, D. (2009). The impact of government incentives for hybrid-electric vehicles: Evidence from US states. *Energy Policy 37*, 972-983.

Dodson, J. (2010). *New Product Forecasting: The Bass Model.* UW School of Business.

Draper, M., Rodriguez, E., Kaminsky, P., Sidhu, I., & Tenderich, B. (2008). *Economic Impact of Electric Vehicle Adoption in the United States.* Berkeley: University of California.

DTI. (2013a). *Industrial Policy Action Plan 2013/2014 - 2015/2016.* Department of Trade and Industry.

DTI. (2013b). *Road Map for Electric Vehicles in South Africa.* DTI.

DTI. (2013c). *South African Automotive Industry Report 2012.* South Africa: The Department of Trade and Industry.

DTI. (2013d). *Automotive Investment Scheme Programme Guidelines.* The Department of Trade and Industry.

Dvir, E., & Strasser, G. (2013). *Does Marketing Widen Borders? Cross-Country Price Dispersion in the European Car Market.* Boston College.

Economic Development Department. (2010). *New Growth Path: The Framework.*

Electric Power Research Institute. (2007). *Environmental assessment of Plug-in Hybrid Electric Vehicles.* National Resources Defense Council.

ElonMusk.com. (2012). Retrieved January 10, 2014, from http://elonmusk.com/

Energy.gov. (2013, August 1). *Energy Sources Archive*. Retrieved August 7, 2013, from http://www.energy.gov.za/files/esources/petroleum/petroleum_arch.html

EPA. (2013). *Fuel Economy Guide.* US Department of Energy, US Environmental Protection Agency, Office of Energy Efficiency and Renewable Energy.

Eppstein, M. J., Grover, D. K., Marshall, J. S., & Rizzo, D. M. (2011). An agent-based model to study market penetration of plug-in hybrid electric vehicles. *Energy Policy 39*, 3789-3802.

ESI-Africa. (2013, March 22). *South Africa launches electric vehicle initiative.* Retrieved May 10, 2013, from ESI-Africa: http://www.esi-africa.com/South/Africa/launches/electric/vehicle/initiative

Eskom. (2013). *Average price increases.* Retrieved May 10, 2013, from Eskom: http://www.eskom.co.za/c/article/143/average-price-increases/

EVI. (2012). *EV City Casebook.* Electric Vehicle Initiative.

EVI. (2013). *Global EV Outlook: Understanding the Electric Vehicle Landscape to 2020.* Electric Vehicle Initiative.

Forbes, A., & Katumba, G. (2009). *Advanced Optical Materials to Improve Solar Absorption.* Alternative Energy Research: Sciencescope.

Ford. (2013). *Ford*. Retrieved July 1, 2013, from http://www.ford.com/

Greve, N. (2013, February 26). *SA launches electric vehicle pilot programme.* Retrieved April 2, 2013, from Engineering News: http://www.engineeringnews.co.za/article/dea-launches-electric-vehicle-pilot-programme-2013-02-26

Hensley, R., Knupfer, S. M., & Krieger, A. (2011). *The fast lane to the adoption of electric cars.* McKinsey & Company.

Hensley, R., Knupfer, S., & Pinner, D. (2009). Electrifying cars: How three industries will evolve. *McKinsey Quarterly No.3*.

Hess, S., Fowler, M., Adler, T., & Bahreinian, A. (2012). A joint model for vehicle type and fuel type choice: evidence from a cross-nested logit study. *Transportation Vol. 39 Iss. 3*, 593-625.

IEA. (2011). *Technology Roadmap: Electric and plug-in hybrid electric vehicles.* International Energy Agency.

IEA. (2012). *World Energy Outlook.* OECD Publishing.

IEA. (2013). *Tracking Clean Energy Progress.* International Energy Agency.

