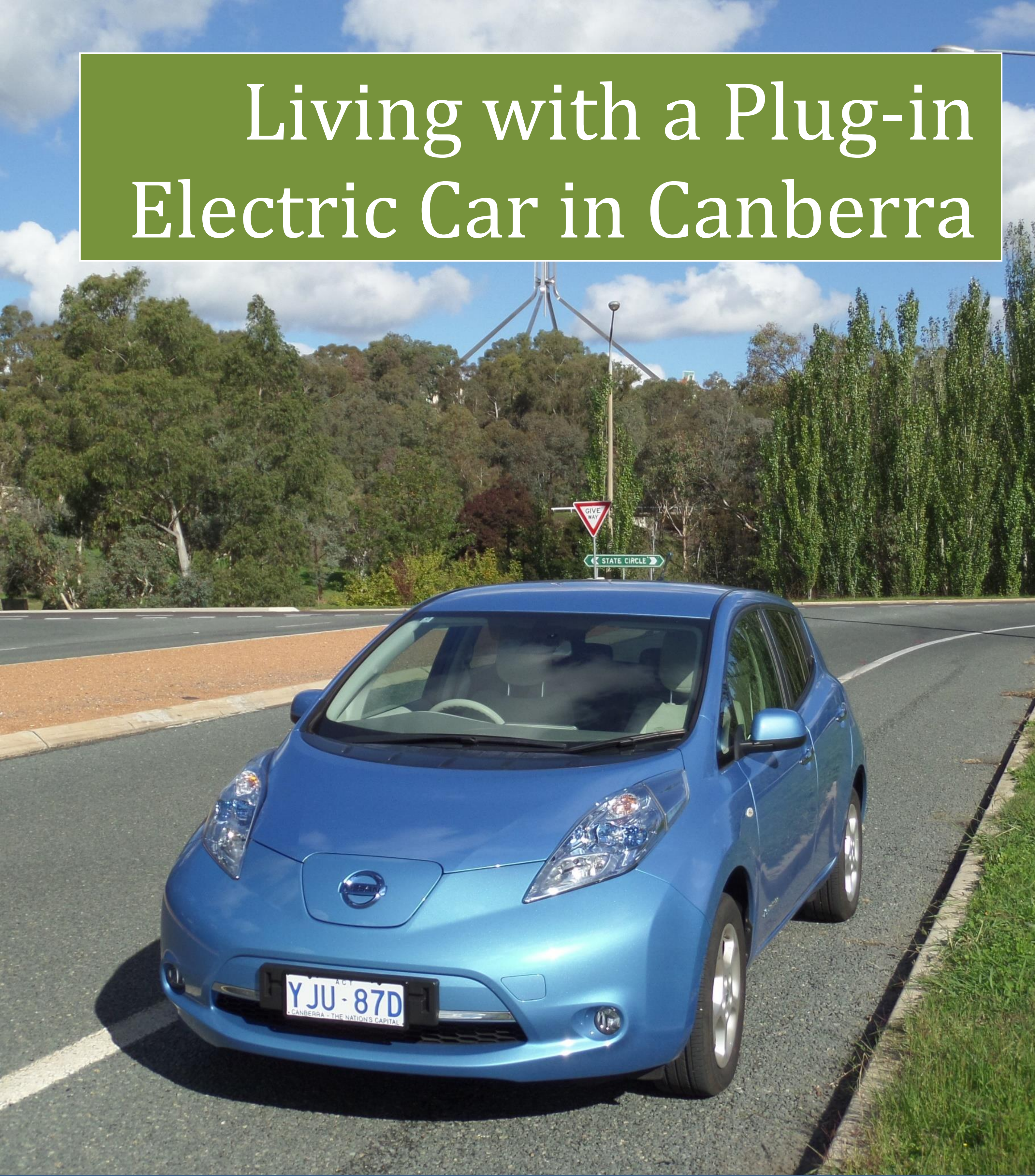
# Living with a Plug-in Electric Car in Canberra




*Driving towards a sustainable ACT*

**Dave Southgate**

**August 2014**

# FOREWORD

The electric car has arrived!

After decades of false starts, production models of plug-in electric vehicles (EVs) are now globally available from major car manufacturers.  They are beautiful to drive and cost very little to run. However, at the moment they cost more to buy and generally have a shorter range than conventional cars.

The sales of EVs are growing rapidly around the world – more than 500,000 plug-in EVs have been sold globally over the past three years.  To date this revolution has largely passed Australia by.  It is exceptional to see a plug-in electric car on the streets in Canberra and the mainstream media in Australia rarely reports on this fundamental transition in the fuelling of the world's land transport. I have therefore produced this book in an attempt to both raise awareness of the practicalities of owning an EV in Canberra and, probably more importantly, to draw attention to how the advent of the EV provides the ACT with opportunities to establish a sustainable future.

The introduction of EVs into Canberra is particularly important given the wonderful strides that the ACT Government has made in introducing renewable energy into the Territory.  By 2020 90% of our electricity consumption should be derived from renewables.  An electricity sector based on renewables opens up a vision of carbon free urban transport.  At the present time the electricity and transport sectors make up about 85% of the ACT carbon footprint – the path to almost total elimination of carbon from these two sectors is now in sight.

While this book is focussed on action within the ACT I think much of the material has wider applicability.  Many cities and regions around the world are now moving towards carbon neutrality - I imagine the EV has a place in all of these.

Dave Southgate

Canberra
Australian Capital Territory (ACT)

August 2014

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## Disclaimer

The author has no commercial interests in the electric vehicle or renewable energy industries.  He is self-funded and has produced this document purely in pursuit of a personal wish to see society adopt more sustainable transport options.

**Cover Photo**:  A Leaf among leaves – Parliament House, Canberra

# SNAPSHOT

## Is Canberra a Good Place to Own an Electric Vehicle?

**Absolutely!** I don't think I'll ever go back to owning a conventional petrol car.

An electric car makes an ideal city car for the Canberra resident.

Electric cars are great to drive and 'filling up' at home is extremely convenient.

## Why Electric Vehicles?

Electric vehicles are rapidly being introduced around the world. There are three key drivers:

- climate change
- air quality
- energy security

*Advances in battery technology mean electric vehicles are now economic and practical.*

## Key Information

- For many motorists the life cycle costs of owning an electric car (EV) are now likely to be less than for owning a petrol car. An EV costs more to buy than a conventional car but the fuel costs are less.

- I estimate that after about 10 years the total costs for my EV will be the same as if I'd bought a petrol car.

- On average I travel about 40km/day in my EV which is about 15,000km/year. Two hours of charging for my car provides about 50km range.

- My electric car uses about 7kWh/day. The annual fuel cost to run my electric car will be around $400 compared to $2,000 for my previous petrol car.

- The day-to-day minimum range of my car is about 100km – more than enough for a city car in Canberra.

- I have a 2kW solar PV system which generates around the same amount of energy in a year as my car uses to travel about 15,000km.

## Sustainable Canberra

The ACT Government has adopted a **goal of 90% of the Territory's electricity consumption being sourced from renewables by 2020**. By 2018 the transport sector will become the largest component of the ACT's carbon footprint.

The 90% renewables goal underpins climate change action in the electricity sector. The development of a **parallel goal for the uptake of electric vehicles** could provide a vital stimulus for $CO_2$ management in the transport sector.

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# Chapter 1

# Introduction

## 1.1 The Rebirth of the Electric Vehicle

The electric vehicle (EV) has been with us for a long time. In the late 1800s and early 1900s electric powered cars outsold petrol cars but as motoring developed liquid fuelled cars became established due to their greater range and speed of re-fuelling. While petrol and diesel fuels have dominated road vehicles for over a century, during that time electricity has been widely used to power public transport (for example trams and trolley buses) and many attempts have been made to produce workable electric cars.[1] Small groups of enthusiasts have continued to use and promote electric cars. In recent years there have been a number of electric vehicle festivals in Canberra which have showcased the latest EV developments.

Until recently most electric cars on the road have been conversions of commercial petrol cars. However, in the past three years there has been a dramatic EV renaissance. Advances in battery technology have led to EVs now becoming both technically feasible and affordable. Around 2010, the major car manufacturers began producing, and selling globally, plug-in electric cars. *Figure 1.1* shows the trends in global sales of plug-in electric passenger cars since 2009 (this dramatic increase is off a very low base).[2] Production electric vehicles are now readily available in many countries and it appears that the EV is transitioning from an enthusiasts' niche to the mainstream. Global EV sales are currently doubling every year and if these trends continue there will be more than 1,000,000 EVs on world roads by 2016.[3] While sales around the world have surged, Australia has not contributed significantly to this trend. Only about 100 EVs were sold to private individuals in Australia in 2013.[4]

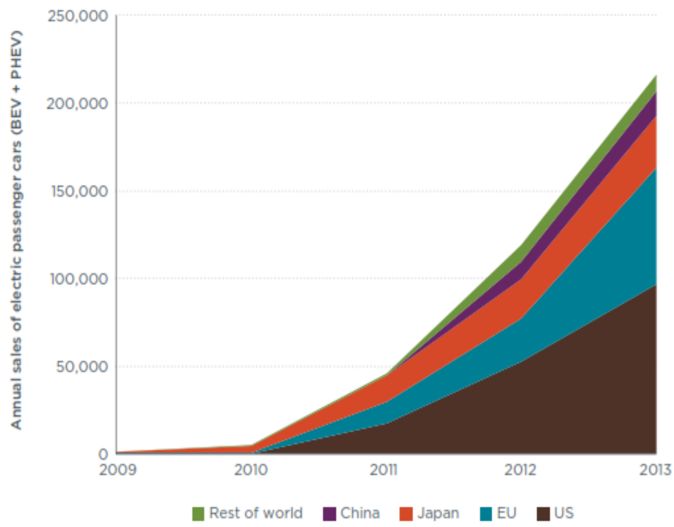


**Figure 1.1: Global sales of plug-in electric passenger cars, 2009-2013**

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[1] *Electric cars and history.* Edison Tech Center: http://www.edisontechcenter.org/ElectricCars.html

[2] *Driving electrification: A global comparison of fiscal policy for electric vehicles.* Figure 1. ICCT. May 2014: http://theicct.org/driving-electrification-global-comparison-fiscal-policy-electric-vehicles

[3] *Electric car sales have doubled every year for three years.* Transport Evolved. April 2014: http://transportevolved.com/2014/04/16/number-electric-cars-world-doubled-past-year-say-academics/

[4] *2013 Plug-in EV sales in Australia*. InsideEVs: http://insideevs.com/2013-plug-in-electric-vehicle-sales-in-australia/

## 1.2 The Pressures for Change

There are many reasons why electric vehicles are now starting to make a comeback. The Box on the next page summarises the key reasons why governments are promoting the transition to EVs. The pressures are varied and different governments clearly place different emphasis on the reasons for wanting to electrify their transport systems.

Many individuals, and governments, see the need to address climate change as the main imperative to adopt EVs. However, EV detractors commonly express the view that if an EV is charged from an electricity network based on coal fired generation there may be no, or very small, climate change advantages to using EVs.[5] *Figure 1.2* captures the essence of this issue.[6] The information in this diagram suggests that a petrol car with a fuel efficiency of 8l/100km has the same life cycle carbon footprint as an electric car which is powered by electricity sourced from coal. This is a complex area which is worthy of examination but in the context of the ACT, where the Territory is rapidly moving toward 90% of its electricity being sourced from renewables, this does not appear to be a significant issue.

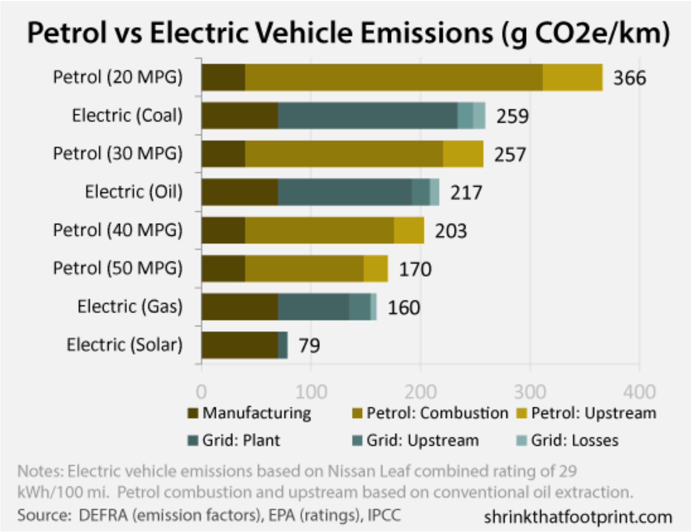


**Figure 1.2: EV carbon footprint – electricity sourced from renewables compared to coal**

While air quality may not be a major driver for the ACT government or residents to opt for EVs, it is a top priority in countries with urban air quality problems. The modern EV has its origins in California where in 1990 the State government mandated that from 2003 10% of all vehicle sales must be zero emissions in order to address air quality issues.[7] In China air quality is one of the key political issues of the day (see *Figure 1.3*)[8]. In March this year, restrictions were placed on petrol/diesel cars in Paris for some days due to a persistent fog.[9] In London Mayor Boris Johnson has recently announced requirements for all London taxis to be zero emission capable from 2018 primarily for air quality reasons.[10]

**Figure 1.3: Smog over Harbin, China**

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[5] *Electric cars' benefit to environment not as great as claimed.* April 2014: http://www.climatechangedispatch.com/electric-cars-benefit-to-environment-not-as-great-as-claimed.html
[6] *What's the greenest car? An extremely short guide to vehicle emissions.* Shrink That Footprint. April 2014: http://shrinkthatfootprint.com/greenest-car-vehicle-emissions
[7] Air Resources Board. California State Government: http://www.arb.ca.gov/knowzone/history.htm
[8] Photo source: http://en.wikipedia.org/wiki/File:HarbinChinaSmog_121226.jpg#file
[9] France curbs Paris car drivers to combat dangerous smog. Reuters UK. March 2014: http://uk.reuters.com/article/2014/03/16/uk-france-pollution-idUKBREA2F0BF20140316
[10] Transport for London. Press release. January 2014: http://www.noodls.com/view/FE88B1370D96FC544154D510865EEC50D48F7F9D?3285xxx1389878269

# Global Pressures to Go Electric

Around the globe there are strong pressures to move toward a carbon free road transport system. In some regions of the world significant changes are occurring. These changes involve not only a move to electric cars but also to electric buses, taxis, motorcycles and bicycles. There appear to be three key drivers for the transition to electric vehicles:

**Climate Change**

In many countries transport contributes around 20% of the carbon footprint. In Australia road transport makes up about 85% of the transport carbon footprint. Electrifying road transport will make significant reductions in global $CO_2$ levels.

**Air Quality**

Urban air quality is poor in many cities of the world. For example, the problems being encountered in China, and earlier this year in France, have been highly publicised. Adoption of electric vehicles with zero emissions in the urban area can lead to significant improvements in the health and quality of life of city dwellers.

**Energy Security**

If a country is heavily dependent on imported fuels for its transport systems its economy is open to disruption. In Australia oil refineries are progressively being shut down and we are becoming increasingly dependent on imported liquid fuels. Electric vehicles offer fuel diversity and are particularly suited to integration with renewable energy.

**Uptake Factors**

There are many factors, both positive and negative, which are influencing the rate of uptake of electric vehicles. These include:

*Cost* – at the present time the purchase price of an electric vehicle is generally significantly more than an equivalent conventionally fuelled vehicle. By the same token the running costs are significantly less. The breakeven point for cost appears to be in the area of 5 to 10 years.

*Range* – electric vehicles generally have markedly less range than their petrol/diesel equivalent. Nevertheless the current generation of electric vehicles have a range which more than adequately meets the day-to-day needs of a 'city vehicle'.

*Limited choice* – only a limited number of models and makes of electric vehicles are currently available on the market. The ones available tend to be at the luxury end of the market. Given their very recent introduction there is effectively no market in used electric cars at the moment.

*Comfort/performance* – people who test drive an electric car generally report a very positive response particularly about the smooth/rapid acceleration and the lack of noise and vibration.

Fuel security is a major driver to go EV in many economies. Electric vehicles offer the potential for liquid fuels to be substituted by other energy sources – coal; natural gas; and renewables are the obvious substitute energy sources when using electricity. Fuel security is particularly relevant to Australia where our capacity to produce petroleum and other liquid fuels is being progressively eroded - we are moving toward a transport regime based very heavily on imported liquid fuels. Many people have raised concerns about what it would mean for our transport systems if there were major interruptions to shipping (strikes; weather; terrorism, etc). Following announcements in 2011 and 2012 of the closure of the Clyde and Kurnell refineries, the NRMA commissioned a report looking into Australia's fuel security.[11,12] Subsequent to the release of that report, in April of this year BP announced the closing of its Brisbane refinery.[13]

Rising petrol prices are an ongoing reason for individuals and governments to look for alternative transport fuels. Electric vehicles are very efficient compared to internal combustion engine (ICE) vehicles. At present EVs cost significantly more to buy than ICE vehicles but have substantially lower fuel costs. Electric vehicles are also mechanically much simpler than ICE vehicles and therefore have lower maintenance costs.[14] For an average driver in the ACT it appears that the current payback period if buying an EV instead of an ICE vehicle will be around 7-10 years (see Chapter 5).

Electric vehicles represent new technology and integrate well with the emerging renewable energy sources. They also offer an ideal platform for autonomous vehicles which are now being trialled as a way, amongst other things, to improve road safety. In September 2013 a Nissan Leaf was the first vehicle in Japan to receive approval to operate in a driverless mode on Japan's public roads.[15]

Noise from road traffic has been an ongoing problem for many decades. At slow speeds EVs are exceptionally quiet. In fact concerns about the lack of noise has led to requirements for slow moving EVs to emit an audible warning signal to alert pedestrians.[16] At high speeds the noise difference between an EV and an ICE vehicle for a person living next to a road is not likely to be great since most of the noise generated by a modern car travelling at speed arises from tyre/road and aerodynamic interactions rather than from the engine.

## 1.3 Author's Motivation for Going EV

After some years working on climate change issues as a Federal bureaucrat I came to the conclusion that agreement on effective strategies to address climate change is unlikely to be achieved at the international level, or indeed at the national level in Australia, within a reasonable time frame. The issues are just too complex and wide ranging. By the same token I was very aware that much was being achieved at the individual and local/regional government level around the world through focussed programs and action. Climate change is an issue that is well suited to 'bottom-up' solutions. On my retirement in 2012 I began to search for a climate change project where I, as an individual, could make a difference.

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11 *Australia's Liquid Fuel Security.* NRMA. 2013: http://www.mynrma.com.au/media/Fuel_Security_Report.pdf
12 *Australia's Liquid Fuel Security.* NRMA. 2013: http://www.mynrma.com.au/images/About-PDF/Fuel-Security-Report-Pt2.pdf
13 *Jobs to go as BP closes Brisbane refinery.* Sydney Morning Herald. April 2014: http://www.smh.com.au/business/mining-and-resources/jobs-to-go-as-bp-closes-brisbane-refinery-20140402-35xkr.html
14 Electric Vehicles: Myths v Reality. Sierra Club: http://content.sierraclub.org/evguide/myths-vs-reality
15 Caradvice website. September 2013: http://www.caradvice.com.au/253761/nissan-leaf-becomes-japans-first-road-legal-autonomous-vehicle/
16 *EU Parliament mandates audible warnings for hybrid and electric vehicles.* EV Fleetworld. May 2014: http://evfleetworld.co.uk/news/2014/Apr/European-Parliament-mandates-audible-warnings-for-electric-and-hybrid-vehicles/0438013782

Two key happenings led me to choose the transition to EVs as a very worthwhile climate change project. To begin with, in 2012 the ACT Government released a visionary and far reaching plan to address the Territory's carbon footprint.[17] In the plan it adopted a target that 90% of Canberra's electricity consumption would be sourced from renewables by 2020 – this approach immediately opened up the way for the transition to fossil fuel free transport in the ACT. The chance to turn this opportunity into personal action came in mid-2013 when production EVs became affordable for me – the price for a mainstream electric car dropped below $40,000.

The ACT's adoption of the 90% renewables target demonstrated that at the local level, where there is a fairly homogenous community, it is possible to take strong action on climate change. Globally much of the progress on climate change action is now taking place at the city and regional level – C40 and Regions 20 (R20) are two organisations which are arguably achieving a greater level of international cooperation on climate change than has been possible through the UNFCCC (United Nations Framework Convention on Climate Change) process.[18,19]

The adoption of carbon neutral electricity leads inexorably to the electrification of transport systems. More than 80% of the ACT's carbon footprint is derived from either the electricity or transport sectors – electrifying our transport would lead Canberra well down the road to becoming a carbon neutral city.

## 1.4 Will an EV Work for You?

It is important to recognise that the current generation of EVs will not be suitable for all users. Due to the range limitations of current EVs, an individual or family needs to fully understand their travel patterns before making a decision to transition to an EV.

The current generation of commercially available EVs (except the very special and highly priced Tesla[20]) have a range which is ideal for a 'city car' (charged at home) but which is unlikely to be satisfactory for an all-purpose car given the effective absence of public charging infrastructure in Australia. For the most part this means that a current EV will likely make an excellent second car and be very capable of replacing a family car that is essentially dedicated to 'running around town'.

The nominal range of a current generation EV is typically 150km-200km when fully charged. However, in practice for many people the workable comfortable range of an EV is not likely to be much greater than 100km (just like a petrol car the range depends on the driver and the conditions). Against this background, the first step in working out whether an EV will be suitable is to keep a daily log of distances you currently travel each day in your 'city car'. The average distance travelled per day by cars in the ACT is about 40km[21] – a distance well within the capability of the current EV. However, decisions on choice of vehicle are very often based on the possible occasional use, rather than the day-to-day use (eg buying a four wheel drive vehicle which in practice is very rarely taken off-road), and this needs to be taken into account when determining the suitability of an EV. The author's personal 'range experience' around Canberra is discussed in detail in Chapter 2.