Ingram, A. (2013, November 25). *Fisker Finally Files For Bankruptcy, DoE Loan Sold For $25 Million.* Retrieved November 26, 2013, from Green Car Reports: http://www.greencarreports.com/news/1088692_fisker-finally-files-for-bankruptcy-doe-loan-sold-for-25-million

Interbrand. (2013). *Best Global Green Brands*. Retrieved November 20, 2013, from http://www.interbrand.com/en/best-global-brands/Best-Global-Green-Brands/2013/Best-Global-Green-Brands-2013.aspx

Jaguar. (2013). *Jaguar*. Retrieved July 1, 2013, from http://www.jaguarusa.com/index.html

Jeon, S. Y. (2010). *Hybrid & electric vehicle technology and its market feasiblity.* Cambridge, MA: Massachusetts Institute of Technology.

Karplus, V. J., Paltsev, S., & Reilly, J. M. (2010). Prospects for plug-in hybrid electric vehicles in the United States and Japan: A general equilibrium analysis. *Transportation Research Part A: Policy and Practice Vol 44 Issue 8*, 620-641.

Kavalec, C. (1996). *CALCARS: The California Conventional and Alternative Fuel Response Simulator.* California Energy Commission.

Krieger, A., Wang, L., Radtke, P., & Malorny, C. (2012). *Recharging China's electric vehicle aspirations.* McKinsey & Company.

Letete, T., Guma, M., & Marquard, A. (2013). *Information on climate change in South Africa: greenhouse gas emissions and mitigation options.* Cape Town: Energy Research Centre.

Lexus. (2013). *Lexus*. Retrieved July 1, 2013, from http://www.lexus.com/

Lilien, G. L., Rangaswamy, A., & De Bruyn, A. (2007). *Principles of Market Engineering.* DecisionPro.

Lilien, G., Rangaswamy, A., & Van den Bulte, C. (1999). *Diffusion Models: Managerial Applications and Software.* Institute for the Study of Business Markets.

Liu, X., Hildebrandt, D., & Glasser, D. (2012). Environmental impacts of electric vehicles in South Africa. *South African Journal of Science 2012*, 603-609.

LSE Cities. (2011, November). *Urban Age Cities Compared.* Retrieved May 10, 2013, from LSE Cities: http://lsecities.net/media/objects/articles/urban-age-cities-compared

MacKenzie, A. (2013, January). *2013 Motor Trend Car of the Year: Tesla Model S.* Retrieved May 10, 2013, from Motortrend: http://www.motortrend.com/oftheyear/car/1301_2013_motor_trend_car_of_the_year_tesla_model_s/viewall.html

Mahajan, V., Muller, E., & Bass, F. M. (1995). Diffusion of New Products: Empirical Generalizations and Managerial Uses. *Marketing Science Vol.14 No.3 Part 2 of 2: Special Issue on Empirical Generalizations in Marketing*, G79-G88.

Maia, J., Giordano, T., Kelder, N., Bardien, G., Bodibe, M., Du Plooy, P., . . . Swanepoel, J. (2011). *Green Jobs: An Estimate of the Direct Employment Potential of a Greening South African Economy.* Industrial Development Corporation, Development Bank of Southern Africa, Trade and Industrial Policy Strategies.

Marklines Database. (2013). *Marklines Automotive Industry Portal*. Retrieved April 7, 2013, from http://www.marklines.com/en/

Massiani, J. (2013). *The Use of Stated Preferences to Forecast Alternative Fuel Vehicles Market Diffusion: Comparisons with Other Methods and Proposal for a Synthetic Utility Function.* Social Science Research Network.

Massiani, J., & Weinmann, J. (2012). *Electric Cars as a Means to Reduce Greenhouse Gas Emissions: Methods, Results and Policy Implications in Germany.* Ca' Foscari University of Venice Department of Economics.

Matthies, G., Stricker, K., & Traenckner, J. (2010). *The e-mobility era: Winning the race for electric cars.* Bain & Company.

McKinsey&Co. (2009a). *Pathways to a Low-Carbon Economy: Version 2 of the Global Greenhouse Gas Abatement Cost Curve.* McKinsey & Company.

McKinsey&Co. (2009b). *Roads toward a low-carbon future: Reducing CO2 emissions from passenger vehicles in the global road transportation system.* McKinsey & Company.

McManus, W., & Senter, R. (2009). *Market Models for Predicting PHEV Adoption and Diffusion.* Ann Arbor, Michigan: U.S. Department of Energy.

Merven, B., Stone, A., Hughes, A., & Cohen, B. (2012). *Quantifying the energy needs of the transport sector for South Africa: A bottom-up model.* South African National Energy Institute: Energy Research Centre.

Michel, J.-B., Shen, Y. K., Aiden, A. P., Veres, A., Gray, M. K., Brockman, W., . . . Aiden, E. L. (2010). *Quantitative Analysis of Culture Using Millions of Digitized Books.* The Google Books Team. Retrieved January 14, 2014, from https://books.google.com/ngrams/chart?content=Electric+vehicle&year_start=1900&year_end=2008&corpus=15&smoothing=3&share=&direct_url=t1%3B%2CElectric%20vehicle%3B%2Cc0#

Mini. (2013). *Mini*. Retrieved July 1, 2013, from http://www.miniusa.com/content/miniusa/en.html

Ministry of Environment of Chile. (2012). *E-mobility Readiness Plan Chile.* Santiago: Ministry of Transport and Telecommunications of Chile.

Mock, P., Hulsebusch, D., Ungethum, J., & Schmid, S. A. (2009). *Electric Vehicles - A model based assessment of future market prospects and environmental impacts.* Stavanger, Norway: EVS24 International Battery, Hybrid and Fuel Cell Electric Vehicle Symposium.

National Treasury. (2013). *Carbon Tax Policy Paper.* Department: National Treasury.

NERSA. (2013). *Revenue Application - Multi Year Price Determination 2013/14 to 2017/18.* National Energy Regulator of South Africa.

Nissan. (2013). *Nissan Leaf*. Retrieved June 12, 2013, from http://www.nissanusa.com/electric-cars/leaf/

Norton, J. A., & Bass, F. M. (1987). A Diffusion Theory Model of Adoption and Substitution for Successive Generations of High-Technology Products. *Management Science Vol. 33 No. 9*, 1069-1086.

OANDA. (2013, November 25). *OANDA*. Retrieved November 25, 2013, from http://www.oanda.com/currency/average

OECD. (2013a). *Economic Growth in South Africa: Getting to the right shade of green.* OECD Publishing.

OECD. (2013b). *OECD Environmental Performance Reviews: South Africa.* OECD Publishing.

Paine, C. (Director). (2006). *Who Killed the Electric Car?* [Motion Picture].

Paine, C. (Director). (2011). *Revenge of the Electric Car* [Motion Picture].

Paixao, P. d. (2010). *Electric Cars in Brazil: A method for assessing innovation impacts on the economy.*

Perdiguero, J., & Jiminez, J. L. (2012). *Policy options for the promotion of electric vehicles: a review.* University of Barcelona: Research Institute of Applied Economics.

Ramsey Media. (2012). *SA Autobrand Survey.* Cape Town: Ramsey Media.

RBSC. (2011). *Powertrain 2020: The Li-Ion Battery Value Chain - Trends and implications.* Roland Berger Strategy Consultants.

Santini, D. J., & Vyas, A. D. (2005). *Suggestions for a New Vehicle Choice Model Simulating Advanced Vehicles Introduction Decisions (AVID): Structure and Coefficients.* Oak Ridge, TN: Argonne National Laboratory.

Snyman, C. (2012). Re-Inventing Mobility. *Driving EV Policy and Charging Infrastructure.* Johannesburg.

Squatriglia, C. (2012, May 3). *Chevrolet Volt Named European Car of the Year.* Retrieved May 10, 2013, from Wired: http://www.wired.com/autopia/2012/03/volt-ampera-europe-car-year/

Struben, J., & Sterman, J. D. (2008). Transition challenges for alternative fuel vehicle and transportation systems. *Environment and Planning B: Planning and Design volume 35*, 1070-1097.