In the case of two car families, the range limitation of the city car can often be overcome by the family owning one electric and one internal combustion engine (ICE) vehicle. When a family or individual owns only one car, owning an EV may be feasible if the need to take 'out of city' trips is

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[17] *AP2 – A new climate change strategy and action plan for the Australian Capital Territory.* ACT Government 2012: http://www.environment.act.gov.au/__data/assets/pdf_file/0006/581136/AP2_Sept12_PRINT_NO_CROPS_SML.pdf
[18] *Global Leadership on Climate Change.* C40Cities: http://www.c40.org/
[19] R20-Regions of Climate Action: http://regions20.org/
[20] Tesla Motors website: http://www.teslamotors.com/en_AU/models
[21] *Australian motorists drive an average of 15,530km per year.* Roy Morgan research. May 2013: http://www.roymorgan.com/findings/australian-moterists-drive-average-15530km-201305090702

only occasional. For example, using public transport or hiring an ICE vehicle to undertake longer trips may be an option. Having said that, this is likely to be inconvenient in many cases and a good compromise solution may be to purchase a plug-in hybrid electric vehicle (PHEV). These cars, which are not yet common in Australia, have a battery which can generally power day-to-day trips around the city (say a range up to 60km). When undertaking a longer journey the PHEV seamlessly switches over to a petrol engine when the battery is depleted.

Unfortunately at the present time there is not a wide range of EVs on the market in Australia. In fact at the time of writing there are only two choices in Australia for production EVs under $40,000 – the Nissan Leaf and the Mitsubishi iMiev. This paucity of EV choice may well mean that while an individual may decide that they would like to own an EV, the models on sale may not meet certain personal requirements or preferences. Globally many of the major car manufacturers are now making and selling either EVs or PHEVs.

Against this background it is interesting to read the 2013 report on a longitudinal survey that was carried out in California to test the views of EV owners (the survey was started in early 2012) - over 90% of more than 2,000 EV users surveyed were satisfied with their vehicle.[22]

## 1.5 Renewable Energy

Using renewable energy is not a requirement for running an EV. However, to date EV use and renewable energy have often been closely linked. The 'early adopter' EV owners are commonly technology enthusiasts who have an interest in achieving carbon neutral transport – either by buying green energy from their electricity retailer or through installing solar PV systems. This has been an effective way of responding to EV detractors who have been very ready to point out weaknesses in the environmental credentials of EVs which use coal based electricity (see Figure 1.2).

About 10% of Canberra houses have solar panels.[23] However, all EV users in the ACT will effectively have carbon neutral road transport in the near future, with or without solar panels on their roofs, given the fact that 90% of our electricity will be sourced from renewables by 2020.

The nexus between renewable energy and EVs is now coming more into focus with the ongoing improvements in battery technology. Battery advances are driving both the uptake of EVs and the increasing interest in residential solar PV systems which include battery storage. In effect solar PV and EV technologies are converging courtesy of advanced batteries.

## 1.6 Report Focus and Structure

I have deliberately given this book a local Canberra focus for a number of reasons. In recent years there has been no shortage of EV discussion papers and project reports examining the potential for introducing EVs across Australia. These have typically been prepared by well-funded bodies from government, industry and academia (see for example ESAA report[24]) - as an individual I am not in a position to develop such comprehensive documents and I also do not want to simply go over old ground. In Section 1.3 I indicated that following several frustrating years working on global solutions to climate change I am now at the point where I believe greater headway may well be made by using bottom-up approaches to $CO_2$ management – focussing a book on one city/Territory allows me to test the reaction to local approaches. Finally, a point I deliberately make many times in this book,

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[22] *California Plug-in Electric Vehicle Driver Survey Results.* Air Resources Board. California State Government. May 2013: http://www.electricdrive.org/index.php?ht=a/GetDocumentAction/id/40805

[23] *Solar Power in the ACT – April 2014 Update.* Canberra Green Energy: http://canberragreenenergy.com.au/solar-power-in-the-a-c-t-april-2014-update/

[24] *Sparking an Electric Vehicle Debate in Australia.* Electricity Supply Association of Australia. November 2013: http://www.esaa.com.au/policy/sparking_an_electric_vehicle_debate_in_australia

the ACT is now in a unique situation where it is likely to have an electricity sector based almost exclusively on renewable energy within the next five years – in my view it is imperative that studies are carried out to identify ways to build on this important achievement. I hope this simple overview book will stimulate thinking on the way ahead.

Part 1 of the report describes the different elements of what I call my 'EV Project'. The key elements of the project: buying the car; charging the batteries; and the installation and operation of a PV solar system on the roof of our house – are examined in turn in Chapters 2, 3 & 4. These separate elements are brought together in Chapter 5 which discusses the costs associated with the project. I have attempted to make clear that there are a number of optional routes for 'going EV' – I describe what I have done but I have also attempted to point out alternative routes for each project stage.

In Part 2 (Chapters 6 & 7) I have endeavoured to examine how the EV can play a role in the ACT achieving the outcomes set out in the ACT Government's climate change action plan.

Chapter 6 looks at the carbon footprint of the ACT and examines to what extent the adoption of EVs could potentially reduce the Territory's carbon footprint. Transport is currently the second largest component of the Territory's carbon footprint (after electricity) and, according to AP2, the ACT Government's Climate Change Action Plan, it will become the largest component of the footprint by 2018 (due to the significant reductions now being made in the ACT's electricity carbon footprint).[25] In the final Chapter I explore strategies for encouraging EV uptake with a view to accelerating the Territory towards its long term goal of carbon neutrality.

While the book has a Canberra focus I think that much of the information has broader applicability, at least throughout Australia. My experience with the project has led me to become very enthusiastic about EV adoption and the book is unashamedly focussed on discussing what can be achieved with EVs. Nevertheless an honest attempt has been made throughout the book to highlight the limitations and weaknesses of EVs – I am very conscious that overhyping EVs will only generate expectations that cannot be met.

Throughout the book there is ongoing reference to the Nissan Leaf. This is not intended to be a promotion of the Leaf – this just happens to be the car I bought and for which I have gathered data. I expect that lessons learnt from my Leaf experience will be broadly applicable to other electric vehicles of a similar capacity used as city cars in Canberra.

The reader will have already noticed that I have used a number of abbreviations to describe different vehicle types. Throughout the book when I use the term 'EV' I am referring to pure electric (battery only) vehicles – these are sometimes referred to as BEVs in other documents. The term 'ICE' (internal combustion engine) vehicles covers vehicles using fuels such as petrol, diesel, CNG and LPG. I believe it is important to differentiate between plug-in hybrid vehicles – 'PHEVs' – and conventional hybrid vehicles such as the Toyota Prius (commonly termed HEVs) which have been on the market in Australia for some years. While HEVs have been very important transition vehicles they do not have any facility for inputting electricity from an external source and hence they are not part of the discussion in this book. [Toyota is now marketing a PHEV version of the Prius in Japan and the US.]

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[25] *AP2, Figure 11.* ACT Government 2012:
http://www.environment.act.gov.au/__data/assets/pdf_file/0006/581136/AP2_Sept12_PRINT_NO_CROPS_SML.pdf

I envisage that, at least in the near term, PHEVs will be the main cars used in the transition from ICE to EV. To date these have not proven too popular in Australia but the concept of using the car in EV mode when around town (very low fuel costs, no pollution) and then using the ICE mode when on extended trips is likely to be attractive to many people if the purchase price of the car is right.

This is not intended to be an academic treatise. I have tried to avoid using technical terms but do use some common technical terminology associated with electricity. I have used 'grey literature' for many of the references (newspaper articles, websites, etc) – if some of the references appear to give odd information I would recommend that the reader cross check that information with other sources. I have endeavoured to cross check 'the facts' wherever possible but inevitably there will be inconsistencies between information drawn from different sources whether in the formal or the grey literature.

# PART 1

# MY ELECTRIC CAR PROJECT

# Chapter 2

# Buying & Using my Car

## 2.1 Introduction

This Part of the book is my own personal experience and contains many totally subjective comments. The data I present depends on a wide range of personal factors – for example, the siting of my home and where and how I drive – and therefore, while I do not believe any of these are particularly unusual, I cannot guarantee that another person's EV experience will be the same, or even similar, to mine. In particular, the range of an EV can vary quite markedly from person to person.

In parallel with buying the car, I purchased and had installed at our house a charger for the car and an additional solar PV system on the roof. These two elements of the project are discussed in the next two chapters.

The period covered by 'the project' is the first 7 months of 2014. I have chosen this time window as it covers the last two months of summer and also the first two months of winter. The data shown in most of the figures relates to the project period.

## 2.2 Getting Set Up

I began the project by monitoring my daily travel distance in my old ICE car for three months in late 2013. *Figure 2.1* shows the distribution of the daily travel distances for the trips I carried out around Canberra during that period. I have only shown the 'around town' days since I live in a two car family and my wife's ICE car is available for when we go away on longer trips.

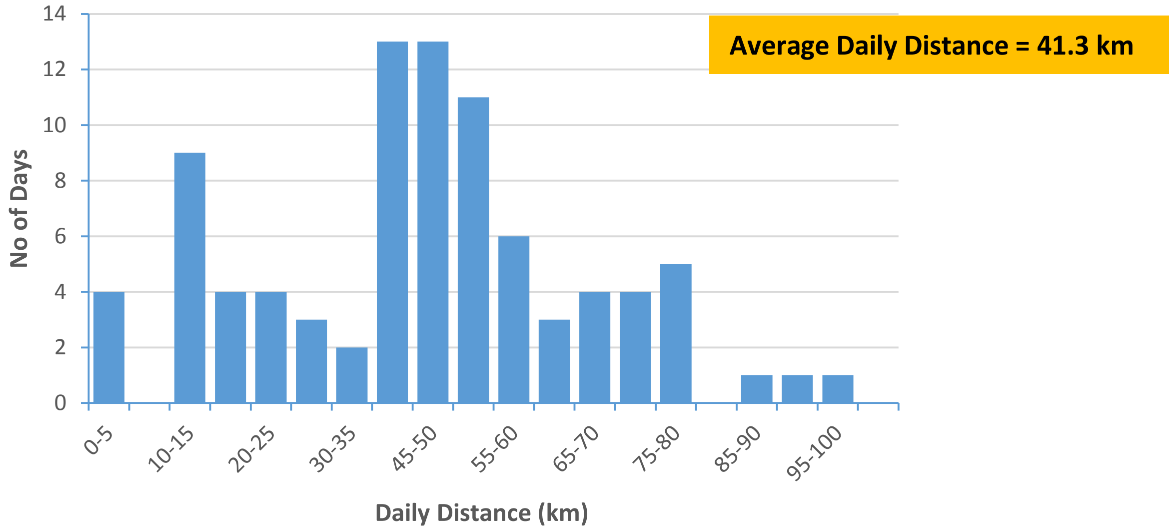


**Figure 2.1: Frequency distribution of my daily travel distances in my old ICE car – Q4 2013**

The Figure shows that the travel distance for my most common day in that period was in the range 40-50km. I travelled less than 70km on about 85% of the days. There were no days during the period where the distance exceeded 100km. This simple preparatory work gave me confidence that an EV with a range of at least 100km would very easily meet my 'around town' car needs. (This distribution equates to about 15,000km/year which is around the average for a car in Australia.[26])

Once I had gathered a reasonable amount of range data I looked at the available EV options. At the time I was in the market for an EV (the end of 2013) I could only find two choices – the Mitsubishi iMiev and the Nissan Leaf. Both of these cars easily met my range requirements. I decided to buy the Leaf, even though it was approximately $10,000 more than the iMiev, mainly because it looks and feels much more like a 'normal' car and also because I think it provides the driver with superior information on energy use and other aspects of car performance. I understand I was the 9th private purchaser of a Leaf in Canberra – a photo of my car is on the front cover.

## 2.3 Living with the Car

I should say upfront that this project has worked out far better than I ever imagined – I love my EV and now cannot envisage ever going back to owning a pure ICE vehicle.

Over the past seven months I've tried to closely observe the reaction of other people when I tell them I have an EV. If they haven't seen the car, the first question I invariably get is 'What colour is it?' Once we get over that hurdle the questions are generally along the expected lines: 'How far does it go without charging?'; 'How do you charge it up?'; 'What does it cost to run?' When people see the car for the first time they tend to be surprised as they are expecting to see something that looks like a 1970s bubble car. When I take them for a ride they are surprised at the comfort and performance. Not infrequently I have to assure people that it is a pure electric car – NO PETROL!


**Figure 2.2: The main instrument panel in my EV**

One of the nicest things has been the driving experience. It is extremely quiet inside, the ride is very smooth since there are no gear changes and the responsiveness is amazing compared to all the other (admittedly rather 'normal') cars I've previously owned. When you're driving it feels a bit like sitting in front of a computer rather than driving a car. *Figure 2.2* is a photo of the instrument panel immediately in front of the driver in a Leaf. When driving I find myself keeping quite a close eye on the distance the car has left to run before the battery runs out (km figure at bottom right of the panel). I'm also usually aware of how efficiently I am driving (the kWh/km figure in the middle of the panel).

The convenience of refuelling the car at home has been an unexpected bonus (see Chapter 3). The very low running costs have induced a feeling that it is costing me nothing to run around town (which is clearly not true). While not ideal, given the fact I am in solar surplus (see Chapter 4) I now tend to not worry too much about how much energy I use in total in my car as long as I can get home.

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26 Roy Morgan research. May 2013: http://www.roymorgan.com/findings/australian-moterists-drive-average-15530km-201305090702

## 2.4 Energy Use Patterns

Examining energy use for an electric vehicle is not straightforward. In this section all the data I am reporting relates to the amount of energy *used by the vehicle.* This is not the same as the energy *put into the vehicle* (and the energy you pay for) since my monitoring indicates there is an approximate 20% loss of energy when charging my car. I discuss this issue in detail in Section 3.4. The data behind all the figures in this section can be found in my project core datasheet which is shown in Appendix A.2.

*Daily Energy Use*

The driver's instrument panel in the Leaf has a display which shows the efficiency of travel in units of kWh/km (See *Figure 2.2)*. At the end of each day over the period of the project I noted down both the distance travelled and the value of the kWh/km reading before re-setting the values to zero. This gave me information on how much energy the car was using each day. You can see from *Figure 2.3* that the average daily energy use, when derived from the information provided by the car, was 6 kWh/day. It can be seen that the most common level of energy use/day is in the 4-5 kWh band.

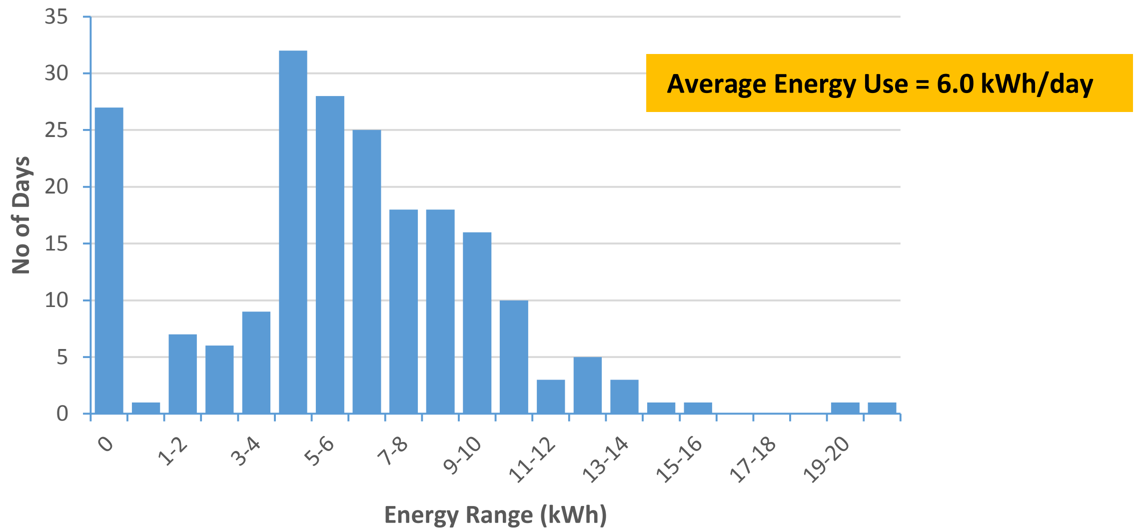


**Figure 2.3: Frequency distribution of the EV daily energy use (car instrument panel)**

The car used more than 10 kWh of electricity on about 15% of the days. The days with high energy use generally involved giving the car a top up charge sometime during the day.

The days with zero energy represent days where we used the family's ICE car to go on a trip beyond the range of the EV; or days where we simply used the bikes and/or walked; and holiday breaks.

*Energy Efficiency*

When discussing energy efficiency in this book I have converted the units 'kWh/km' shown on my EV's instrument panel to 'kWh/100km' in order to allow easier comparisons with fuel use in ICE vehicles (the common unit for fuel consumption used in Australia is 'litres of fuel/100km').

As indicated in the previous Section, when I am driving I find myself automatically tracking how efficiently I am driving by looking at the car's instrument panel (Figure 2.2). For me this figure generally tends to stay in a range between 12 and 17 kWh/100km.

While driving I can see the quite dramatic increase in instantaneous energy use of say going up a hill or accelerating quickly. I have tried to not let this unduly affect the way I drive – I have tried to be a normal driver and go with the flow of the traffic. When I peruse the web I can see that many EV drivers are much more efficient than I am and tend to get greater range out of their vehicles than I do. By the same token there are no doubt those who perform less efficiently. This seems to be very much an individual issue and is heavily influenced by prevailing conditions – weather, terrain, desired temperature inside the car, etc.

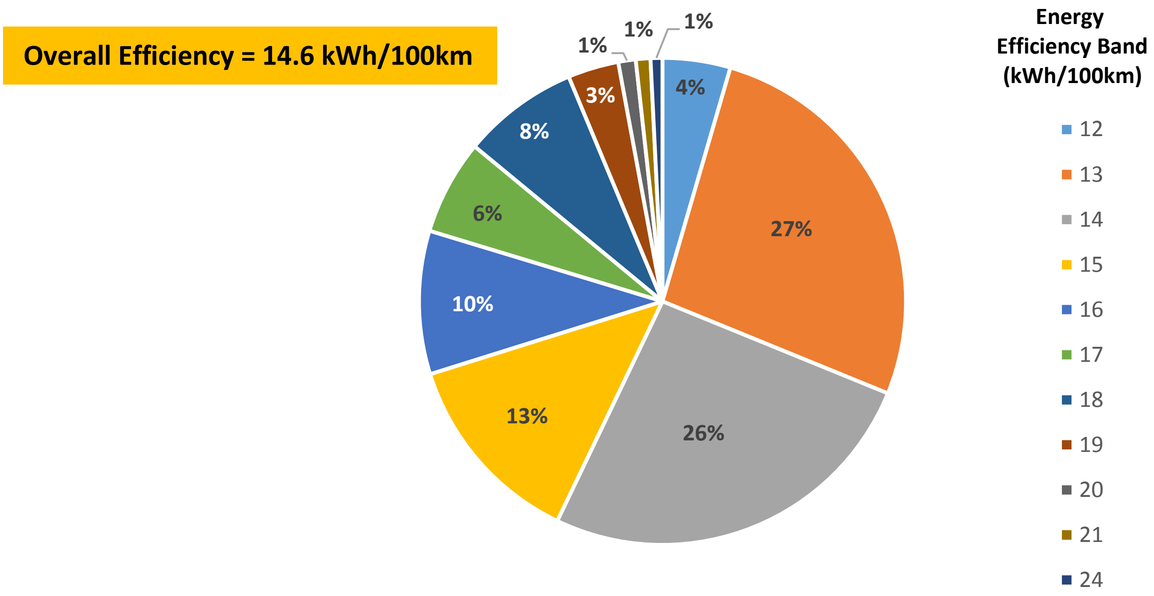


**Figure 2.4: Proportion of EV energy use by daily efficiency band**

*Figure 2.4* shows a breakdown of the total energy I used in the car over the project period by daily energy efficiency band (this is based on the energy efficiency figure shown on the driver's instrument panel at the end of each driving day). It can be seen that more than 50% of the car's energy use during the project period was on days in the 13 and 14 kWh/100km efficiency bands.

I did some very informal monitoring of the effect of having the climate control on – in summer this seemed to degrade performance by up to around 10% but this figure rose to over 15% on those cold Canberra winter days when I needed to use the lights and the wipers in addition to keeping warm. *Figure 2.5* pulls these observations together. You can see from this Figure that the driving efficiency was relatively constant at just under 15kWh/100km from January to early June and then it began to deteriorate quite markedly when the cold weather hit (the line shows a 7 day moving average of the daily efficiency).

It usually starts to become noticeably cold in Canberra at the end of April but this year it was unseasonally warm during May – the onset of the cold seemed to be delayed until the start of June. Warmer weather reappeared at the end of July and this is reflected in the improvement in the efficiency at the end of the project period. I am confident that this loss of efficiency due to cold weather is a real effect – I don't believe I made any changes in my driving patterns in June/July.

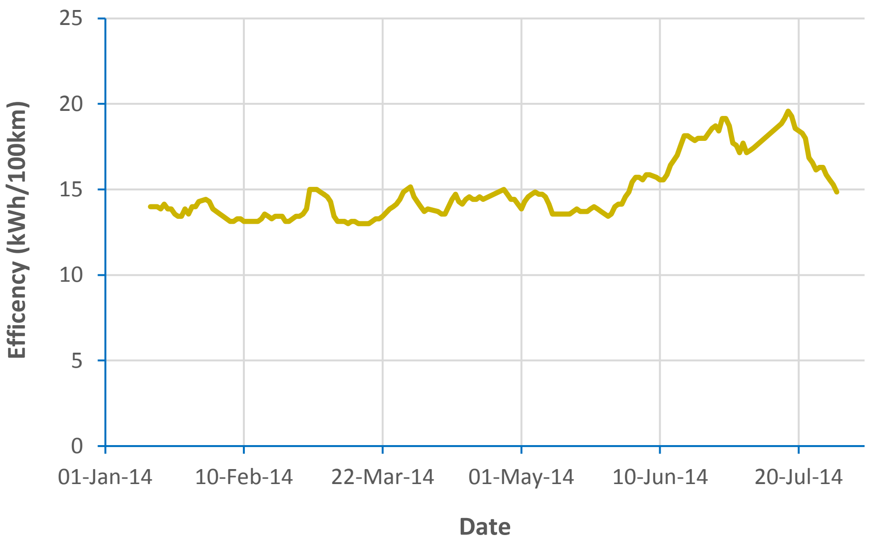


**Figure 2.5: Daily EV energy efficiency (7 day moving average) showing impacts of cold weather**

Placing this energy efficiency information in context, in my previous petrol car (a Nissan Pulsar) I was achieving an efficiency of around 8l/100km when driving around Canberra. On an energy basis this is equivalent to about 75 kWh/100km.[27] Comparing this with my EV which has a running efficiency of about 15 kWh/100km it can be seen that, at the point of energy use, the EV is about 5 times more efficient than the ICE – this difference in energy efficiency is reflected in the fuel costs of running the two different types of vehicle (see Chapter 5).

## 2.5 Range Anxiety

All cars, both EV and ICE, have a limited range but the differences are very stark. The ICE typically has a range of 500km+ and it is virtually always within range of a service station where it can fill up with fuel within a few minutes. The current generation EV vehicles typically have an effective range which is somewhere in the 100km-150km region and public charging stations are very few and far between in Australia. Even if there is a charging station in range, 'filling up' may take 2 or more hours (see Chapter 3). Running out of petrol in an ICE car can usually be rectified with a small can of fuel; running out of charge in an EV probably means your car being put on the back of a recovery truck. It is hardly surprising that 'range anxiety' is one of the most talked about topics amongst EV owners!

My car has a nominal range of 'up to 170km'. In practice, based on my experience, I start to get anxious when I travel anything over 100km. I think my car would go about 130km on a full battery in the Canberra area but psychologically I find I want to leave around 20-30km as a 'reserve in the tank' just in case there is some unusual event (road accident, diversion, etc) that might leave me electrically embarrassed. I understand that this is quite a normal reaction.[28]

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[27] *What are the units to submit energy data? What are the conversion factors?* Sustainable Energy Authority of Ireland: http://www.seai.ie/Your_Business/Public_Sector/FAQ/Energy_Reporting_Overview/What_units_do_we_use_to_submit_energy_data_What_are_the_conversion_factors_used_.html

[28] *EV range drops by 25% due to psychological safety buffer.* Inside EVs. March 2014: http://insideevs.com/study-ev-range-drops-by-25-due-to-psychological-safety-buffer/

Having said that I think most EV drivers like to push their cars towards the end of the range every now and then just to test out the capabilities. At this point I should say that my car has two charging levels - 80% and 100%. The car handbook advises to charge to 80% full for normal day-to-day operations to preserve the life of the battery and to go to 100% charge when you are trying to maximise the range for a particular trip.

*Daily Use*

I imagine my day-to-day around town travel patterns are very similar to those of many families in the ACT – going shopping; picking up kids from school; visits to museums; short trips around the ACT; driving to the start of walks, etc. Over the time I've owned the car I've deliberately tried to use and drive it as I would my previous cars when travelling around Canberra. I've always used the climate control to maintain a comfortable temperature inside the car. I have found no need to creep along or to fry/freeze in order to save the battery. The range of the car has worked out fine for normal day-to-day driving around Canberra.

*Figure 2.6* shows the distribution of daily travel distances I recorded in the EV over the project period. Comparing this with *Figure 2.1*, the distance distribution in my old ICE car, the shape is very similar in the frequency bands around the most common days but I have possibly done a few more over 60km trips in the EV. This suggests that the range limitation of my EV is not having any material impact on my 'around town' travel behaviour compared to my previous petrol engine car. Overall the EV gets the family from A to B in much the same as my previous ICE car – but with so much more comfort and excitement. On average I travelled 41.0 km/day in the EV during the project period compared to the 41.3 km/day I did in my ICE vehicle in the last three months of 2013.

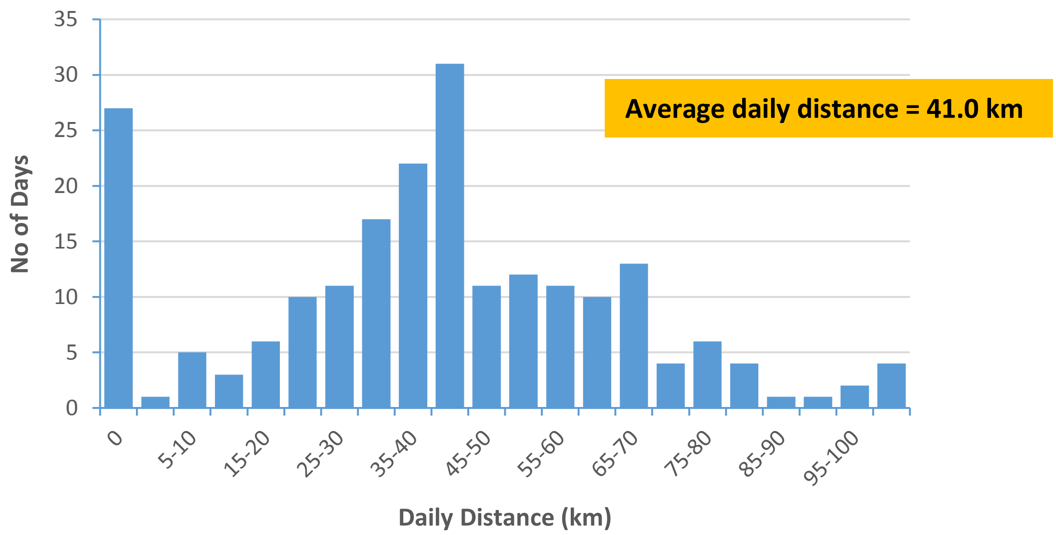


**Figure 2.6: Distribution of daily travel distances in my EV**

I normally take the handbook advice and charge my car to 80% full (I usually charge the car overnight) – this typically gives a nominal range of about 120km (more on charging the battery in the next Chapter). As you can see from *Figure 2.6* this very easily lets me do my normal day-to-day running around. On some days I've found myself going more places than usual during the day followed by commitments in the evening – on these days I've given the car an approx. 2 hour 'top up' in the late afternoon. When I know I'm going to have a big day around town I charge up to 100%.

*The Sunday Afternoon Drive*

Canberra, I guess like most Australian cities and towns, has a number of places within say 1 hour's drive where families go on weekends for picnics, afternoon tea, craft shops, bush walks, river swimming, etc. It's on these sorts of trips that range anxiety starts to appear. *Figure 2.7* shows five locations (roughly north, south, east and west of Canberra) where as a family we have ventured to 'range test' the EV. Taking on board what I have said earlier about the effective range of the car being around 100km for my driving in the Canberra region we have restricted ourselves to visiting places within about 50km from home (Belconnen). You can see from the map that these places are all a similar distance from Belconnen – I think I would say that I had some mild 'range concern' but not anxiety when we undertook these trips. If you live in Tuggeranong some of these trips (eg Tidbinbilla) will be trivial, others will probably not be possible without a great deal of anxiety (and/or a recovery vehicle).

*Figure 2.7* is also useful in that it also gives a good visualisation of the size of the urban area of Canberra relative to places that I consider to be at about the end of the car's range. From north to south Canberra now extends for approximately 50km so I always charge my car up to 100% if I am venturing to the southern part of Tuggeranong.

*Further Afield*

I don't see trips going much further than 50km being practical at the present time in current generation EVs (Teslas aside) since there is no *en route* charging infrastructure in place in our region. Nevertheless it's nice to think that this will be a short term constraint and regional and long distance EV trips will be feasible in the not too distant future for Canberran EV owners. I discuss this in Chapter 7.

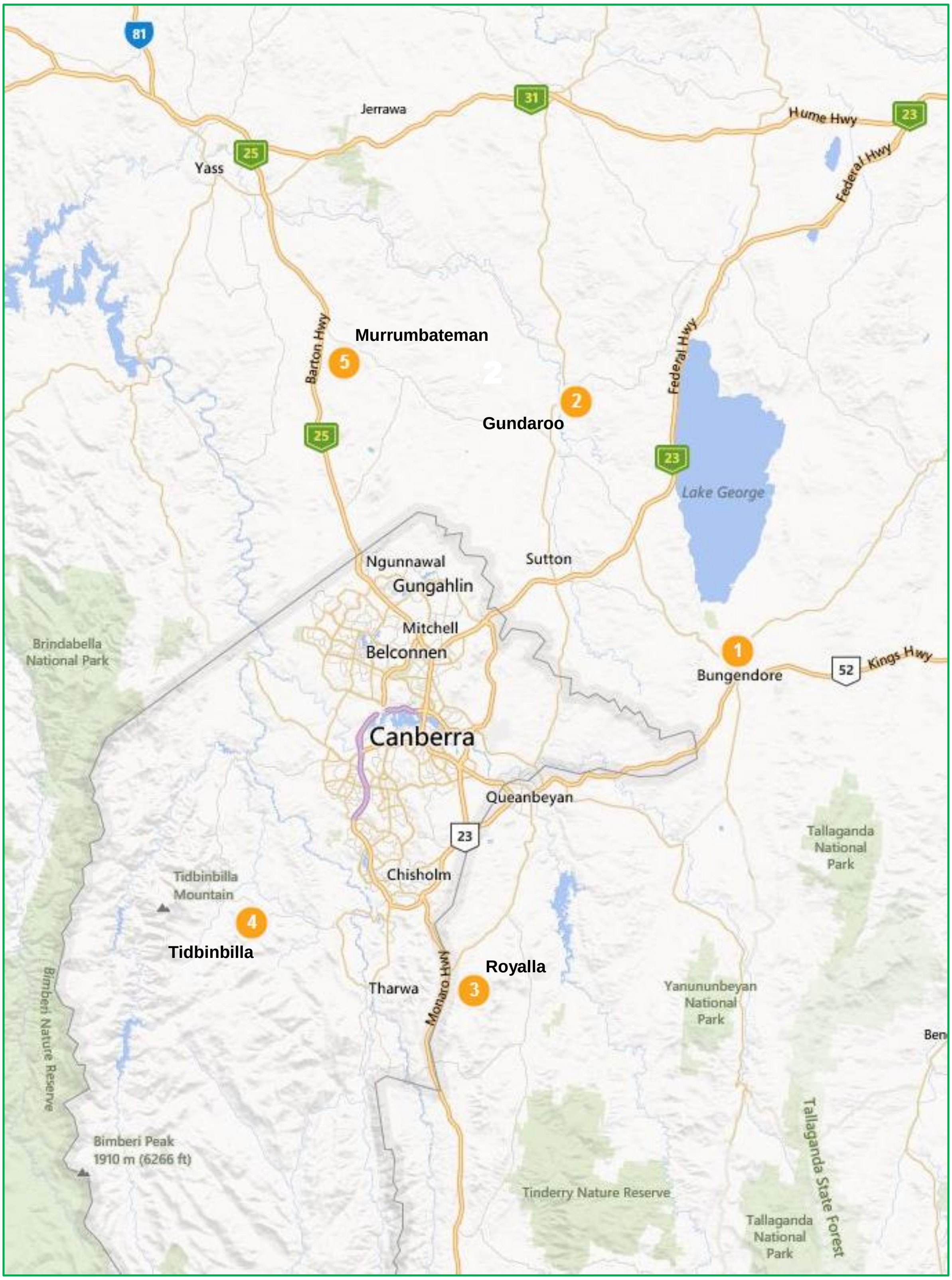


**Figure 2.7: Map showing comfortable range of my EV (for trips to/from Belconnen) compared to the size of urban Canberra**

**Scale: 1 cm ≈ 10 km** **Source: Bing Maps**

# Chapter 3

# Charging the Battery

## 3.1 Introduction


Refuelling your car at home rather than visiting a service station is probably the only lifestyle change you'll notice if you transition from an ICE vehicle to an EV. For me this has been one of most pleasant surprises of owning an EV - charging at home is absolutely brilliant! Having said that, since there is no practical public charging infrastructure in place in Canberra at the present time, charging at home is the only real option for refuelling your car if you have an EV.

The lack of public charging infrastructure is often cited as a key reason for the slow uptake of EVs around the world. I can see that certain out of town EV users would need to use public chargers in Canberra (eg people visiting Canberra in EVs from surrounding towns and villages) but for Canberra residents who use their EV as a city car I don't think this is an issue. I've never had the need to use a public charger and I don't think I would change my city driving behaviour even if Canberra were to suddenly become dotted with public chargers. On the other hand, if there were a network of public chargers in regional towns around the ACT I would almost certainly venture further afield in my car (see discussion in Chapter 7). Such a network would enable me to convert my EV from a 'city car' to a 'regional car'.

There are three broad categories of EV charger[29] in use around the world:

*Level 1* – the 'slow charger'; these typically draw about 10 amps and will charge an average car in 8+ hours. A Level 1 charger is usually included with most new EVs as a standard accessory. I have never used the one that came with my car.

*Level 2* – the standard home use charger; these are typically hard wired into a 32 amp circuit and are fixed on a wall. These will typically charge an average car from 'flat to full' in about 4-6 hours. I have one of these and (drawing about 16 amps) on an average night it takes about 2 hours to charge my car (providing around 50km range).

*Level 3* – these are the 'fast' public chargers; they typically draw over 60 amps and will charge a car battery to 80% full in about 30 minutes.

While I just love the home battery charging part of owning my EV, this is the one area where I think I would consider doing things differently if I were to start my electric car project over again.

## 3.2 The Charging Experience

This is one of the most raised topics when I talk to people about the EV owning experience. I've been surprised by the number of people who have told me they hate going to service stations and would love to be able to re-fuel their car at home. Looking back I had no problems with going to service stations to fill my car but I must say the experience of arriving home; just plugging in the

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[29] Strictly speaking the EV charger is on board the vehicle and what is commonly termed 'the charger' is simply a device to safely provide electricity to the charger. Within the EV family this device is commonly called the EVSE (Electric Vehicle Supply Equipment). In this book I use the term 'charger' as this is the most widely used terminology.

charger, then walking away and coming back the next day to a car with a 'full tank' sure beats going to 'the servo'.

I can only speak about my Leaf, but I'm sure it is similar for other EVS - charging is a trivial routine. You take the plug out of some form of holster and insert it in a socket in the front of the car (see *Figure 3.1)* - the car then automatically fills up the battery to a user selected level at a time also chosen by the user. The car has a very simple interface on the interior computer screen which lets the user set up times for charging. I use an off-peak tariff and usually charge my car overnight (see *Figure 3.5)*. However, on occasions I press an over-ride button and charge the car immediately (usually a top up charge during the day).

## 3.3 Which Charger?

*Charging at Home*

I understand from reading the EV blogs that when charging at home many people solely use the Level 1 charger that comes with the car they bought. This is the cheapest option but it does mean that it will not be possible to do 'quickish' battery top ups. The Level 1 charger that comes with the Leaf has a 15 amp plug which means that, unless you do a workaround, you will need to have a 15 amp circuit/socket installed in your garage if you don't already have one. This is generally not a major job for an electrician.

**Figure 3.1: Charging my car at home**

I decided against the Level 1 charger option since I figured that it would be nice to be able to do top up charges whenever I wanted to (this has turned out to be a good decision!). However, deciding to go down the Level 2 charger path does involve decisions and this is the area where I would look harder if for some reason I had to install a new charger.

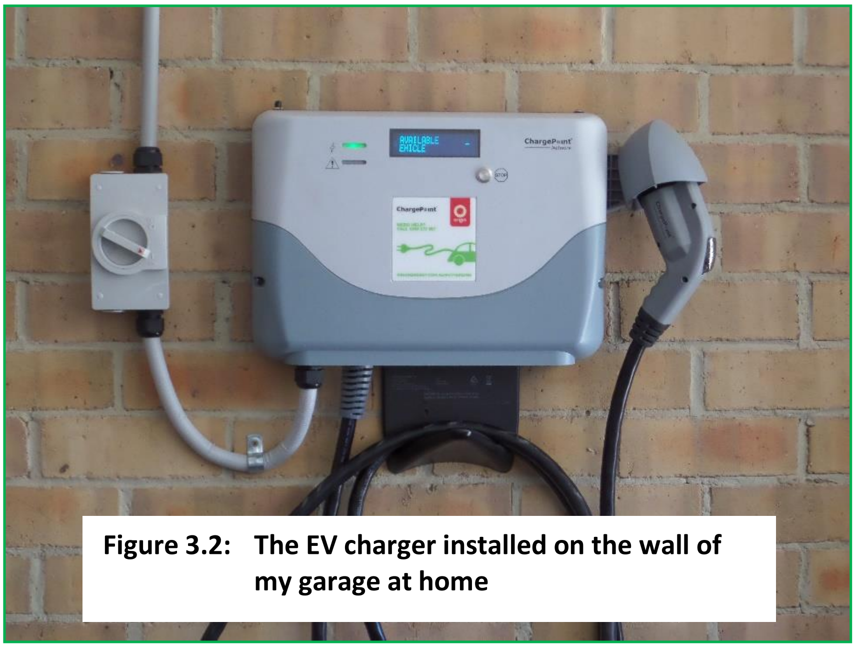

**Figure 3.2: The EV charger installed on the wall of my garage at home**

When it came to choosing a Level 2 charger I took the straightforward option. I bought the unit recommended by Nissan. This unit is sold by Origin Energy (see *Figure 3.2)* – you can see an example of one of these at the Lennock Nissan Philip showroom in Woden. It seems that many Leaf owners are resisting buying this unit because of price. It costs $2,750 fully installed – well over 5% of the price of the car! If you scour around the internet it is possible to find a wide range of alternative chargers and picking one of these could, on the face of it, save you more than $1,000 but of course there are inherent risks in choosing to be independent.

If you research the charger issue on the web you get the sense that in the US people are looking to pay around $500 for a charger. It is not too hard to find Level 2 chargers on the web in the $750 – $1,500 range. These have to be installed by an electrician so it is important if buying from overseas to make sure that the unit meets Australian electrical standards. For me the main concern with buying a non-standard unit would be what happens if the charger fails. There is probably not a lot of expertise in Australia at the moment to fix these units and dismantling and sending a unit somewhere to be repaired could be a real hassle. Having said I believe that these devices are comparatively simple so the chances of failure are probably low.

I should say that I find the Origin unit technically very solid. I am confident that it is not going to break down; electrocute me or the family; burn the house down; damage my car if there is a massive electrical storm, etc. It is extremely easy to use. If something does go wrong I am confident that it will be fixed very rapidly – this is important since if the charger fails I will effectively have no independent car transport (given the lack of public fast chargers in Canberra). If things came to a push I think I could do a workaround and charge the car from a standard 10 amp socket in my house using the Level 1 charger that came with the car.

Putting aside the cost, my main misgiving with the Origin unit is that it does not provide an indication of the energy used during a charging session (the display simply shows instantaneous power). I felt disempowered when I first got the EV. As an ICE owner I knew to the last cent what the fuel for my car was costing; with the EV I could only gain a broad indication of what it was costing (by reading my electricity meter and making assumptions about the energy use of other devices in the house). I overcame this problem by purchasing data logging equipment which I used to gather key parts of the information used in this book (see Appendix A.2). If I were looking for a new charger I would look for one that is capable of providing a datalog on energy use and, ideally, one that gives visual feedback on the total cost of electricity used (it would need to be capable of letting the user input local electricity tariffs by time of use).

**Figure 3.3: EV charger on the University of Canberra campus**

*Public Charging*

Public charging has yet to take off in the ACT. As I indicated earlier Canberra residents who charge their EVs at home are not likely to need to charge their cars at public places in Canberra. Nevertheless, public charging will presumably be essential if residents from surrounding areas are going to use EVs to come into Canberra to use the city as a regional centre (shopping trips; medical appointments; sporting/cultural events, etc).

As far as I can ascertain there are only two operational public charging stations in the ACT at the present time – one on the University of Canberra campus in Belconnen (*Figure 3.3)* and one at the Abode Hotel in Woden (*Figure 3.4*). I was unable to find a charging station sign at either site and both seem to be tucked away in rather 'interesting' places. The situation in Australia is in marked contrast to that overseas where major EV charging infrastructure is being installed.[30] Another interesting move overseas is the setting up of 'electric highways'.[31]

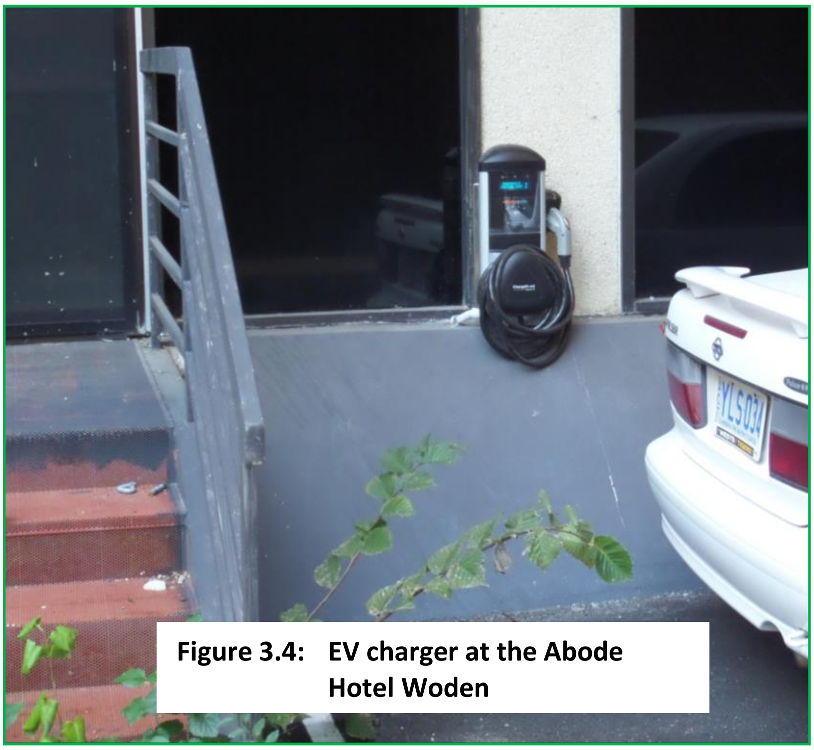

**Figure 3.4: EV charger at the Abode Hotel Woden**

The establishment of 'electric highways' in Southern NSW would probably be of more interest and potential use to Canberra residents than installing chargers in Canberra itself – this is discussed in Chapter 7. A proposal for this concept has been put forward for Western Australia.[32]

The issue of where and when to build EV charging infrastructure, and the design and rules of its use, is a complex topic. I have included some preliminary discussion on this in Section 7.6.

## 3.4 Other Charging Issues

*Homes without Garages*

In Canberra most dwellings provide some form of off-street parking for the residents. This contrasts with many of the inner suburbs of our major cities where only on-street parking is available. However, apartment living is becoming more popular in Canberra and residents often only have access to an allocated parking space rather than a private garage. This can make charging at home difficult or indeed impossible. There are issues around, for example, the security of charging equipment in open parking spaces; getting approval from Body Corporates to install chargers; metering and paying for electricity in communal parking areas. These are not trivial issues and these types of constraints may effectively prohibit many people in Canberra from owning an EV. In these circumstances the installation of public charging stations at sites close to apartments may be the only avenue to EV ownership for some Canberra residents.