Sullivan, J. L., Salmeen, I. T., & Simon, C. P. (2009). *PHEV Marketplace Penetration An Agent Based Simulation.* Ann Arbor: University of Michigan Transportation Research Institute.

Sultan, F., Farley, J. U., & Lehmann, D. R. (1990). A Meta-Analysis of Applications of Diffusion Models. *Journal of Marketing Research Vol.27 No.1*, 70-77.

Tamor, M. A., Gearhart, C., & Soto, C. (2013). A statistical approach to estimating acceptance of electric vehicles and electrification of personal transportation. *Transportation Research Part C 26*, 125-134.

Toyota. (2013). *Toyota*. Retrieved July 1, 2013, from http://www.toyota.com/

Venter, I. (2013a, April 19). *BMW to launch electric, plug-in hybrid cars in South Africa during 2014.* Retrieved April 20, 2013, from Engineering News: http://www.engineeringnews.co.za/article/auto-industry-2013-04-19-2

Venter, I. (2013b, November 22). *Electric vehicles make commercial debut in SA as Nissan unveils Leaf.* Retrieved November 25, 2013, from Engineering News: http://www.engineeringnews.co.za/article/electric-vehicles-make-commercial-debut-in-sa-as-nissan-unveils-leaf-2013-11-22

Venter, I. (2013c, November 15). *VWSA to introduce first full-electric vehicle to South Africa in 2014.* Retrieved November 20, 2013, from Engineering News: http://www.engineeringnews.co.za/article/auto-industry-2013-11-01-8

Volkswagen. (2013). *Volkswagen*. Retrieved July 2013, 1, from http://www.vw.com/en.html

Wansart, J., & Schnieder, E. (2010). Modeling market development of electric vehicles. *Systems Conference, 4th Annual IEEE*, (pp. 371-376). San Diego, CA.

Wilson, L. (2013). *Shades of Green: Electric Car's Carbon Emissions Around the Globe.* Shrink That Footprint.

Winkler, H. (2007). *Long Term Mitigation Scenarios: Technical Report.* Pretoria: Prepared by the Energy Research Centre for the Department of Environmental Affairs and Tourism.

Woosey, J. (2012, July 26). *Car prices revisited: SA vs abroad.* Retrieved November 8, 2013, from IOL motoring: http://www.iol.co.za/motoring/industry-news/car-prices-revisited-sa-vs-abroad-1.1349644#.UrL7H9IW395

World Bank. (2010). *World Development Report: Development and Climate Change.* Washington, DC.

10. Appendices

Appendix 1: Average 2012 Exchange Rates

Currencies	Bid/Ask Year Average
ZAR/EUR	0.09494
ZAR/GBP	0.077045
ZAR/JPY	9.74104
ZAR/USD	0.12207
USD/CNY	6.3116
USD/EUR	0.778155
USD/JPY	79.80144

Source: (OANDA, 2013)

Appendix 2: Regression of vehicle sales on indicator variables for petrol and vehicle prices

```
. reg vsales PPIpetrol PPItransport n

      Source |       SS       df       MS              Number of obs =     516
-------------+------------------------------           F(  3,   512) =  252.58
       Model |  346903.294     3  115634.431           Prob > F      =  0.0000
    Residual |  234402.805   512  457.817978           R-squared     =  0.5968
-------------+------------------------------           Adj R-squared =  0.5944
       Total |  581306.099   515  1128.74971           Root MSE      =  21.397

------------------------------------------------------------------------------
      vsales |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
   PPIpetrol |   .4272083   .0250047    17.09   0.000     .3780839    .4763328
PPItransport |  -.4644816    .092349    -5.03   0.000    -.6459112   -.2830521
           n |    .075583   .0286044     2.64   0.008     .0193867    .1317794
       _cons |   90.42782   2.892494    31.26   0.000      84.7452    96.11044
------------------------------------------------------------------------------
```