[30] *Charging Station.* Wikipedia: http://en.wikipedia.org/wiki/Charging_station
[31] *Supercharger.* Tesla Motors website: http://www.teslamotors.com/supercharger
[32] *The REV project*. University of Western Australia: http://www.therevproject.com/

*Time of Charging*

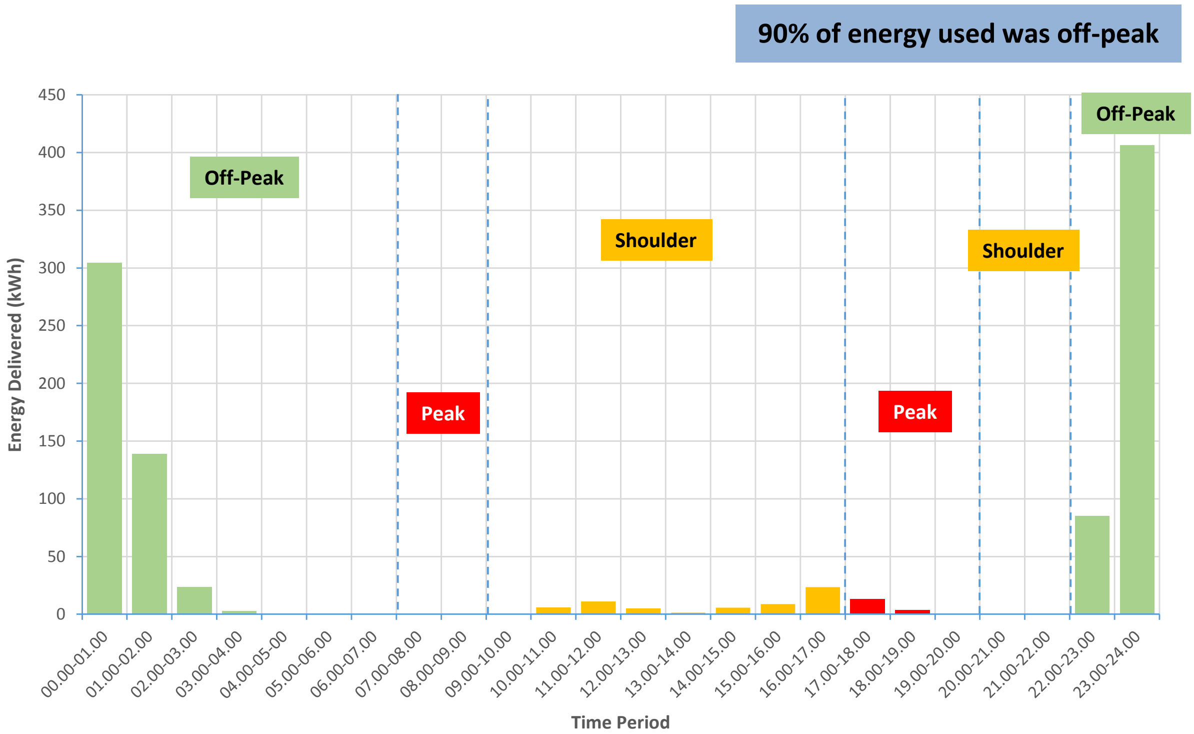


**Figure 3.5: Total energy delivered to the EV by hourly time slots. The coloured labels show the electricity provider's 'time of use' periods**

Our house uses a time-of-use tariff and as I have said earlier I generally charge the car at night using the off peak rate but do occasionally top the battery during the day which of course involves more expensive electricity. *Figure 3.5* shows the time distribution of energy put into the battery by one hour time bands for the part of the period when my data logger was in place (see Appendix A.3). It can be seen that over the logged period the greatest amount of energy input was in the hour 23.00 to midnight – this is because I set the automatic charging to commence at 11pm. About 90% of the energy I put into my EV during the project period was off-peak electricity. The cost outcomes of this pattern of charging are discussed in Chapter 5.

*Figure 3.6* shows the frequency distribution of the amount of energy put into the car per day during the datalogged period. It can be seen that the most common daily charge input was between 10 and 11kWh. The charger delivers about 20-25km of range per hour – given that my average daily travel is around 40km, this suggests that my car needs to charged, on average, for about two hours each day. The data on minutes of charging per day shown in *Figure A.1* indicates that on average the daily charge time is 122.5 minutes.

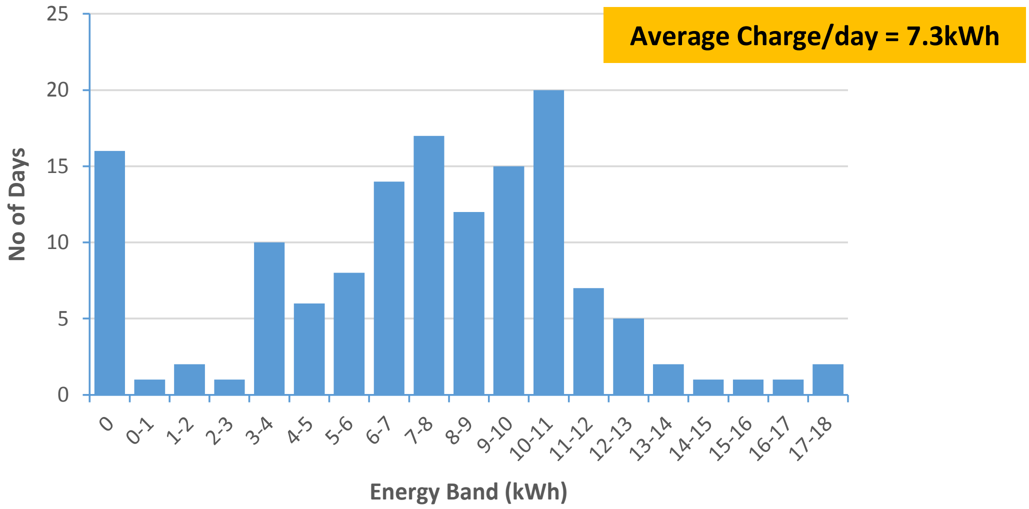


**Figure 3.6: Frequency distribution of energy delivered to the EV battery per day**

*Charging Inefficiency*

The charging of any battery has inefficiencies – when a battery is discharged it delivers less energy than was put in during the charging process (energy is primarily lost as heat). For Li-ion batteries the charging efficiency is typically around 80-90%.[33] I have attempted to compute this efficiency for my car/charger set up by comparing the energy used by my charger with the energy use reported by the car's data system. This involves some derived data and I have only been able to compute an approximate efficiency figure: my calculations indicate the charging efficiency to be about 80**%.** This derivation is shown in Appendix A.3. That is, by my calculations my car uses around 20% more energy than is indicated by the energy efficiency reading shown in the car. This charging inefficiency figure is consistent with the 80-90% efficiency range cited above. This means that in practice, while the EV driving efficiency for the project period was about 15kWh/100km, the overall efficiency of the car was about 17kWh/100km when the charging inefficiency is taken into account. As the user who pays for the fuel I consider this latter figure to be the best indicator of the efficiency of my EV (which of course is still very significantly better than my previous ICE vehicle).

*Battery Degradation*

EV detractors often like to suggest that the life of the battery in an EV is short and the cost of replacing the battery is high so the cost advantages of running an EV are much less than first appears. EVs are relatively new but they have been around for a few years now and, as far as I can tell, much of the commentary on EV battery short life and expensive replacement does not hold true. The batteries will slowly degrade over time, but I have not been able to find any reports on the internet of dramatic battery failure in a Nissan Leaf even from people who have had the car for a few years and who have chalked up big kilometres. I guess the life of a modern family car is around 10yrs (say 100,000km -150,000km) and I'm not envisaging any problems getting that sort of life out of my EV. This assessment is essentially consistent with the Nissan Leaf warranty which states the *'…Lithium-ion battery is warranted against any capacity loss below nine bars of capacity as indicated on the vehicle's battery level gauge for a period of 60 months or 100,000 kilometres…'.* [At full capacity the Nissan Leaf battery has twelve bars so on the face of it the warranty is guaranteeing the battery capacity will remain at 75% or better.]

33 *Car Battery Efficiencies.* J Sun. October 2010:http://large.stanford.edu/courses/2010/ph240/sun1/

*Remote Charging*

In common with many new cars, EVs let the user remotely access and control some facilities in the car using an app on your smartphone. These apps let you do things such as check the charge status of your car; start or stop the charging of your car's battery if it is hooked up to a charger; send you a message if your current charging session fails; and lets you turn on the climate control before you get in your car. *Figure 3.7* shows a sample screen shot from the official Nissan Leaf Android app (there are quite a few independent apps which essentially do the same thing). I occassionally use my phone to check the car battery's state of charge; I've never used it to do any of the other fancy tricks.


**Figure 3.7: Screenshot of Nissan Leaf Android App**

# Chapter 4

# My Solar System

## 4.1 Introduction

You don't need a solar system to run an EV but for me this is a key part of my project. As noted earlier, you'll commonly find that EV owners deliberately aim to have carbon neutral transport and will often buy green energy to achieve this goal if the solar route is not open to them. However, as I also noted before, the ACT Government is planning to source 90% of the Territory's electricity from renewables by 2020 so Canberra EV owners will no longer need to take any independent action in this area.

When I decided to go EV I did this on the basis that my transport would be carbon neutral and that I would aim to do this by generating more solar energy from panels on the roof of our house than we use in total both in the car and the house. In fact for us this is not a really big ask as we use gas for heating, hot water and cooking. You can see from *Figure 4.1* that we have achieved this over the life of the project - our electricity generation and consumption are more or less in balance.

| MONTH | Solar Energy Production (kWh) | EV Energy Consumption (kWh) | Total Energy Consumption (House + EV) ( kWh) |
|---|---|---|---|
| January | 646 | 152 | 206 |
| February | 500 | 229 | 288 |
| March | 446 | 244 | 338 |
| April | 346 | 172 | 295 |
| May | 317 | 267 | 455 |
| June | 208 | 258 | 475 |
| July | 276 | 196 | 385 |
| **TOTAL** | **2,739** | **1,518** | **2,442** |
| **kWh/day** | **13.0** | **7.2** | **11.6** |

**Figure 4.1: Comparison between energy generated and energy consumed over life of the project**

The data for the solar energy in the first column in the Table contains simulated figures for January and most of February to take account of the fact that we installed an additional 2kW solar PV system at our house in late February. The simulated figures show the electricity generation for the whole period assuming the new solar PV system had been in place on 1 January 2014 (this is explained in Appendix A.4). The monthly EV energy consumption shown in the second data column is similarly a simulated dataset since my charger data logging only commenced in mid March (this is explained in Appendix A.3). This column shows the simulated actual amount of electricity put into the car – not the energy used by the car as derived from the instrument panel (discussed in the previous chapter).

The seven months from January to July was selected as the project period so that I could gather a dataset that contained data from two months of summer, all of autumn and then two months of winter. July is generally the coldest month in Canberra and is the month when we usually use the most electricity in the house (this year we took a holiday in July and this of course reduced both our EV and household energy use for the month).

I am very happy with my solar system since it has enabled me to meet my project carbon goal. However, as things have turned out, my solar system effectively runs independently of my EV use, due to mismatches between my solar output and my EV charging requirements. In the long run (or possibly even the short run) I would like to use a home battery storage system which lets us export less of the electricity we generate.

## 4.2 System Description

When we moved into our house in 2012 it already had a 2kW solar PV system which operated under the old gross Feed in Tariff (FIT) regime. I added an additional 2kW system in early 2014 as part of the EV project. A schematic description of our household energy flows, including the two solar systems, is shown in *Figure 4.2*.

In the Figure 'Solar 1' represents the original FIT system – this feeds straight into the grid and ActewAGL pays us for all the electricity generated.

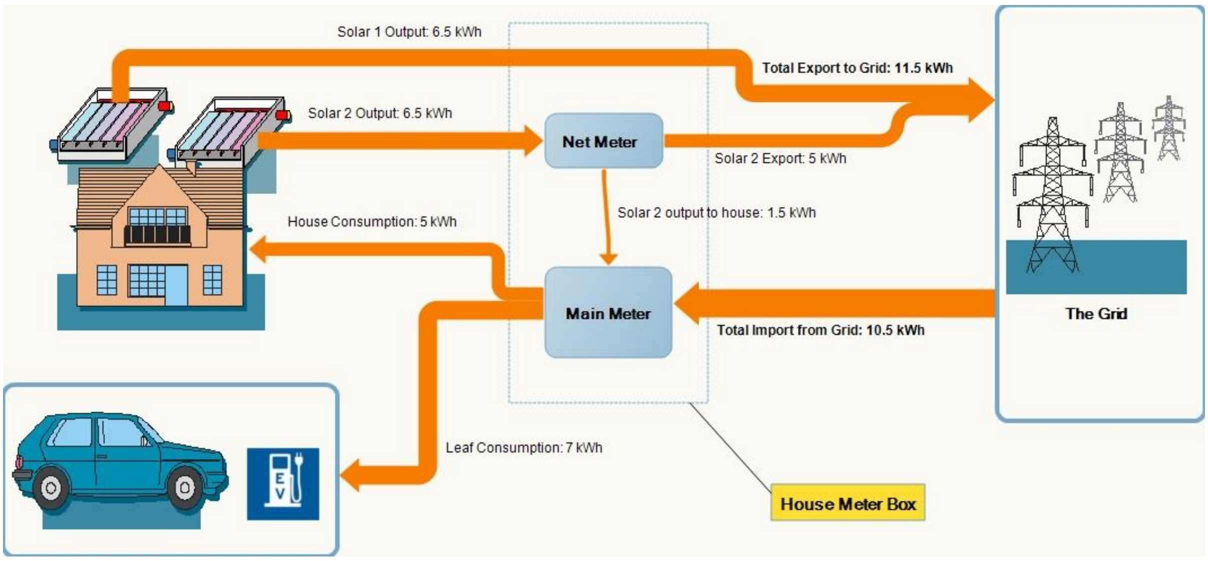


**Figure 4.2: Schematic diagram of average daily electrical energy flows in our house for the project period**

'Solar 2' in the Figure represents the new 'net metered' solar system. Since September 2013 all new solar PV systems installed in the ACT are required to operate under a net use tariff. Under this tariff regime, at any given point in time any electricity generated by the panels is first used to meet demand from electricity appliances in the house; if the demand from the house is less than the amount of electricity generated the excess is exported to the grid. The key point here is the instantaneous nature of the netting action – the time of maximum generation of electricity (around noon) rarely matches peak demand in our house and hence about 80% of the electricity we have so far generated with the net metered system has been exported to the grid (detailed data is shown in *Figure A.1*).

The two systems sit side by side on a roof face of our house which is oriented more or less to the NW and has no shading during the day. The systems are standard installations and broadly generate the expected amount of kWh/year for a PV system of this size in the Canberra region.[34] The weekly electricity generation and consumption patterns for our house and the EV during the project period are shown in *Figure 4.3.*

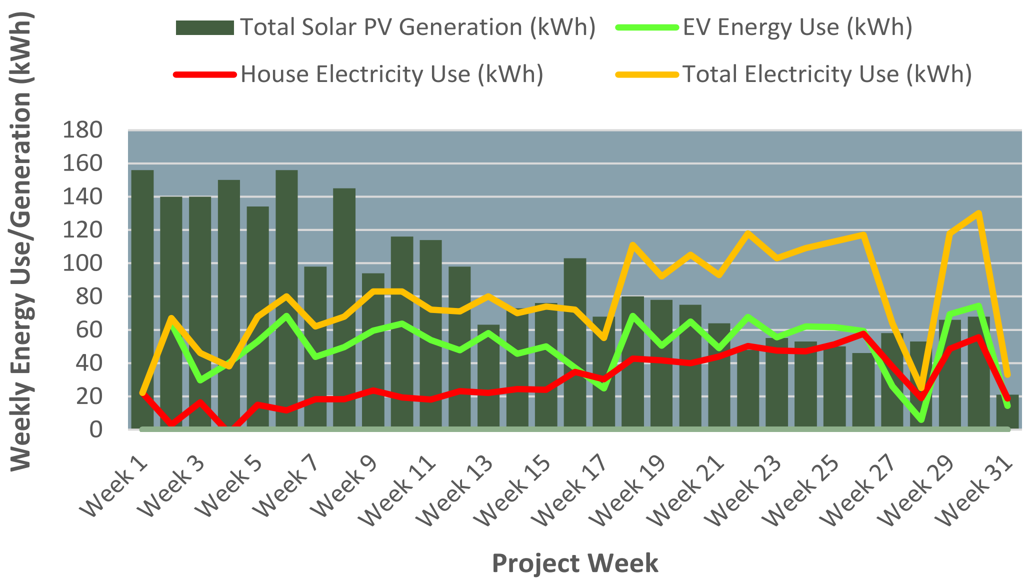


**Figure 4.3: Weekly solar PV electricity generation compared with EV and household electricity consumption**

During the first four months of the project total generation exceeded total consumption (see also *Figure 4.1*) – this reversed over the last three months as solar generation weakened and our household electricity showed the expected winter increase in use. Until mid April (Week 16) the EV used significantly more electricity than the rest of the house. As the colder weather arrived our household electricity consumption increased to more or less match the EV use until the end of the project period (Week 17 includes Anzac Day – the day when Canberrans usually say the home heating season begins).

## 4.3 Solar PV Contribution to Car Energy Use

While we generate more energy from our solar system than we use in our house and EV combined, as indicated in Section 4.1 we run the solar system quite independently of the EV. One of the key aims of net metering PV systems is that, as far as possible, a householder uses the electricity that they generate rather than exporting it (electricity retailers pay very little for any electricity exported from new solar PV systems). It would be nice if we could use all the electricity we generate to directly charge the EV but this doesn't work in the current circumstances. As you can see from Figure 4.2, the electrons that get excited in my solar panels do not end up directly delivering energy to my EV; rather the solar energy is mainly exported to the grid and I charge my car from the grid using the off-peak rate which, in the ACT, operates between 10pm and 7am.

[34] *A Performance Calculator for Grid-Connected PV Systems:* http://rredc.nrel.gov/solar/calculators/PVWATTS/version1/

I do this because of mismatches between the:

1) power output of my solar system and the power demand of my car charger; and

2) time when I want to use my car and the time when my solar system produces electricity.

**Discussing these in turn:**

1) When charging the battery my charger draws about 3.7kW. The maximum power output that I have measured from my net metered system is about 1.8kW. This means that if I tried to use the output of my net metered system to charge my car, the charger would have to draw at least about 2 kW from the grid in order to deliver 3.7 kW. On cloudy days the charger would have to draw more power from the grid. This is illustrated in *Figure 4.4.*

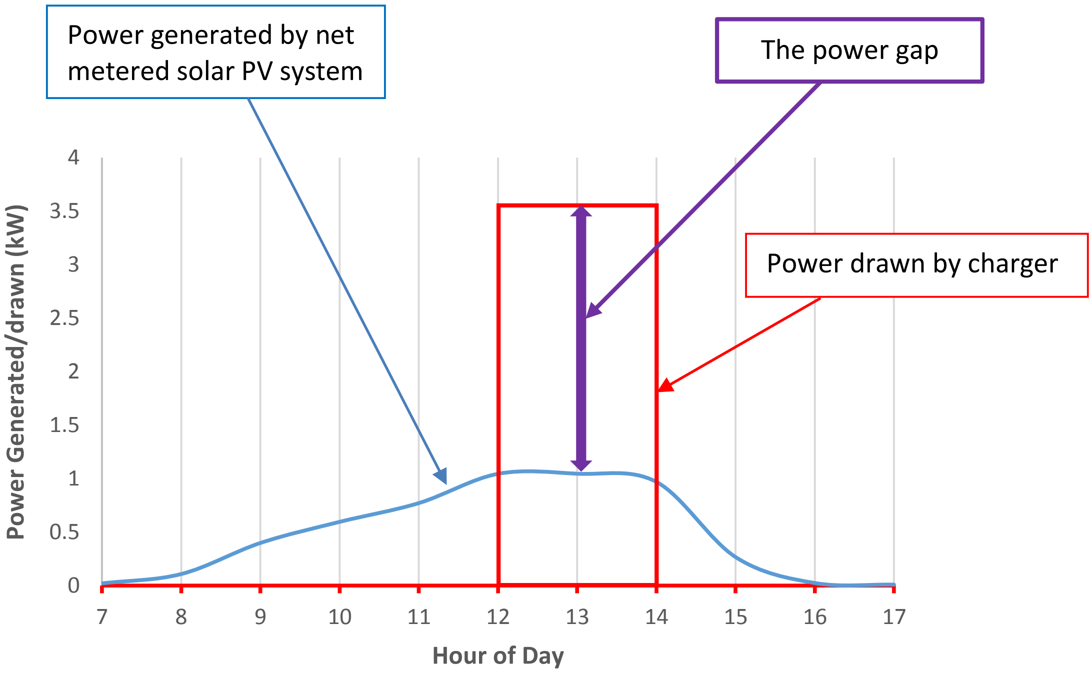


**Figure 4.4: Illustrative data - power drawn by the EV charger overlaid on the power generated by the net metered solar PV system**

The Figure shows the solar PV generation time profile for a typical day in the project period overlain with a charging profile for a two hour charge between noon and 2pm – the 'power gap' is labelled. This diagram is purely illustrative and does not represent an actual day – the example profiles are based on information derived from my data logger (see Appendix A.4). I estimate that if, for example, on a sunny day around noon I were putting 7 kWh into the EV battery (this takes about 2 hours), around 3 to 5 kWh would have to come from the grid (this would vary from summer to winter).

By default, charging directly from the solar PV system during the day would take place at a time when the shoulder period tariff applies (see Figure 3.5). On sunny days the cost to me of charging during the day (which involves direct input from solar 2 plus the abovementioned supplementary energy from the grid) would be broadly similar to the cost of charging at night using the off-peak rate. On cloudy days almost all my electricity would be drawn from the grid at the shoulder tariff rate (which costs about 20% more than off-peak).

I could address this power mismatch to some extent by 'trickle charging' my car using the Level 1 charger that came with my Leaf, or by adding panels to the net metered part of my solar system, but neither of these approaches would overcome the timing mismatches discussed in 2) below.

2) The peak output from my solar system is in the 12pm to 1pm hour. Given the NW orientation of my solar systems it would be expected that they will deliver more energy in the early afternoon than in the late morning. *Figure 4.5* shows the time based energy output of my net PV system for a two month sampling period during the project. About 60% of the energy generated by my net PV system was between noon and 4pm – this is reflected in the asymmetric shape of the curve in the Figure.

Unfortunately at the time when my net PV system is most productive, my personal commitments mean that the car is rarely at home. I am usually using the car between noon and 4pm every weekday and most weekends. Therefore this means that even if the power mismatch issue discussed in 1) could be overcome, in the absence of a storage battery, I would not be able to charge my car from my net metered system to any great extent since I am almost always using my car during the period when my solar PV is generating a major part of its electricity.

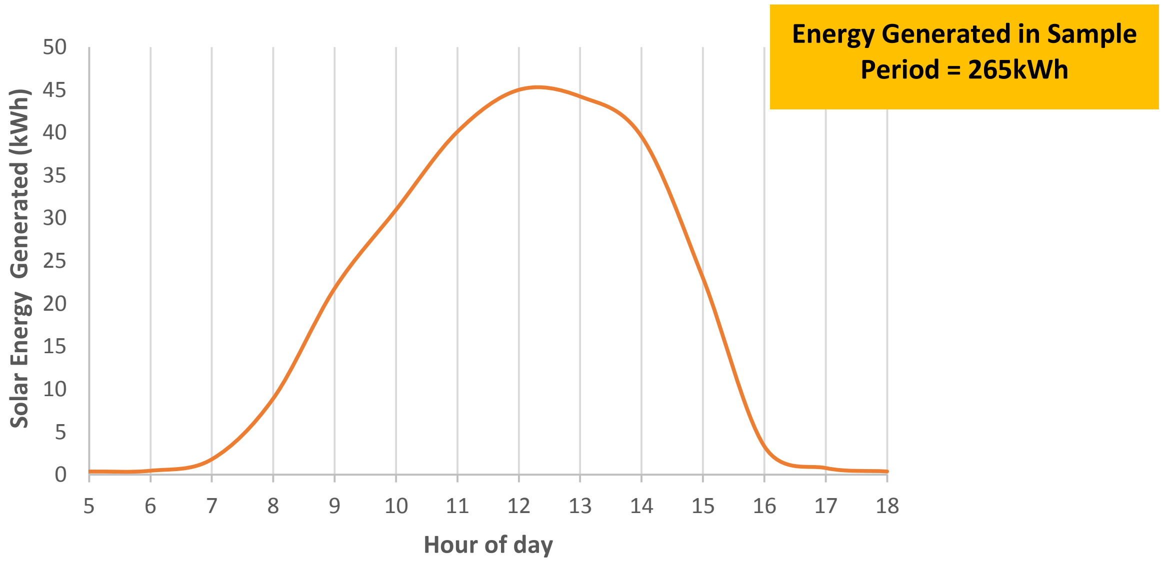


**Figure 4.5: Time of day profile of the total energy output of the net solar PV system for the sample period**

Given these constraints, the best charging option for me during the project period was to set up the automatic charging interface in the car so that it charged at night from the grid using the off-peak tariff.

## 4.4 Discussion

It can be seen from *Figure 4 .1* that over the project period our combined 4kW solar PV system generated about twice as much energy as I put into the EV. Therefore, given that during this period I travelled about 40km/day (the equivalent of 15,000km/year), in broad terms I expect that my EV will travel about 15,000km/year on the output of our 2kW net metered solar PV system.

While I have effectively achieved my carbon neutrality goal, I have not achieved any direct integration between my EV and my solar system. The extent to which the solar system can be integrated with an EV (ie the extent to which a solar system can practically be used to directly charge an EV) is determined by how well the EV charging and solar generating power match and how closely the timing of the PV output and the availability of the car can be aligned. My car and PV systems only indirectly complement each other – I achieve my carbon neutrality by time shifting my energy generation and consumption via the grid. To rectify this situation I will need to incorporate battery storage into my solar PV system.

*Battery Storage*

I have no problems with using the electricity grid and recognise that it needs to be paid for equitably. However, the current tariff structures are now driving the owners of net metered solar PV systems to seriously consider the installation of home battery storage and energy management systems.

Domestic battery storage systems are now appearing on the Australian market but as yet are relatively expensive. In some regional areas of Australia electricity providers are mandating battery storage for small (and larger) solar systems under some circumstances for 'energy smoothing' purposes.[35] In the United States pundits seem to be surprised at the rate of reduction in battery prices.[36] It is not difficult to envisage that in a year or so it will be financially beneficial to add a battery storage system to domestic net metered solar PV systems in Canberra.

Without going into any great detail, during the project period my 'solar 2' system generated 840 kWh of electricity and we exported about 80% of this (ie we were not able to use this electricity at the time it was generated). We received 7.5c/kWh from our electricity retailer (ActewAGL) for exported electricity and then bought back electricity for 24.86c/kWh at peak times and for 14.08c/kWh at off-peak times. Clearly the bigger the gap between the sell and buy prices the more attractive battery storage becomes. In simple terms the aim of the battery storage will be to store electricity generated by the solar PV system during the day so that it can be used at peak times (when the sun is not shining). In addition, at times when the solar system is not generating sufficient energy (a cloudy day) some systems enable the battery to be replenished at off-peak times (and tariffs) to make electricity available for use during peak periods.

For some people acquiring battery storage is likely to be a prelude to going 'off-grid'. However, for most people (including my household) it will simply be a way to minimise the amount of external electricity they buy. Either way battery storage does threaten the status quo for long established electricity generators who are now seeing a progressive fall in demand for their product – electricity consumption in Australia's National Electricity Market has fallen every year over the past five years (about 6% in total).[37]

There are important synergies between EVs and solar PV with battery storage. Reductions in the price of batteries will generate a positive feedback loop between the two technologies since the batteries used in both applications are identical. Cheaper batteries will reduce the price, and increase the uptake, for both EVs and domestic solar PV with battery storage. Tesla Motors has announced it will build a 'gigafactory' to produce Li-ion batteries and expects that this will drive down the costs of batteries by more 30% at the end of the first year of production.[38] The batteries are intended for use in both EVs and home solar systems.[39]

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[35] Horizon Power. WA: http://www.horizonpower.com.au/renewable_energy_technical_requirements.html

[36] *Are EV battery prices much lower than we think?* Clean Technica. January 2014: http://cleantechnica.com/2014/01/07/ev-battery-prices-much-lower-think/

[37] *National Electricity Market electricity consumption.* Australian Energy Regulator: http://www.aer.gov.au/node/9765

[38] *Gigafactory.* Tesla Motors. February 2014: http://www.teslamotors.com/blog/gigafactory

[39] *Home energy battery backup.* SolarCity: https://www.solarcity.com/residential/energy-storage

# Chapter 5

# The Costs

## 5.1 Introduction

Computing and reporting costs is not a straightforward issue – there are many ways to evaluate the benefit of projects. In this chapter I describe the costs/benefits of my project from my perspective – I will leave it to the reader to form a view of how legitimate the costing methodologies I've adopted are.

To reinforce what I have said earlier, my 'EV project' involved the purchase of the EV, the battery charging system and the new net metered solar PV system. I have therefore included all three of these elements in my costings. However, you do not have to buy a charger or a solar system to successfully buy and operate an EV – the inclusion of the latter two elements reflects my personal choice.

In broad terms, EVs cost more to buy than conventional cars but cost significantly less to run. I estimate that the costs of owning and running an EV will generally be level with the costs of owning and running an ICE somewhere between 5-10 years after purchase (see Section 5.4).

*Over the project period costs have changed – electricity prices in the ACT increased by about 4% on 1 July 2014. The Federal Government has announced its intention to index excise on petrol.*

## 5.2 Upfront Costs

**The Car**

*My costs – Nissan Leaf* **$40,000.**

At the present time I estimate that an EV costs somewhere between $10,000 and $15,000 more than an equivalent ICE. This is a rather subjective assessment of what is a dynamic situation. The Nissan Leaf was costing more than $50,000 until mid-2013. I entered the market when the price was dramatically reduced to about $40,000. When looking for an EV I was offered a brand new Mitsubishi iMiev for $29,000 when the advertised price was around $52,000.

Unfortunately there is little competition in the EV market in Australia at the moment. The established Nissan Leaf[40] and Mitsubishi iMiev[41] are still for sale in Canberra. Two new 'high end' EVs – the BMW i3[42] and the Tesla Model S ($100,000)[43] - have arrived on the scene in recent months. Some PHEVs can be bought in Canberra – the Holden Volt[44] has been on sale in Canberra for some time; this has recently been joined by the Mitsubishi Outlander ($50,000)[45]; and there is also a PHEV

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[40] *Nissan Leaf. 100% Electric. Zero Petrol.* Nissan: http://www.nissan.com.au/Cars-Vehicles/LEAF/Overview
[41] *i-Miev. Plug into the Future.* Mitsubishi Motors: http://www.mitsubishi-motors.com.au/vehicles/i-miev
[42] *BMWi3. Electric and Electrifying.* BMW: http://www.bmw.com.au/com/en/newvehicles/i/i3/2013/showroom/introduction.html
[43] *Model S. Zero Emissions. Zero Compromises.* Tesla Motors: http://www.teslamotors.com/en_AU/
[44] *Long Range Electric Holden Volt.* Holden: http://www.holden.com.au/cars/volt#/overview
[45] *Outlander PHEV. The world's first plug-in hybrid SUV*. Mitsubishi Motors: http://www.mitsubishi-motors.com.au/vehicles/outlander-phev

version of the BMW i3. [The prices in this paragraph are purely indicative and have been taken from the manufacturers' websites for what appear to be base models.]

There are Australian companies specialising in conversions of ICE vehicles to EV. In addition to the cars cited in the previous paragraph, many major global car manufacturers are now either making, or are on the point of making, EVs and/or PHEVs but are not yet marketing these in Australia. The latest figures that I can find indicate that there are 18 EV and PHEV models for sale in the United States at the present time.[46] As more competition enters the market and production volumes increase one would expect to see EV prices fall. Developments in battery production are indicating a 30% reduction in the price of batteries by 2017.[47]

**The Charger**

*My costs – Origin Energy Charger* **$ 2,750**

In Section 3.3 I briefly discussed costs for Level 2 EV charging systems – in broad terms an installed hard wired charger is likely to cost somewhere between $1,000 and $3,000. You can certainly pay more than $3,000 if you want a charger that is networked or that has security card access, etc but not surprisingly most interest is in looking for chargers at the bottom end of the price range.
I haven't researched this topic to any great extent but the search for inexpensive chargers generates a fair bit of discussion on the EV websites.

If you don't intend to purchase the recommended charger for your car it means spending some time on the web looking at discussion forums and the sites of independent EV equipment providers. It goes without saying that if you go down this route it is important that the equipment you buy meets the relevant Australian electrical standards. As mentioned earlier, while probably somewhat restrictive, the cheapest option is to simply use the charger that is included when you buy a new EV.

**The Solar System**

*My costs – 2kW system* **$3,500**

As far as I can tell the cost of my solar PV system was about the average, or a little below the average, for a 2 kW domestic rooftop solar PV system installed in Canberra at the present time (this works out at approx. $1.75 per Watt).

The price of PV systems has been dropping dramatically throughout the world for many years. This trend is shown in *Figure 5.1.*[48] There is now price uncertainty in the Australian market because of the yet to be resolved debate surrounding the future of the Federal Government's RET (Renewable Energy Target). While this debate is holding up large renewable energy projects, the domestic solar PV sector is still active.[49]

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[46] *Electric vehicle sales growing fast, cross half million mark.* RenewEconomy. July 2014: http://reneweconomy.com.au/2014/electric-vehicle-sales-growing-fast-cross-half-million-mark-13784
[47] *Gigafactory.* Tesla Motors. February 2014: http://www.teslamotors.com/blog/gigafactory

[48] *Solar PV module prices have fallen by 80% since 2008, Wind turbines 29%.* Clean Technica. May 2014: http://cleantechnica.com/2013/05/06/solar-pv-module-prices-have-fallen-80-since-2008-wind-turbines-29/
[49] *People power: Rooftop solar PV reaches 3 GW in Australia. Reneweconomy. Dec 2013:* http://reneweconomy.com.au/2013/people-power-rooftop-solar-pv-reaches-3gw-in-australia-99543

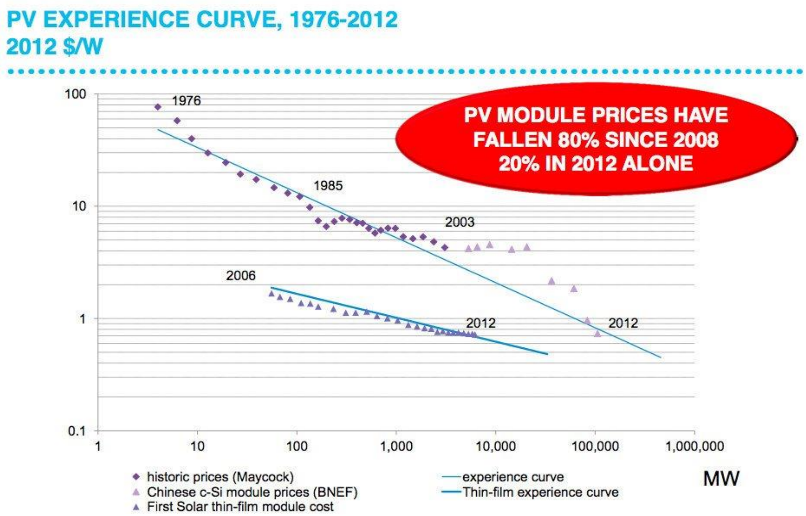


**Figure 5.1: Price trajectory of solar PV modules 1976-2012**

## 5.3 Ongoing Costs

**The Fuel - Electricity**

*My Costs* - **$1.16/day**

*Figure 3.*5 shows that during the project period I primarily charged the vehicle using the ActewAGL off-peak rate of 14.08c/kWh which is a component of the Home time-of-use plan. The tariff schedule for the first six months of the project period is shown in *Figure 5.2.*[50] *Figure 3.5* also shows I did on occasions also give the car a top up charge which was mainly at the shoulder tariff of 19.25c/kWh.

On 1 July ActewAGL increased its electricity rates by around 4%. The daily EV charging costs shown in *Figure 5.3* incorporate the new tariffs.

| Home time-of-use plan | GST excl. | GST incl. |
|---|---|---|
| Supply fee ($ per day) | 66.80¢ | 73.480¢ |
| or, with Direct Debit discount* | 61.80¢ | 67.980¢ |
| Usage rate (¢ per kWh) | | |
| • Peak (7–9am, 5–8pm) | 22.60¢ | 24.860¢ |
| • Shoulder (9am–5pm, 8–10pm) | 17.50¢ | 19.250¢ |
| • Off-peak (All other times) | 12.80¢ | 14.080¢ |

*Discount does not apply to payment by credit card

All times referred to are in Australian Eastern Standard Time and they are not adjusted for daylight savings time.

**View the Energy Price Fact Sheet**
Home time-of-use plan [ACT4094SR] (PDF, 44KB)
Home time-of-use plan with off-peak [ACT4095SR] (PDF, 44KB)

**Figure 5.2: ActewAGL 'Home time-of-use plan' tariff on 1 January 2014**

ActewAGL also has a tariff called 'off-peak night plan' which it states is *'…applicable to [amongst other things] charging electric vehicles…'*. This tariff was 10.23c/kWh. Naturally I explored this option but I decided not to use it as it has strict limitations on the times of use - while I put about 90% of the energy into my EV at night (see *Figure 3.5*), I would not want to limit use of my home charger to specific times. I find it difficult to imagine this 'electric car' tariff being attractive to any private individual but it could be useful for a business that routinely charges a fleet of vehicles at night and has alternative charging points for use during the day.

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50 *Residential Electricity Prices.* ActewAGL: http://www.actewagl.com.au/Product-and-services/Offers-and-prices/Prices/Residential/ACT/Electricity-prices.aspx [This link takes you to the current tariff (post I July)]

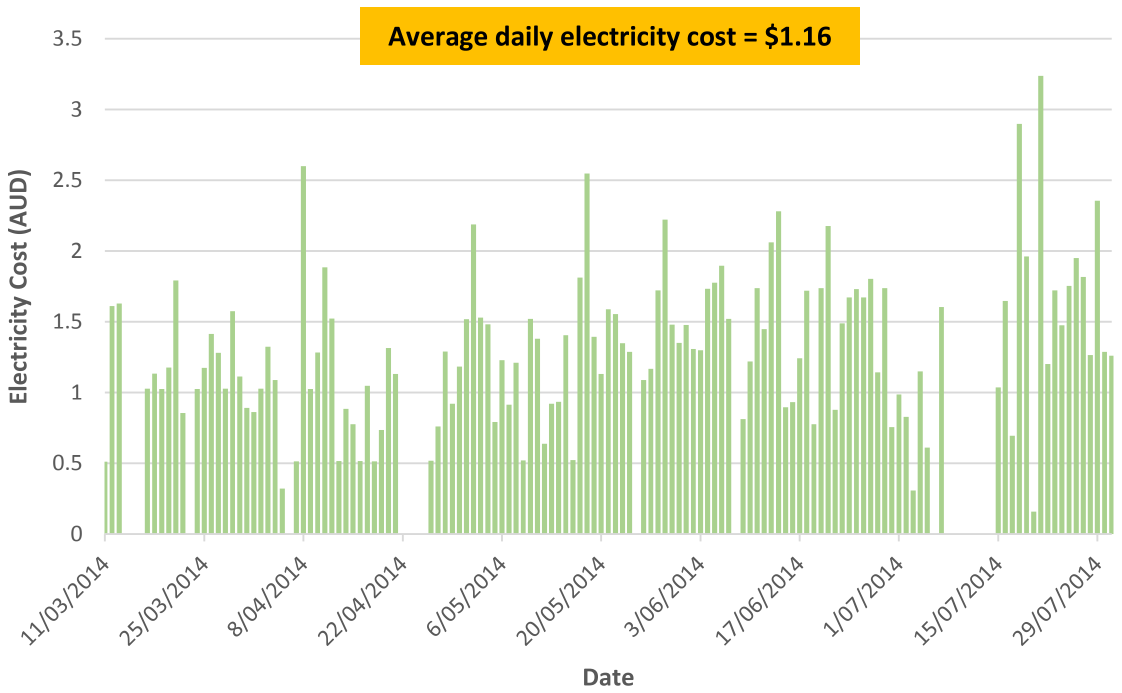


**Figure 5.3: Daily cost of electricity to fuel my EV**

*Figure 5.3* shows my daily expenditure on electricity for the EV during the project period (see Appendix A.3 for the details of the computations). For the most part, the cost was between 50c and $2.50/day while the average cost was about $1.15/day. By way of contrast, I estimate that I was spending about $5/day to fuel my previous ICE vehicle.

The rate of increase in the price of electricity would very reasonably be a concern for someone contemplating moving to an EV. After all, between June 2007 and June 2012, the retail price of electricity in Canberra rose 45%.[51] However, it appears that the outlook for electricity prices is now more stable - the Australian Energy Market Commission has stated that electricity prices are expected to decrease by 0.7 per cent a year over the three years from 2012/13 to 2015/16.[52] [It is interesting to place this advice in context – the prices of electricity have just risen by 4% in the ACT]. Putting this aside, many people are now installing solar PV systems as a way to cushion against increases in the price of electricity.

***Battery Degradation***

As an EV progresses through its life the battery degrades along with the rest of the car – detractors commonly cite this as a hidden cost of running an EV. I briefly discussed battery degradation in Section 3.4 and as far as I can tell battery degradation should be of no greater importance than degradation of other parts of the car (all cars degrade with age and distance travelled). This is certainly an issue of interest on the Leaf owners' sites but there don't seem to be any great problems emerging.[53] The Nissan Warranty suggests that the battery may lose up to 25% of its capacity after 100,000 km. If this is the case it would not have any great impact on my use of the car

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[51] *Household energy use and costs.* Australian Bureau of Statistics. September 2012: http://www.abs.gov.au/AUSSTATS/abs@.nsf/Lookup/4102.0Main+Features10Sep+2012

[52] *2013 Residential Electricity Price Trends.* Australian Energy Market Commission. December 2013: www.aemc.gov.au/media/docs/2013-Residential-Electricity-Price-Trends-Final-Report-723596d1-fe66-43da-aeb6-1ee16770391e-0.PDF

[53] *How to check battery capacity, degradation and range.* US Nissan Leaf users discussion forum: http://www.mynissanleaf.com/viewtopic.php?f=31&t=8342

as a city vehicle since I would still have plenty of range for my normal day to day journeys (see *Figure 2.6*). Nissan recently announced that the cost for a new battery for the Leaf in the US will be about $5,500 USD.[54]

***Maintenance***

Electric vehicles are mechanically very simple compared to ICE vehicles. The EV contains no liquid fuel or exhaust systems; has no clutch and one gear; the engine essentially has one moving part compared to the hundreds of moving parts in an ICE. It would appear reasonable to assume that this simplicity will result in lower maintenance costs. At the present time the total cost of the 'capped price service' for a Nissan Leaf (first six years of the car's life) is about 40% less than for the same 'capped price service' for the Nissan Pulsar, a similar sized car from the same manufacturer.[55]

***Depreciation***

This is an unknown since at the moment there are virtually no well-used EVs on the second hand market in Canberra (or indeed in Australia). Since EVs have only been on sale in Australia for about 2 or 3 years there is no experience of what they will be worth when they reach what may be a typical re-sale threshold of around 100,000 km.

If there are fears about the longevity of the battery, the value of EVs may depreciate more quickly than ICE vehicles. On the other hand, the possibility to purchase a second hand car with very low running costs could make EVs a very attractive proposition compared to the purchase of a similar aged ICE vehicle.

I was fully aware of possible accelerated depreciation when I purchased my Leaf and any residual value after say 10 years will be a bonus (the resale value of my last ICE car had more or less evaporated by the time I sold it with around 100,000 km on the clock). In the US, which has a much longer EV experience than Australia, media articles indicate that EVs do not do well in the resale market. However, it is important to note that in the US the actual purchase price of new EVs is commonly heavily discounted via government grants and incentives so any quoted % depreciation may be somewhat misleading.[56]

## 5.4 Overall Costs

The fundamental question is how do the total costs of owning and using an EV compare to those of owning and using an ICE? There is no straightforward answer to this question as there are many cost variables which need to be taken into account on an individual by individual basis.

In an effort to demonstrate some indicative costs I have generated two example charts which show a family of scenario payback times for a given variable. These charts are purely illustrative – there are many possible variables that could be explored. I have chosen one variable which gives a broad spread of payback times and another where the payback times are much more closely spaced. Both examples are based on charging the car with off-peak electricity.

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[54] *Update on Nissan Leaf Battery Replacement.* My Nissan Leaf. June 2014: http://www.mynissanleaf.com/viewtopic.php?f=4&t=17168#p374490

[55] *Capped price service.* Nissan Motors Australia website: http://www.nissan.com.au/Owners/Owner-Information/Capped-Price-Service

[56] *Depreciation hits electric cars hard.* USA Today. December 2013: http://www.usatoday.com/story/money/cars/2013/12/26/plug-in-cars-electric-cars-depreciation-resale-residual-value/4194373/

1) Variable distance travelled

*Assumptions:* EV efficiency: 17 kWh/100km. ICE efficiency 8 litres/100km (approx. average city cycle efficiency for Australia). Electricity cost 16c/kWh. Petrol cost $1.55/litre.

The lines in *Figure 5.4*, for three distance scenarios, have been constructed by computing the annual fuel cost for an EV and an ICE vehicle using the above assumptions and then plotting the accumulated savings in fuel costs of an EV compared to an ICE vehicle over time.

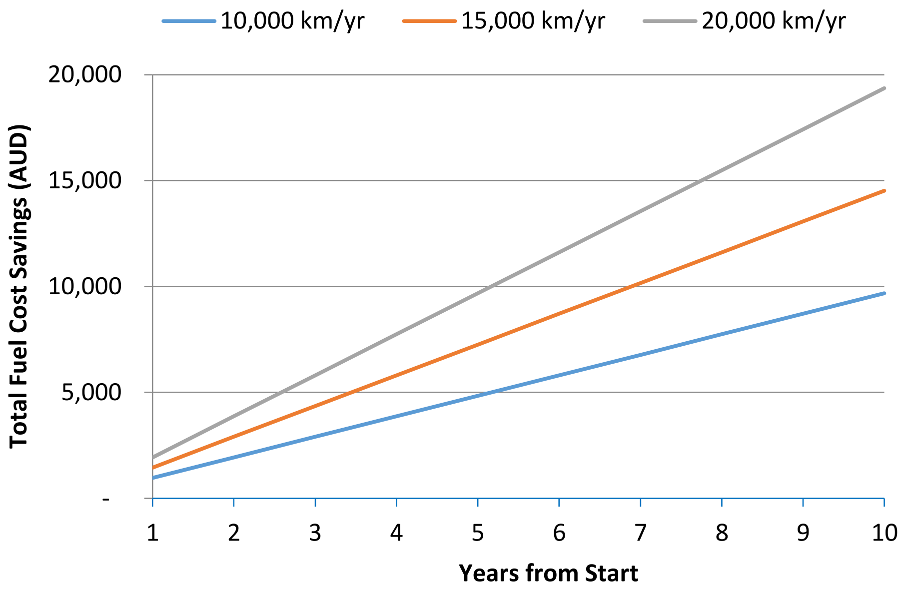


**Figure 5.4: Indicative cumulative fuel cost savings for three different distance travelled scenarios (EV v ICE)**

As noted earlier, an EV has cheap running costs and high capital costs while the reverse is true for an ICE vehicle. *Figure 5.4* shows three lines which give the payback time relationship between distance travelled and savings in fuel costs that are made when transitioning from ICE to EV. For any given additional capital cost the payback time will be shorter the further the EV travels (this assumes that an ICE would be used to travel this distance if an EV were not being used). For example, say a person spent $10,000 more for an EV + charger than he/she would have paid for an ICE vehicle, the payback time would be about 5 years if the vehicle were used for 20,000km/yr and about 10 years if the vehicle were used for 10,000km/yr.

I have shown in *Figure 2.6* that I use my car on average about 40 km each day which equates to around 15,000km per year. I guess very roughly that I spent around $15,000 more for my EV plus the charger than I would have done had I bought an equivalent new ICE vehicle (something I have never done in my life) so I think that my payback time will be of the order of 10 years.

This is a very crude assessment which doesn't, for example, take into account discount rates. It is also one dimensional in that it doesn't take into account the accelerated depreciation that will take place if an EV travels 20,000km rather than 10,000km per year or the depreciation of an EV compared to an ICE.

2) Variable driving efficiency

Assumptions: Distance travelled: 15,000km/yr. ICE efficiency 8 litres/100km (approx. average city cycle efficiency for Australia). Electricity cost 16c/kWh. Petrol cost $1.55/litre.

In a similar manner to *Figure 5.4*, the lines in *Figure 5.5* have been constructed by computing the annual fuel cost for an EV and an ICE vehicle using the above assumptions and then plotting the accumulated savings in fuel costs of an EV compared to an ICE vehicle over time for three driving efficiency scenarios. I have chosen efficiencies which essentially cover my range of driving efficiencies (see *Figure 2.4)* even though I barely registered any days at 12kWh/100km or 22kWh/100km.

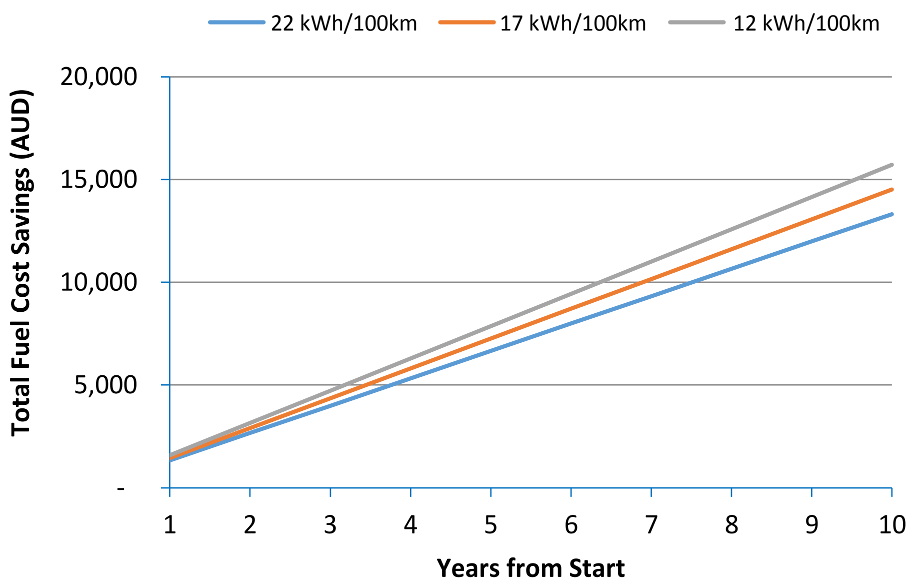


**Figure 5.5: Indicative cumulative fuel cost savings for three different driving efficiency scenarios (EV v ICE)**

I discussed driving efficiency in Section 2.4. When I've had a day where I've achieved 12kWh/100km for the day's driving I feel very proud of myself; when I only achieve about 18kWh/100km for a day I feel like I have transgressed some unwritten law (the difference is often due to factors like having to use the lights, heater, wiper, etc). In the Nissan Leaf the feelings of triumph or guilt are compounded by a rather annoying female voice from the car's computer system which ranks your efficiency performance each day. Against that background the obvious question is does driving efficiency significantly affect your payback time?

You can see from *Figure 5*.5 that differences in driver efficiency in fact make relatively little difference to payback time. This outcome primarily arises due to the fact that while the differences in energy use per year between the efficiency scenarios are relatively large, these do not translate into significant monetary differences due to the low price of electricity compared to petrol. For example, after 10 years the savings of an EV over an ICE are about $15,700 when driving at 12kWh/100km and about $14,500 when driving at 17kWh/100km.

This example also shows that the issue of charging inefficiency which was discussed in Section 3.4 is not significant when considering impacts on payback time.

*Discussion*

You can see from the Figures that under some scenarios the payback times can be very short; under other scenarios the payback time could well be greater than 15 years. In the ACT the average retirement age of a car is 16 years[57] and therefore if this figure also applies to EVs in the future, in many circumstances the life cycle cost of owning an EV will be less than that of owning a conventional petrol car.

Putting the cost scenarios aside, in my cost assessment I don't put a monetary value on the 'feel good' elements of going EV. While an accountant or an economist may blanch, subjectively I feel that I have already got my money back just seven months after my ICE/EV transition.

Based on my discussions/observations to date, I think it is unlikely that many people will go EV at the present time in order to save money. Undoubtedly many EV owners will spend less money than if they had bought another ICE car but this will largely be a bonus arising from a decision driven by other considerations: a desire to reduce one's personal carbon footprint; fascination with new motoring technology; concerns about air quality or fuel security; etc. I believe that until EVs are highly cost competitive the transition away from ICE vehicles will only be gradual. However, like the introduction of many new technologies, I believe the EV transition is likely to be a 'tipping point' phenomenon – when the critical mass is reached things will happen very rapidly. This raises questions which are addressed in the next Part of the book.

[57] *Low Emission Vehicle Strategy – Discussion Paper 2014*. Figure 2. ACT Government. June 14: http://www.timetotalk.act.gov.au/consultations/?engagement=low-emission-vehicle-strategy-discussion-paper-2014

# PART 2

# SUSTAINABLE CANBERRA

# Chapter 6

# Role of the EV in Reducing the ACT Carbon Footprint

## 6.1 Background

At the Federal level, climate change politics within Australia have been effectively gridlocked for at least the past five years – any sense of consensus has disappeared and the uncertainty which this has brought has delayed investment in many climate change projects (eg large renewable energy projects). Due to this lack of progress at the national level citizens are now looking to State, Territory and Local Government to implement climate change actions. This situation is not unique to Australia – the benefits of taking climate change action at the sub-national level has led to the setting up of global alliances amongst regions and cities such as R20 and C40.[58] Climate change appears to be one of those issues best addressed by using 'bottom up' approaches.

In recent years the South Australian (SA) and ACT Governments have been the leaders in Australia in implementing measures to introduce renewable energy (Tasmania has effectively operated on 100% renewable energy for many years with its hydro resources). In 2013 approximately 30% of SA's electricity was sourced from renewable energy – principally wind with a relatively small, but important, contribution from solar.[59] The ACT Government has adopted a policy that by 2020 90% of the Territory's electricity will be sourced from renewables (see Box on the next page). [60]

In case the reader may believe the ACT Government's goal is impractical or is 'getting ahead of the game' it is worthwhile quoting from the Renewables 2014 Global Status Report: *Growing numbers of cities, states, and regions seek to transition to 100% renewable energy in either individual sectors or economy-wide. For example, Djibouti, Scotland, and the small-island state of Tuvalu aim to derive 100% of their electricity from renewable sources by 2020. Among those who have already achieved their goals are about 20 million Germans who live in so-called 100% renewable energy regions*.[61]

Ultimately when government action is seen as inadequate, communities and individuals are likely to act. More than 1 million homes in Australia now have solar panels installed on their roofs[62]. This attacks the greatest source of anthropogenic $CO_2$ in our economy – the generation of electricity from fossil fuels. In the ACT, with our lack of manufacturing and extractive industries, transport is the second largest contributor to our carbon footprint. In common with most communities the private motor car is the vehicle type that makes the greatest contribution to our transport carbon footprint. On the face of it, electric vehicles, particularly electric cars, have the potential to make a very significant contribution to reducing the ACT's carbon footprint.

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58 *Global Leadership on Climate Change.* C40 Cities: http://www.c40.org/ ; R20-Regions of Climate Action: http://regions20.org/

59 *SA on verge of 30% renewables.* Climate Spectator. July 2013: http://www.businessspectator.com.au/article/2013/7/11/renewable-energy/sa-verge-30-renewables

60 *ACT sets 90% renewable energy target in law*. ACT Government. November 2013: http://www.cmd.act.gov.au/open_government/inform/act_government_media_releases/corbell/2013/act-sets-90-renewable-energy-target-in-law7

61 Renewables 2014 Global Status Report. REN21. http://www.ren21.net/REN21Activities/GlobalStatusReport.aspx

62 *Rapid uptake of solar panels puts dent in electricity market.* Australian Broadcasting Commission (ABC). August 2013: http://www.abc.net.au/news/2013-08-05/new-report-shows-rapid-take-up-of-solar-panels/4864954

# ACT Government Climate Change Action Plan

In 2012 the ACT Government released the document *AP2 A new climate change strategy and action plan for the Australian Capital Territory.*[63] AP2 lays out the Territory government's proposed strategy for reaching carbon neutrality by 2060. At present electricity (60%) and transport (25%) make up the lion's share of the ACT carbon footprint.

While AP2 covers a number of sectors, action on electricity and transport are naturally the two areas of interest when considering electric vehicles:

**Electricity**

Prior to adopting strategies to reduce the electricity $CO_2$ footprint for the ACT, the community view was sought on a range of options – this survey indicated very strong support for transitioning to renewable energy.

The key commitment has been to adopt a target of 90% of the ACT electricity usage to be provided by renewables by 2020.

Work on implementation of the renewable energy target is now underway with the construction of three large solar farms in various stages of readiness: a 20MW solar farm at Royalla (close to completion – see photo); a 13MW solar farm at Mugga Lane; and a 7MW solar farm near Uriarra.[64]

In March 2014 the ACT Government announced a 200MW wind auction as the next major step toward the 90% renewables target.[65]

**Transport**

The ACT Government's climate change strategy recognises the importance of reducing $CO_2$ emissions from transport in the Territory. It has produced a *Transport for Canberra Policy* which is focused on actions for developing a sustainable transport system between 2012 and 2030.[66] While the emphasis of the policy appears to be on mode change – getting more people on to public transport; walking; and cycling – it also recognises the benefits of increasing EV use. In June 2014 the ACT Government released a discussion paper on the development of a Low Emission Vehicle Strategy.[67]

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[63] *AP2.* ACT Government 2012: http://www.environment.act.gov.au/__data/assets/pdf_file/0006/581136/AP2_Sept12_PRINT_NO_CROPS_SML.pdf
[64] *Solar Auction*. Environment and Sustainable Development Directorate. ACT Government: http://www.environment.act.gov.au/energy/solar_auction
[65] *Wind Auction.* Environment and Sustainable Development Directorate. ACT Government: http://www.environment.act.gov.au/energy/wind_power
[66] *Transport for Canberra Policy.* ACT Government: http://www.transport.act.gov.au/policy_and_projects/transport_for_canberra_policy
[67] *Low Emission Vehicle Strategy – Discussion Paper 2014*. ACT Government. June 2014: http://www.timetotalk.act.gov.au/consultations/?engagement=low-emission-vehicle-strategy-discussion-paper-2014

## 6.2 The ACT Carbon Footprint

*Figure 6.1* gives a breakdown of the carbon footprint for the ACT by energy source in 2011[68]. It can be seen that $CO_2$ derived from electricity and transport fuels together make up about 85% of the total footprint. The remaining 15% - the 'Other' category - comprises contributions from natural gas, waste, agriculture and industrial processes. The Figure also shows the extent to which petrol is the dominant transport fuel in the ACT. If a broad assumption is made that this petrol use is associated with passenger car use, cars contribute about 75% of the transport carbon footprint for the ACT (nationally this figure is about 60%[69]).

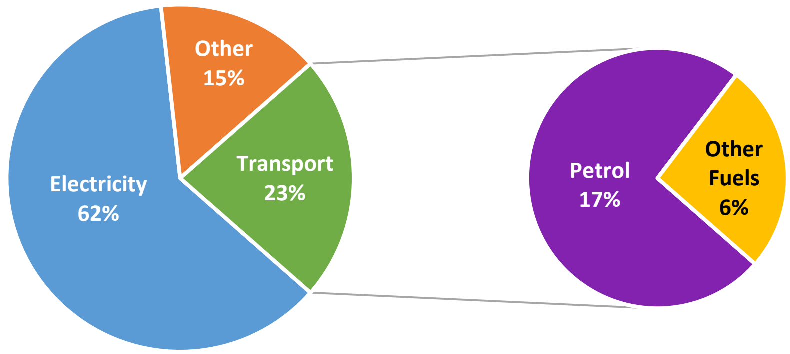


**Figure 6.1: Breakdown of the ACT's current carbon footprint**

As indicated in Section 6.1, the ACT Government has committed itself to achieving 90% renewables by 2020. Under the ACT Action Plan, renewable energy projects (wind and solar) will be progressively implemented during the period 2013–2020. The Plan shows that by 2018 transport will become the biggest contributor to the ACT carbon footprint.[70]

Assuming the 90% target is achieved, the ACT carbon footprint in 2020 will look something like that shown in *Figure 6.2*. The proportion of the 'carbon pie' contributed by electricity will have shrunk to around 10% while that from transport will have more than doubled to about 55% (in absolute terms transport contributions will have fallen by about 10% from 2012 levels). At this point transport will clearly need to be the focus of attention if ongoing carbon reductions are to be achieved.

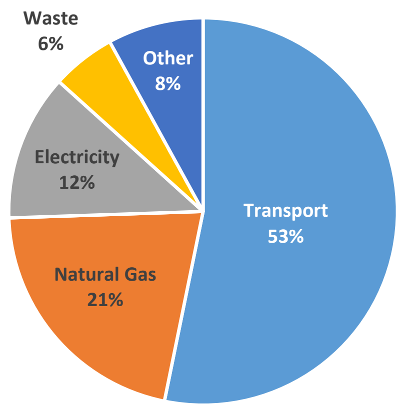


**Figure 6.2: Indicative breakdown of ACT carbon footprint when 90% renewable energy electricity is achieved**

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68 *ACT Greenhouse Gas Inventory 2011.* ACT Government: http://www.icrc.act.gov.au/wp-content/uploads/2013/10/Report-7-of-2013-September-2013.pdf

69 Green Vehicle Guide. Australian Government: http://www.greenvehicleguide.gov.au/gvgpublicui/Information.aspx?type=VehicleEmissions

70 *AP2, Figure 11*: http://www.environment.act.gov.au/__data/assets/pdf_file/0006/581136/AP2_Sept12_PRINT_NO_CROPS_SML.pdf

## 6.3 Trajectory for Shrinking the ACT Transport Carbon Footprint

*Figure 6.3* shows the proposed trajectory of the ACT's carbon footprint to carbon neutrality in 2060.[71] It can be seen that the line has a relatively steep gradient to 2020 when the 90% renewables target for electricity is due to be reached, and then it flattens out significantly for the next forty years.

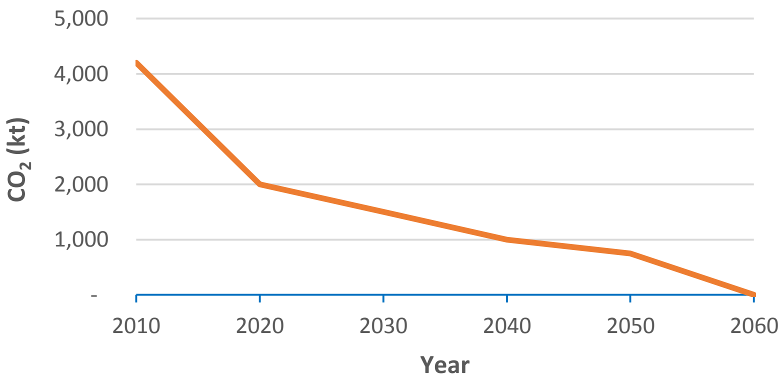


**Figure 6.3: ACT Government's proposed $CO_2$ trajectory to carbon neutrality in 2060**

One of the key strategies for reducing the ACT's transport carbon footprint spelt out in the ACT Government transport policy [72] is to bring about mode change for Canberra residents. The aim is to get residents to use cars less and to walk, cycle and use public transport more. Clearly laudable aims but despite many years of concerted effort Canberra residents have been reluctant to mode shift – there are undoubtedly many reasons for this but the dispersed layout of the city does mean that any mode shift for transport within Canberra will be disruptive for many families and individuals. Projects such as the light rail may lead to major changes in land use patterns in the ACT, which will assist mode change, but this will presumably take many years.

Would it be feasible to accelerate the shrinking of the ACT transport carbon footprint? Could this be done in a less disruptive way than wholesale mode change?[73] EVs would appear to offer at least one solution. In my view, electrifying our land transport whether that be in personal or public vehicles, should not be relegated to a second tier strategy behind mode change. Given our excruciatingly slow progress on addressing climate change, we need to take up all feasible options to reduce our carbon footprint**.** EVs seem to be the best alternative we have at present to ICE vehicles (recognising that other technologies such as fuel cells are also on the horizon).

In saying this I should point out that I am not particularly comfortable with promoting any form of car use over public transport or cycling/walking. I come from a cycling background. I commuted by bike from southern Woden into Civic daily for about 27 years until my retirement in 2012. I am a past president of Pedal Power ACT. While I would like to see everyone walking or on bikes or public transport I recognise that this isn't going to happen in the near future.

Given that the ACT transport carbon footprint is primarily derived from cars, buses, taxis and light commercial vehicles, in theory the transport sector could be electrified today – electric vehicles are currently available in all these categories and are now being used throughout the world. While in the long run electrification of our transport system is almost certain to occur, the pertinent question is at what rate is this likely to happen?

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[71] Derived from Executive Summary Figure 2 – AP2: http://www.environment.act.gov.au/__data/assets/pdf_file/0006/581136/AP2_Sept12_PRINT_NO_CROPS_SML.pdf

[72] *Transport for Canberra Policy*: http://www.transport.act.gov.au/policy_and_projects/transport_for_canberra_policy

[73] *To get people of cars we need to know why they drive.* The Conversation. June 2014: https://theconversation.com/to-get-people-out-of-cars-we-need-to-know-why-they-drive-27279

It is useful to break this discussion down into three categories: private vehicles; corporate/commercial vehicles and public transport. The next three sections look at the transport sub-sectors in turn.

## 6.4 Going Electric - Private Vehicles

***Electric Cars***

There are three broad issues which appear to be the main impediments to rapid adoption of private electric cars at the present time: lifestyle disruption; purchase cost; and lack of EV choice.

*Lifestyle Disruption*

The extent of any lifestyle disruption caused by EV use will depend on the circumstances. Owning an EV will not suit everyone at the present time particularly due to the limited distance range of current generation EV models. Putting aside cost issues, how practical is EV adoption?

1) City car

   *Two car family* – about 50% of ACT homes have 2 or more cars.[74] Clearly in many homes the cars are used independently and therefore the vehicles are not interchangeable, but many households do have flexible arrangements for car use. In these circumstances there would commonly be no real disruption if one of the cars were an EV (the 'the city car') while the other car (the ICE car) would be available for longer trips when required.

   This is what has happened in our household and the outcome has not been disruptive – in fact just the opposite – it is much more convenient to fuel a car at home and using an EV is a much nicer way to travel around town.

   *One car family* – EV adoption would not be disruptive if the family car is solely used for running around town but this is likely to be very unusual - most families with only one car will want to do out of town trips at least on some occasions. That is, the normal need will be for an 'all purpose car'.

2) All purpose car

   If out of town use is only occasional then a family could get by by owning an EV and hiring an ICE car on those occasions when they want to venture beyond Canberra. This could be described as inconvenient but not too disruptive to lifestyle. On the other hand if a family frequently goes out of town a current generation EV is not likely to be a suitable car. The introduction of charging infrastructure could address this constraint for some people (see Section 7.3).

   A good compromise solution in these circumstances would be to purchase a PHEV – this would enable a family to use mostly electricity around town and then use petrol when going beyond Canberra.

*Purchase Cost*

As noted previously, at the present time I estimate that an EV costs somewhere around $10,000-$15,000 more than an equivalent ICE car. Even though the total costs of owning an EV may be cheaper than an ICE vehicle over a 5-10 year period the difference in initial purchase cost will deter

[74] *'…in 2011 53% of households in Australian Capital Territory had access to two or more motor vehicles…'*. Profile.id: http://profile.id.com.au/australia/car-ownership?WebID=170

many potential buyers. The costs of buying an EV have dropped quite significantly in Australia over the past year and, if trends in costs for other new technologies are used as a guide, it would be expected that costs for EVs will continue to drop. As mentioned earlier, announcements have already been made about dramatic drops in the costs of batteries within the next three years - Tesla is proposing to construct a battery 'gigafactory' which it claims will bring down the price of Li-ion batteries by 30%.

Around the world high up-front costs for EVs have been addressed by governments providing incentives to assist EV purchase. This topic is discussed in Section 7.3.

*Lack of EV Choice*

As discussed in Chapter 5, only a few models of EVs and PHEVs are available on the Australian market at the present time. The Mitsubishi iMiev and the Nissan Leaf are the two EVs in the middle price range while the BMW i3 and the Tesla S are EVs at the luxury end of the market. This compares say to the US where there are now 18 different models of EV and PHEV for sale.

If there is to be a significant uptake of EVs there will need to be a wide choice of vehicles available to accommodate the wide differences in wants from a large customer base. Vehicle distance range is clearly critical, but as I have noted throughout the text – the current generation EVs are fine if you are looking for a city car. One current EV on the market – the Tesla S has a range of about 500 km but it is a specialised car that will be out of the price range of most buyers (price between $100,000 and $150,000).[75] I imagine that to get significant take up of EVs in Australia there will need to be a reasonable choice of cars with a range of at least 300km (notionally twice the range of the current generation EVs) lying in broadly the same price range as today's popular ICE cars.

Lack of EV choice is not an area that the ACT Government could directly address, but if policies were adopted to stimulate EV use, an increase in EV sales would presumably encourage more motor vehicle companies to market their EVs in Australia.

***Electric Motorcycles***

Electric motorcycles are now being sold in Australia. As far as I can gather there has been an established international electric motorcycle racing fraternity for some time and the technology is now spilling over into commercial motorbikes for personal transport.

The bike shown in *Figure 6.4*[76], which is imported from the US, has a range of approximately 250km and an efficiency of about 5kWh/100km. These specifications are more than adequate for normal commuting in the Canberra area. The advertised price for the bike in the Figure is just over $20,000 (AUD).


**Figure 6.4: Electric motorbike now being imported into Australia**

[75] Tesla Motors: http://www.teslamotors.com/en_AU/models/design
[76] *2014 Zero DS Electric Motorcycle.* Zero Motorcycles: http://www.zeromotorcycles.com/high-res-photos/photo.php?bl&img=2014:2014_zero-ds_studio_orange-rp-wbg

***Electric Bicycles***

In contrast to the two previous categories of private vehicles the selection of electric bicycles (e-bikes) available in Canberra is bewildering. They are available from a number of Canberra bike sellers and from retailers across Australia via the internet. The cost of an e-bike in Australia is generally somewhere between $1,000 and $3,000. Typically the bikes sold in Canberra have a range of around 50km and a top speed of about 25km/hr. As far as I can tell the e-bikes are almost all sourced from China. There are now around 150 million e-bikes in China.[77]


**Figure 6.4: The other member of our e-family - the e-bike**

These bikes can legally be ridden on Canberra's bike paths. While they tend to be looked down on by hardened cyclists they clearly do get some people out of their cars (and probably off public transport as well). I seem to see an increasing number of e-bikes on the bike paths these days. They certainly make cycling much easier.

Toward the end of my project I thought I'd better do something more than just write about these bikes – ownership and use had to be tried out so we became the proud possessor of the e-bike in *Figure 6.4*.[78] It's yet to be fully tested but it already has very strong family approval (I'll just stick to my human powered bikes!).

## 6.5 Going Electric - Corporate/Commercial Vehicles

In the ACT these vehicles are generally a mixture of passenger vehicles and light commercial vehicles.

A number of government departments have been using electric passenger vehicles (both Mitsubishi iMiev and Nissan Leaf) for some time to courier material around Canberra. I have been unable to locate any published reports on the performance of these vehicles for this task.

[77] *Electric bikes: what experiences in China can tell us.* The Guardian. November 2013: http://www.theguardian.com/local-government-network/2013/nov/20/lessons-electric-bikes-china
[78] *Products.* Switched on Cycles: http://www.switchedoncycles.com.au/products.htm

Electric delivery vans are now being developed by a number of companies. These are typically being designed to carry small loads/parcels etc around urban areas. The use of electric vehicles for delivery of relatively small parcels reminds me of the situation 50+yrs ago when I was a child growing up in post war England - milk and bread were delivered door to door by electric vehicles. Large scale production of the NV200 Nissan electric delivery van (shown in *Figure 6.4)* [79] began in early May 2014 (with all global production from a plant in Spain).[80]


**Figure 6.4: Electric light commercial vehicle on test in the United States**

Australia Post has recently announced it is adding 4 Renault Kangoo electric vans to its parcel delivery fleets in Sydney and Melbourne to assess the potential of electric vehicles.[81]

## 6.6 Going Electric - Public Transport

*Buses*

The EV and environmental media is increasingly reporting on the advent of electric buses.

Adelaide City Council has introduced a pure battery electric bus called 'Tindo' (Figure 6.5). [82]

A Chinese company BYD appears to be making big inroads into global bus markets. Trials of BYD electric buses have reported that the life cycle costs of these are about 60% less than an equivalent diesel bus[83].


**Figure 6.5: Electric bus in Adelaide**

In many countries the introduction of electric buses appears to be primarily driven by pressures to improve air quality (AQ) [84] – urban buses tend to be significant contributors to poor AQ since in many cities they spend much of their time travelling slowly in congested traffic. AQ is not generally seen as a problem in Canberra but there are still compelling health reasons for aiming to achieve the best AQ outcomes. For example,

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[79] Source of photo. Nissan media release. April 2013: http://www.nissan.com.au/~/media/Files/Press%20Release/2013-04/20130412_NissanFedEx_e-NV200Singapore_MR.ashx

[80] *Nissan e-NV200 production is now underway.* Inside EVs. May 2014: http://insideevs.com/nissan-e-nv200-production-is-now-underway/

[81] *Australia Post takes delivery of first Renault electric vans.* Australia Post. May 2014: http://auspost.com.au/about-us/renault-electric-van.html

[82] Tindo. The World's First Solar Electric Bus. Adelaide City Council: http://www.adelaidecitycouncil.com/assets/acc/Environment/energy/docs/tindo_fact_sheet.pdf

[83] *The Future of Transport is Electric*. Uruguay National Utility Company. March 2014: http://www.byd.com/news/news-224.html

[84] *BYD receives record bus and taxi order; 2,000 buses and 1,000 taxis!* Inside EVs. May 2014: http://insideevs.com/byd-receives-record-bus-2000-buses-1000-taxis/

a recent study has indicated that fine particulates (such as those emitted by modern diesel buses) may be linked to autism.[85] Other recent Australian reports have drawn similar conclusions about the need to improve our air quality.[86]

*Taxis*

Taxis are in a similar situation to buses – they commonly operate in urban areas as part of congested traffic streams and therefore in many cities there are pressures to use EV taxis as a means of improving air quality. For example, as mentioned in Chapter 1, the Mayor of London has recently announced that by 2018 all taxis in London will need to be able to operate in a zero emissions mode in designated parts of the city as a measure to control AQ.[87] The London cab is quite unique and the preliminary designs for some of the new electric cabs look similar to the classic design (see example in *Figure 6.6)*. The specifications for the UK made Metrocab shown in the Figure suggest that transitioning to EV cabs should not be a problem[88].


**Figure 6.6: Electric London taxi**

While it would be unlikely that the London electric cab would migrate to Canberra, the move to EV cabs is occurring throughout the world. For example, the new electric taxis in Bogota look like the conventional large cars typically used as taxis in Australia.[89] In the UK a provincial taxi company has reported very successfully using Nissan Leafs as half the cars in its fleet. [90]

An interesting EV self-drive 'taxi' model is now in operation in France – the Bluecar.[91] Under this program EVs can be picked up and dropped off at charge points around Paris in a similar manner to the push bike hire schemes that are now commonly found in many large cities.

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[85] *Pollution and autism spectrum disorder.* ABC Radio National. April 2014: http://www.abc.net.au/radionational/programs/healthreport/pollution-and-autism-spectrum-disorder/5362338
[86] *Clearing the Air.* Environmental Justice Australia. May 2014: https://envirojustice.org.au/sites/default/files/files/Submissions%20and%20reports/Envirojustice_air_pollution_report_final.pdf
[87] *London's black cabs to go green.* The Telegraph. January 2014: http://www.telegraph.co.uk/motoring/news/10576635/Londons-black-cabs-to-go-green.html
[88] Media release. Metrocab. April 2014: http://www.newmetrocab.com/resources/Press_Release-Trade_days.pdf
[89] *Bogota charges forward with electric taxis.* National Geographic. January 2014: http://newswatch.nationalgeographic.com/2014/01/17/bogota-charges-forward-with-electric-taxis/
[90] *Nissan LEAF Taxi Fleet Surpasses 150,000 Miles.* Inside EVs. June 2014: http://insideevs.com/nissan-leaf-taxi-fleet-surpasses-150000-miles-logs-37000-fares/
[91] *Autolib*. Paris: https://www.autolib.eu/en/

# Chapter 7

# Action Options

## 7.1 Introduction

The previous chapter suggested that significant inroads could be made into the ACT's transport carbon footprint across all the transport sub-sectors by using EVs currently available today. The question is do we just let the market determine the rate at which the transition to electric vehicles takes place or should the ACT government and/or the Federal Government be proactive in driving the change?

It is important to recognise that the ACT Government is supportive of EVs and has previously been involved in significant promotion of these vehicles. In 2011 the ACT Government gave high profile support to a proposal by a private company 'Better Place' to install an EV charging network around Canberra. This company ultimately failed and the network did not materialise.

In its sustainable transport policy document, 'Transport for Canberra – 2012-2031' the ACT Government has undertaken to '*Release a low emission vehicle strategy by June 2013, including an evaluation of the Green Vehicles Duty Scheme to identify how it could better encourage the purchase of lower emissions vehicles including electric vehicles'. (Action 26).* The Transport for Canberra document also includes other encouraging statements such as: *Another positive development in coming years is the advent of commercially produced electric vehicles and the ACT Government is considering the adoption of electric vehicles into its own fleet to lead by example.*[92]

As mentioned in the previous chapter, in June 2014 the ACT Government released a discussion paper on its proposed Low Emission Vehicle Strategy. This document clearly indicates the Government's intention to move forward on the promotion of low emission vehicles which includes EVs. However, the way ahead is not yet clear and based on our experience in other areas it is very likely that the ICE/EV transition will take much longer than would appear to be necessary or desirable.

When thinking about the ACT process it is instructive to look at the parallel process which is going on in South Australia. In 2012 the SA Government released a policy paper entitled *South Australia's Low Emission Vehicle Strategy, 2012-2016.* This publication is a high level document and devotes one page to EVs – it sums up its policy commitment with the words *'The South Australian Government will endeavour to remove information, policy and market barriers to electric vehicles and, accordingly, increase the number of electric vehicles on our roads'.*

While 'removing barriers' is useful, the SA Government policy statement does not include any proactive measures and unfortunately does not convey a vision of how EVs will play a role in the reduction of that State's transport sector carbon footprint. This seems to be far removed from the priorities that are evident in other countries (see Sections 7.4 & 7.5). Hopefully, when the ACT Government develops its Strategy it will demonstrate a strong commitment to the electrification of the ACT road transport system.

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[92] *Transport for Canberra Policy.* ACT Government. Chapter 4: http://www.transport.act.gov.au/policy_and_projects/transport_for_canberra_policy

## 7.2 The ACT Government Low Emission Vehicle Strategy

As indicated in the previous Chapter, in June 2014 the ACT Government released a Discussion Paper on its proposed Low Emission Vehicle Strategy (LEVS).[93] It is certainly positive that the Government is seeking community input into the LEVS.

In broad terms the paper puts forward three potential Strategy strands for comment: *'To promote the purchase and use of low emission vehicles'*; *'For the ACT Government to lead by example'*; and *'To promote a change in driver behaviour'*.

Clearly all very useful areas for exploration. However, as always in the implementation of any policy program, the final outcome will have to boil down to the allocation of resources between competing alternatives.

In my view, in order to obtain significant resources for tackling the carbon footprint of the ACT transport sector, efforts should be made to establish a clear vision for the role of zero emission vehicles which goes beyond the laissez faire approaches commonly adopted. A good start could be the establishment of an EV Target and Action Plan for the ACT (see Section 7.4).

## 7.3 Why Should the ACT Act on EVs?

The widespread adoption of EVs in the ACT would be an ideal fit with the 90% renewable target for electricity. As discussed in the previous chapter, by 2020, if the 90% renewable target is achieved, $CO_2$ from road transport will constitute more than 50% of the ACT's carbon footprint unless complementary action is taken to reduce road vehicle $CO_2$ emissions. On the face of it, EVs offer the most practical and easily attained route to $CO_2$ reductions in the transport sector.

EV adoption will improve air quality (AQ). There are always imperatives to maximise air quality. While AQ may not be seen as a major problem in the ACT at the present time, in all cities there are likely to be AQ black spots in locations where there is slow moving congested traffic. As mentioned earlier, recent research has linked autism with fine particulate pollution – this is commonly associated with motor vehicles, particularly diesel powered vehicles.

Canberra is probably the best placed State/Territory in Australia to introduce EVs due to its constrained size and the fact that it will effectively be running on renewable energy by 2020. If we can achieve carbon neutrality for almost all of our electricity and transport we will be close to being a carbon free community. This will make us a model for Australia and give Canberra profile as a 'high-tech' city which will help us attract low carbon industries and potentially lead us to being a knowledge based centre of excellence.

## 7.4 Develop an EV Target and Action Plan for the ACT?

The setting of targets and the development of associated action plans is now more or less standard political/administrative practice around the world to achieve policy outcomes.

Targets do work. As indicated in the Box in the previous Chapter, the ACT Government's 90% renewables target has led to the letting of contracts for 40MW of solar power and an auction for 200MW of wind power (closing on 13 Aug 2014). This has enabled the government to announce that the 90% target will be reached at a cost, which peaks in 2020, of around $4 per week for the

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[93] *Low Emission Vehicle Strategy – Discussion Paper 2014*. ACT Government. June 2014: http://www.timetotalk.act.gov.au/consultations/?engagement=low-emission-vehicle-strategy-discussion-paper-2014

average Canberra household.[94] Although now under review, the Federal Renewable Energy Target (RET) has been very successful in establishing renewable energy projects across Australia. The RET kick started the rooftop solar PV and wind energy sectors that are now proving to be such important components of our electricity system.

Would the establishment of an EV target for the ACT assist in the ICE to EV transition? Several jurisdictions around the world are considering, or have adopted, EV targets. Examples of proposed or actual overseas EV targets include:

| | |
|---|---|
| ***China*** | 5 million EVs on the road by 2020[95] |
| ***Germany*** | 1 million EVs on the road by 2020[96] |
| ***International Energy Agency (IEA)*** | 20 million EVs on the road globally by 2020 – 2% of all vehicles[97] |
| ***Norway*** | 50,000 registered EVs (incentives stop in 2018)[98] |
| ***UK*** | EVs to constitute 60% of new car sales by 2030[99] |

If a target were seen as being desirable, a detailed study would need to be carried out to determine the appropriate EV target for the ACT. The target would presumably be of a similar form to the examples shown above and would aim for a specified number of EVs (or proportion of total sales) by a specified date. The broad aim of the target would presumably be to reach a point of critical mass which, when reached, would enable EV use to increase through normal market forces. For example, a certain number of EVs would need to be in the fleet to make the construction of public charging stations viable.

The setting of a target and the development of an Action Plan would presumably be best achieved as an integrated study. The design and quantum of the target would be largely driven by the cost and implementation feasibility of potential EV incentive options.

## 7.5 Possible Policy Measures to Increase EV Use in the ACT

It was shown in Chapter 1 that there are many reasons why governments are attracted to increasing the use of EVs. It would appear that in most countries where there has been a significant up-take of EVs there have been either government incentives to encourage, or government regulation effectively requiring (eg California), EV use.

To date in Australia, government EV incentives have been very low key: the Federal Government provides a reduced luxury car tax for electric vehicles; in the ACT EVs are exempt from stamp duty;

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[94] *90 percent renewable energy target*. Environment and Sustainable Development Directorate. ACT Government: http://www.environment.act.gov.au/energy/90_percent_renewable
[95] *Chinese cities open up green market as government battles pollution.* Global Post. March 2014: http://www.globalpost.com/dispatch/news/thomson-reuters/140321/chinese-cities-open-green-car-markets-government-battles-pollut
[96] *Germany: new measures needed to meet EV targets.* EV Update. July 2012: http://analysis.evupdate.com/commercialization-evs/germany-new-measures-needed-reach-ev-targets
[97] *Global EV Outlook.* Electric vehicles initiative. April 2013:http://www.iea.org/publications/globalevoutlook_2013.pdf
[98] *Norwegian Parliament extends electric car initiatives until 2018*. AVERE. June 2012: http://www.avere.org/www/newsMgr.php?action=view&frmNewsId=611&section=&type=&SGLSESSID=phhp3v7n4cs275g46piss4bv71
[99] *Pathways to high penetration of electric vehicles.* UK Committee on Climate Change. December 2013: www.theccc.org.uk/wp-content/uploads/2013/12/CCC-EV-pathways_FINAL-REPORT_17-12-13-Final.pdf

while in Victoria EVs have a reduced annual registration fee. It is interesting to note that when I bought my EV in Canberra I had no benefit from the reduced stamp duty for ACT residents as the Australia-wide published price for the car included 'on road costs' which captured the stamp duty.

In developing an EV target/Action Plan it would be instructive to examine what incentives are being used in other countries. The Tesla Motors website includes a very useful interface showing government EV incentives that are in place around the world.[100] Wikipedia also provides a good summary of the incentives that are now in place in other countries.[101]

As an example, it is interesting to look at Norway which is commonly cited as the country that is leading the transition to electric vehicles.

## Electric Vehicles in Norway

In March 2014 20% of car sales in Norway were EVs - Tesla at 10.8% of the market sold more than twice as many cars as the second most popular car.[102] EVs made up about 10% of passenger car registrations in Norway over the seven month period Nov 2013 to May 2014.[103]

The UK Guardian reports that battery powered cars in Norway:

- *are exempt from high rates of purchase tax, and VAT* [GST]
- *pay no road and ferry tolls or parking fees*
- *cost less to insure*
- *can be charged up for free electricity from thousands of points*
- *local government subsidises the installation of charging points in homes.*[104]

It is ironic that Norway's export revenues derive in large part from North Sea oil. About 99% of Norway's electricity is generated by hydro.

One other very popular EV incentive in Norway (and in California) is free access to bus lanes (carpool lanes) – while I don't think this would make a great difference to the life of an ACT commuter it is a highly treasured incentive particularly in congested southern California.

In developing its Low Emission Vehicle Strategy it would be hoped that the ACT Government will evaluate the sorts of incentives cited above for potential application in the ACT. Given the very low running costs for EVs I envisage that incentives focused on reducing the upfront costs of going EV

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100 *Electric vehicle incentives around the world.* Tesla Motors: http://www.teslamotors.com/en_AU/incentives/AU

101 *Government incentives for plug-in electric vehicles.* Wikipedia: http://en.wikipedia.org/wiki/Government_incentives_for_plug-in_electric_vehicles

102 *Electric car sales smash records in Norway*. The Australian. April 2014: http://www.theaustralian.com.au/business/latest/electric-car-sales-smash-records-in-norway/story-e6frg90f-1226876483237

103 *Norway All Electric Vehicle Sales Report May 2014.* Insideevs: http://insideevs.com/norway-all-electric-vehicle-sales-report-may-2014/

104 *Norway has fallen in love with electric cars – but the affair is coming to an end*. The Guardian. January 2014: http://www.theguardian.com/environment/2014/jan/29/norway-electric-cars-sale

(eg some form of assistance for EV purchase or home charger installation) would be the most successful. Having said that, workers in the Parliamentary Triangle are now facing parking charges for the first time and reduced parking fees for EVs could well be seen as an enticing incentive.

A detailed assessment of the benefits of providing financial incentives to encourage EV uptake has recently been carried out by the International Council on Clean Transportation (ICCT). It can be seen from *Figure 7.1,* which is extracted from the ICCT study report, that there is only a loose correlation between the magnitude of financial incentives and the rate of EV uptake. For example, while the graphic shows the high EV penetration in Norway it also shows that substantial financial incentives for EVs in Denmark for private cars appear to have been totally ineffective.[105] The report hypotheses that incentives other than direct financial incentives (eg access to bus lanes or better located parking bays) are possibly significant influences on EV uptake – these were not examined in the ICCT report.

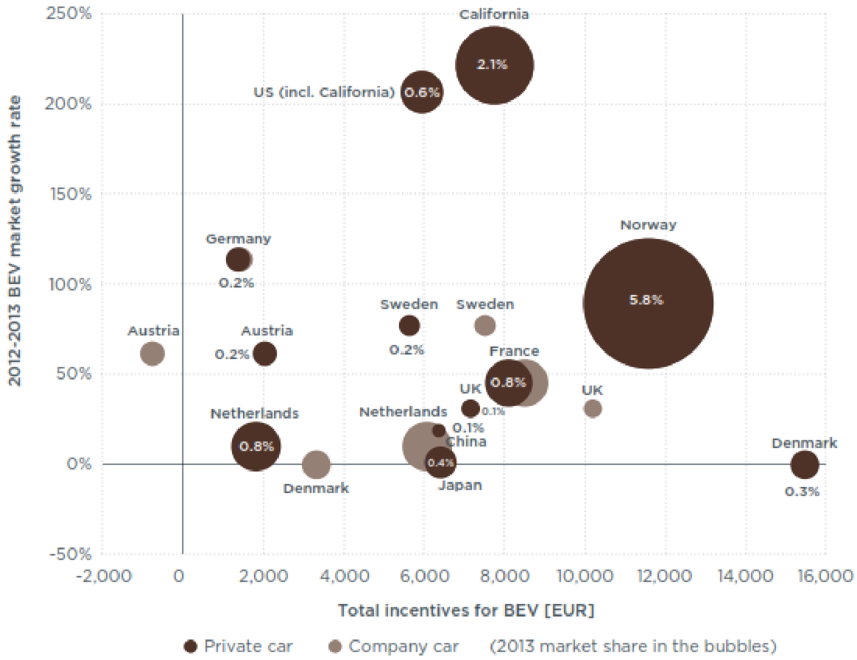


**Figure 7.1: Market growth rate v per vehicle financial incentive**

As I have noted earlier, in my view there is little need to install public charging infrastructure in Canberra while EVs are being used solely as 'city cars' and the owners are able to charge their cars at home. The charging infrastructure becomes necessary when we want to turn our 'city cars' into 'regional cars' (see the next section). Clearly there is a danger that unused charging infrastructure in the public eye will give EVs a bad image.[106] Given this, and the failed Better Place venture to set up an EV charging network in Canberra, I would hope that the temptation to put Government resources

[105] *Driving electrification: A global comparison of fiscal policy for electric vehicles.* Figure 11. ICCT. May 2014: http://theicct.org/driving-electrification-global-comparison-fiscal-policy-electric-vehicles

[106] *Taxpayer Funded Public Charging Stations Come Under Fire in Ohio For Lack of Usage.* Inside EVs. June 2014: http://insideevs.com/taxpayer-funded-public-charging-stations-come-fire-ohio-lack-usage/

into public charging infrastructure is resisted and any available funding is dedicated in the first place to building up the number of EVs in the Canberra transport fleet.

Noting that the ACT Government has given commitments to increase its departmental ownership and use of EVs, in my view it would be useful for the Government to also consider the adoption of strategies aimed at:

- Increasing the Federal Government departmental use of EVs in Canberra.
- Converting the ACTION bus fleet over to battery power (notwithstanding ACTION's current efforts to 'green' its fleet).[107]
- Encouraging and/or requiring taxi companies to adopt EVs.

## 7.6 Canberra Region EV Charger Network

While I do not believe the lack of charging infrastructure in Canberra is a major impediment to EV uptake in the ACT at the present time, I do think the existence of fast charging networks will be essential in the next few years if EV adoption is to thrive. I can see that working out the optimum timing for installation, the locations for the chargers, and determining who will own/operate them, will not be a simple undertaking. In broad terms, to take my Leaf from being a 'city car' to a 'regional car' or even a 'normal' car I envisage that there will need to be two sorts of charger networks: one based on regional population centres and one based on 'electric routes'.

*Regional Network*

Establishing fast chargers in regional towns and population centres (eg Bungendore, Braidwood, Yass, Collector, Cooma, etc) would open up EV access for Canberra residents to the whole SE NSW region and would facilitate regional tourism. Installing a comprehensive charger network in Canberra would enable residents from regional communities to travel to/from Canberra in EVs to use the city as a regional centre (for medical appointments, cultural/sporting events, shopping trips, etc). This area is a catchment with a population of around 650,000 people.[108] For this concept to work the distance between chargers will need to be no more than 100km.

*Electric Routes*

The 'electric routes' could possibly best be started by establishing charging stations on the most used routes linking Canberra to:

1) 'The Coast' (chargers at say Braidwood, Ulladulla, Batemans Bay, Narooma, Bega, Merimbula).

2) 'The Snow' (chargers at say Cooma and Jindabyne).

3) Sydney (chargers at say Goulburn, Sutton Forest, Pheasants Nest – the locations of service centres on the Hume Highway).

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[107] *ACTION launches new, greener Euro 6 buses*. ACTION. July 2014: http://www.action.act.gov.au/news/news_articles/action-launches-new,-greener-euro-6-buses

[108] *The ACT and its region: economic relationships and key drivers of economic growth*. Access Economics. 2008: http://www.cmd.act.gov.au/__data/assets/pdf_file/0004/119722/ae-act-linkages.pdf

The possible locations of chargers on these routes are shown in *Figure 7.2*. On these conceptual routes the distance between chargers ranges from 35km to 115km. Almost all the chargers are between 55km and 90km apart. Cooma would be a problematic location as it over 100km from both Canberra and the coast. In particular the journey from Bega to Cooma (110km) would be unlikely to be practical in a current generation EV given the long climb up Brown Mountain. Supplementary charging locations would be required.

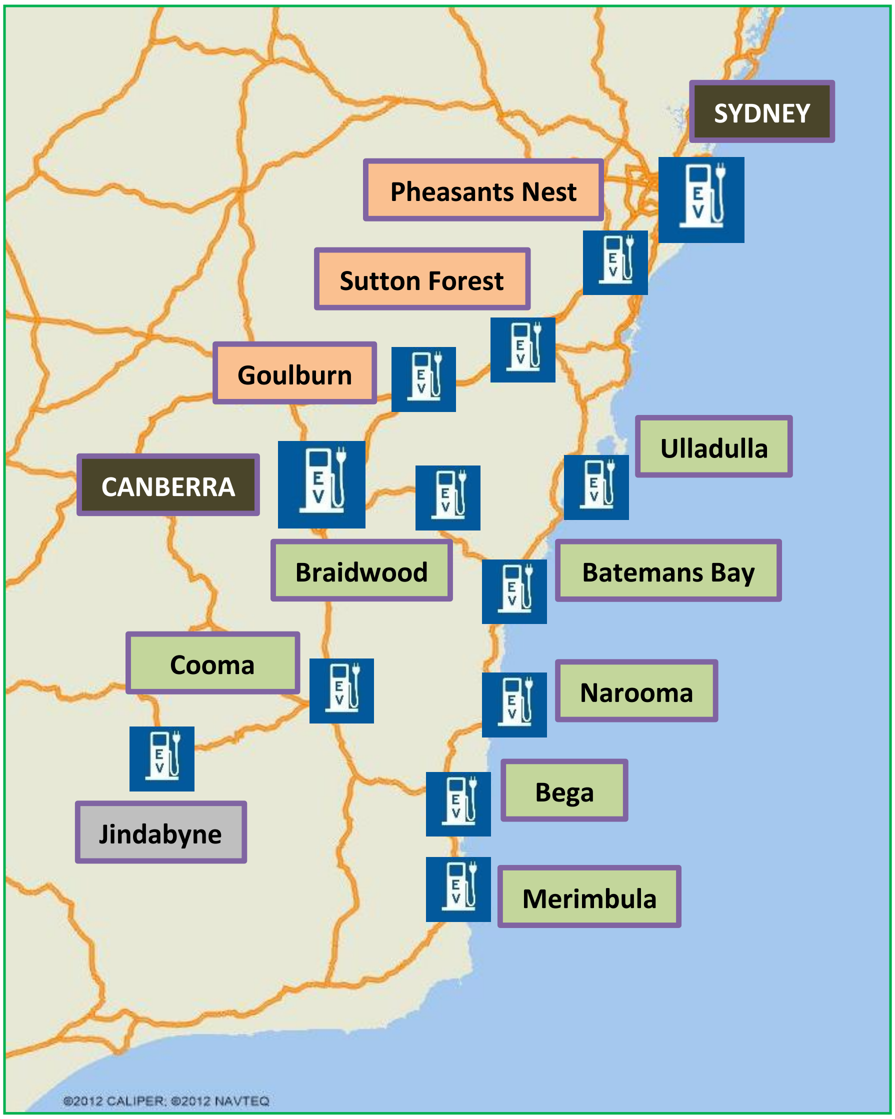


**Figure 7.2: Potential sites for quick chargers on 'electric routes' serving Canberra**

The establishment of these types of electric routes would mirror the electric route between Perth and Margaret River that is now being proposed by the University of Western Australia.[109] This proposed route would have distances of 50km to 80km between charging stations.

[109] *Electric Highway.* The REV project. University of Western Australia: http://www.therevproject.com/trials/highway.php

*Who installs the chargers?*

While the concept of establishing charger networks is fine in theory the fundamental question is who or which entity would install the chargers? Ideally the chargers would mainly be Level 3 (80% charge in about 30 mins) particularly on the 'electric routes' where the users would be on the way to another destination. Smaller towns and population centres may deliberately elect to install Level 2 chargers as this would 'capture' visitors for say 2 hours and give them time to visit shops, cafes, local museums, etc

A Level 3 charger requires 3 phase electricity and will probably cost at least $50,000 to install.[110] Having said that, latest developments indicate very significant drops in the price and complexity of fast chargers.[111] A Level 2 charger is simpler and installation costs are likely to be in the region of $10,000. Costs will vary considerably from site to site – a good summary of the challenges in setting up EV charging networks can be found in a book published by the Hawaii State Government.[112] Against this background the setting up of a charging network has real attractions compared to establishing a liquid fuel distribution network. In particular an electric charger network can be established incrementally with relatively little expenditure; the 're-fuelling points' take up little space and can be widely distributed throughout communities. Very importantly the infrastructure to transport the fuel is already in place (ie the electricity network) and the elaborate trucking and pipeline distribution regimes required for liquid fuels are not required.

Any entity installing an EV charger will expect some form of financial return – this may be direct (ie payment for the electricity used) or it may be indirect. For example, local government could install Level 2 chargers in small population centres as a way to encourage tourism and support local business. On the electric routes major food franchises could install the Level 3 chargers with a view to enticing the occupants of *en route* EVs to take a coffee/meal at their establishments while the car recharges. This latter approach has been adopted widely in the UK and there are some interesting videos on the internet which describe quite long EV road trips which have been taken by hopping between fast chargers at motorway service centres.[113]

## 7.7 Where to From Here?

It seems the pressures for us to reduce our carbon footprint will only increase. The reports of the Intergovernmental Panel on Climate Change (IPCC) are indicating increasing certainty about human impacts on climate.[114] This year, 2014, looks as if it will be the first year in modern history when the $CO_2$ levels in the world's atmosphere will be consistently above the psychological level of 400ppm.[115]

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[110] Article on the cost of installing EV chargers. EcoWatch. October 2013: http://ecowatch.com/2013/10/18/nissan-offers-15000-to-businesses-that-install-ev-charging-stations-before-2014/

[111] *BMW Launches New Low Cost DC Fast Chargers From $6,458*. InsideEVs. July 2014: http://insideevs.com/bmw-launches-new-low-cost-dc-fast-chargers-6458/

[112] *Hawaii EV Ready.* Plug in America. March 2012: http://www1.eere.energy.gov/cleancities/toolbox/pdfs/hawaii_ev_guidebook.pdf

[113] *The Electric Highway - London to Edinburgh*. Fully Charged. February 2014: https://www.youtube.com/watch?v=eHcC65ZoyBw

[114] *What's New in the Fifth Assessment Report.* Department of the Environment. Sep 2013: http://www.climatechange.gov.au/climate-change/climate-science/intergovernmental-panel-climate-change-ipcc/what%E2%80%99s-new-fifth-assessment-report

[115] *Earth's $CO_2$ Home Page*. $CO_2$Now.org: http://co2now.org/

Throughout the book I have made many references to developments in other countries. The technology in the area of EVs and solar energy is moving very quickly globally and inevitably this will spill over to Australia.

Many of the major global motor vehicle manufacturers are now producing either EVs or PHEVs but only a few models are currently being sold in Australia. Presumably the range of electric vehicles available in Australia will increase when there is evidence of more widespread demand. I have only made passing reference in the book to fuel cell technology. Toyota in particular is promoting fuel cells as the best future technology for powering motor vehicles – it released its first fuel cell vehicle (FCV) in both Japan and the US in late June 2014.[116] While it appears that FC technology is at a much earlier stage of development than EV technology, it clearly cannot be ignored.

Urban air quality, particularly in China, is likely to be an increasing driver of electrification of transport in cities. Very large orders are now being reported for delivery of electric buses and taxis for cities in China.[117]

Battery science/technology is evolving very quickly and companies such as Tesla in the US and BYD in China are in the process of scaling up battery production levels with the expectation that battery prices will drop dramatically within a few years. These batteries are destined to be used both in EVs and in residential/commercial combined solar PV + battery storage systems – it seems that the technology around renewables and EVs are converging courtesy of battery advances.

Around the world the conventional approach of generating electricity in major power stations and then distributing this via extensive networks is under extreme pressure. For the private individual the option of generating the energy for the home and the car via solar panels and battery storage is looking increasingly feasible and attractive.

The energy independence offered by renewables makes them very alluring – this is not necessarily a good story for a major energy exporting country like Australia but it is inevitable that all countries will use renewables wherever possible even if this does incur some cost penalties. The attractiveness of using domestic based clean energy to run a country's transport and other systems rather than relying on imported coal, liquid fuels and gas is likely to be overwhelming for many States.

In recent times we've seen the incumbent electricity generators fighting a strong rearguard action against renewables as part of the RET review. It would be surprising if the oil companies don't take a similar stance against electric vehicles when the ICE/EV transition begins to gain some critical mass. It is ironic that in this circumstance there will be natural synergies between the electric car manufacturers and the electricity generators – maybe the electric car will prove to be the vehicle that gives the legacy electricity generators a soft landing as we transition to renewables. Interesting times!!

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[116] *Toyota Fuel Cell Sedan Makes US Debut Today.* Inside EVs. June 2014: http://insideevs.com/toyota-fuel-cell-sedan-makes-us-debut/

[117] *BYD Receives Record Bus and Taxi Order*. BYD. May 2014: http://www.byd.com/news/news-235.html

# APPENDIX

## A.1 Introduction

This appendix contains background information and data which has been used to generate many of the figures in the body of the report. It also contains other information which is associated with, but peripheral to, the arguments put forward in the main text.

Throughout the project I collected simple data, at least daily, about the energy used in my EV and in our house and about the output of my solar PV system(s). My data gathering essentially involved:

1) reading the house electricity meter and the total kWh reading on the inverter of my net metered solar PV system each day

2) reading the distance travelled and the car efficiency from the instrument panel in the EV at the end of each day (I reset these readings to zero each day once I had recorded the data)

3) placing a data logger on the circuit of my EV charger and on the AC output of my net metered solar PV system.

I routinely transferred the data to a master data sheet (the 'core datasheet') which contains the information aggregated to a daily level. The core datasheet is shown in *Figure A.1.*

## A.2 The Core Datasheet

*Figure A.1* is difficult to read at normal resolution but if the document is being read electronically it can be readily magnified to make it more or less legible. The datasheet contains five broad groups of data which are labelled on the top row:

1. Meter Reading
2. Net Metered Solar PV System
3. Generation and Consumption Data – Derived from Meter Readings
4. Data from Car Instrument Panel
5. EV Charger – Data from Dataloggger.

***Notes on the datasheet***

*Meter Reading*

These columns show the daily readings on my house ActewAGL electricity meter. I took these readings manually each morning.

*Net Metered Solar PV System*

The first column in this group shows the daily value of the total amount of electricity generated by the net metered PV system – this was read from a small data readout window on the inverter for my net metered solar system. This figure is not as accurate as the reading on my ActewAGL electricity meter for my gross solar PV system but cross checking between the readings showed very good agreement – both systems are 2kW.

The next three columns are simply derived from previous columns.

The net metered system was not installed until late February and therefore there was no data available for the first few weeks of the project (colour coded blue on the datasheet).

*Generation and Consumption Data – Derived from Meter Readings*

The figure for the daily capacity factor of the total solar system is the % of the total daily system capacity (96 kWh) that has been generated on any given day.

The data in all the other columns has simply been derived from the earlier columns (see note below about simulated data).

*Data from Car Instrument Panel*

The first two columns are readings that I took at the end of each day from the car instrument panel when I put my car in the garage and hooked it up for its daily charge.

The figures in the other two columns are derived from the previous two columns.

*EV Charger – Data from Dataloggger*

This data has been derived from the dataset I have built up using the datalogger on my charger circuit (see Appendix A.3).

***Notes on simulated data***

After the beginning of the project I made two key additions to the equipment I was using:

- In late February our net metering solar PV system was installed (see Section A.4)
- In late March I purchased a datalogger and installed a sensor on the circuit of my EV charger (see Section A.3).

This delayed implementation meant that I had an incomplete dataset for the energy used in charging the EV over the time of the project. I also only generated energy from the net metered PV system for about five months of the project period. In order to normalise the data, and produce a dataset which describes the system energy flows for the full seven month period, I generated simulated data for both the EV energy use and net metered PV solar output to fill in the gaps in the dataset from 1 January 2014.

The simulated data for the both the net PV solar system and the charger is shown on *Figure A.1* in the red coloured columns. The derivation of the simulated data is discussed in the next two Sections.

No data available. Net metered PV system installed: 24 Feb. Charger datalogger installed: 17 Mar.

Simulated data. See notes in text.

| Date | Meter Reading | | | | | Net Metered Solar PV System | | | | Generation & Consumption Data - Derived from Meter Readings | | | | | | | | Data from Car Instrument Panel | | | | EV Charger - Data from Datalogger | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Peak (kwh) | Shoulder (kWh) | Off-Peak (kWh) | Solar Ouput (Gross Tariff) (kWh) | Total Solar Export (Net Tariff) (kWh) | Inverter Total | Daily Generation (kWh) | Daily Export (kWh) | Daily % Exported | Daily Consumption (kWh) | Daily Generation [both systems- actual] (kWh) | Simulated Daily Generation (kWh) | Capacity Factor % | Cumulative Consumption (kWh) | Cumulative Generation [both systems - actual] (kWh) | Average Daily Consumption (kWh) | Average Total Daily Generation (Actual) (kWh) | EV Distance (km) | Efficiency (kWh/km) | EV Energy Use (kWh) | Cumulative EV Energy Use (kWh) | Charger Time (min) | Charger Input (kWh) | Cost of Charge ($) |
| 1/01/2014 | 2432 | 2434 | 2904 | 5723 | | | | | | 1 | 11 | 22 | 22.9 | 1 | 11 | 1.00 | 11.00 | | | | | | | |
| 2/01/2014 | 2432 | 2434 | 2905 | 5734 | | | | | | 1 | 11 | 22 | 22.9 | 2 | 22 | 1.00 | 11.00 | | | | | | | |
| 3/01/2014 | 2432 | 2434 | 2906 | 5745 | | | | | | 1 | 11 | 22 | 22.9 | 3 | 33 | 1.00 | 11.00 | | | | | | | |
| 4/01/2014 | 2432 | 2434 | 2907 | 5750 | | | | | | 1 | 5 | 10 | 10.4 | 4 | 38 | 1.00 | 9.50 | | | | | | | |
| 5/01/2014 | 2433 | 2435 | 2908 | 5763 | | | | | | 3 | 13 | 26 | 27.1 | 7 | 51 | 1.40 | 10.20 | | | | | | | |
| 6/01/2014 | 2433 | 2442 | 2909 | 5777 | | | | | | 8 | 14 | 28 | 29.2 | 15 | 65 | 2.50 | 10.83 | | | | | | | |
| 7/01/2014 | 2434 | 2447 | 2910 | 5790 | | | | | | 7 | 13 | 26 | 27.1 | 22 | 78 | 3.14 | 11.14 | | | | | | | |
| 8/01/2014 | 2434 | 2451 | 2910 | 5800 | | | | | | 4 | 10 | 20 | 20.8 | 26 | 88 | 3.25 | 11.00 | 27.6 | 0.14 | 3.86 | 3.86 | | 4.64 | |
| 9/01/2014 | 2446 | 2463 | 2911 | 5808 | | | | | | 25 | 8 | 16 | 16.7 | 51 | 96 | 5.67 | 10.67 | 145.5 | 0.14 | 20.37 | 24.23 | | 24.44 | |
| 10/01/2014 | 2454 | 2471 | 2912 | 5819 | | | | | | 17 | 11 | 22 | 22.9 | 68 | 107 | 6.80 | 10.70 | 101.8 | 0.14 | 14.25 | 38.49 | | 17.10 | |
| 11/01/2014 | 2455 | 2474 | 2913 | 5825 | | | | | | 5 | 6 | 12 | 12.5 | 73 | 113 | 6.64 | 10.27 | 8.8 | 0.14 | 1.23 | 39.72 | | 1.48 | |
| 12/01/2014 | 2456 | 2480 | 2914 | 5836 | | | | | | 8 | 11 | 22 | 22.9 | 81 | 124 | 6.75 | 10.33 | 69.7 | 0.14 | 9.76 | 49.48 | | 11.71 | |
| 13/01/2014 | 2457 | 2482 | 2915 | 5848 | | | | | | 4 | 12 | 24 | 25.0 | 85 | 136 | 6.54 | 10.46 | 11.2 | 0.14 | 1.57 | 51.04 | | 1.88 | |
| 14/01/2014 | 2457 | 2485 | 2916 | 5860 | | | | | | 4 | 12 | 24 | 25.0 | 89 | 148 | 6.36 | 10.57 | 16.1 | 0.14 | 2.25 | 53.30 | | 2.70 | |
| 15/01/2014 | 2458 | 2488 | 2918 | 5870 | | | | | | 6 | 10 | 20 | 20.8 | 95 | 158 | 6.33 | 10.53 | 24.3 | 0.14 | 3.40 | 56.70 | | 4.08 | |
| 16/01/2014 | 2461 | 2493 | 2919 | 5882 | | | | | | 9 | 12 | 24 | 25.0 | 104 | 170 | 6.50 | 10.63 | 30.4 | 0.14 | 4.26 | 60.96 | | 5.11 | |
| | | New House Meter | | | | | | | | | | | | | | | | | | | 60.96 | | | |
| 17/01/2014 | | 2 | 1 | 11 | | | | | | 3 | 11 | 22 | 22.9 | 107 | 181 | 6.29 | 10.06 | 34.2 | 0.13 | 4.45 | 65.41 | | 5.34 | |
| 18/01/2014 | 1 | 7 | 2 | 21 | | | | | | 7 | 10 | 20 | 20.8 | 114 | 191 | 6.33 | 10.05 | 11.1 | 0.16 | 1.78 | 67.18 | | 2.13 | |
| 19/01/2014 | 2 | 8 | 3 | 30 | | | | | | 3 | 9 | 18 | 18.8 | 117 | 200 | 6.16 | 10.00 | 32.7 | 0.12 | 3.92 | 71.11 | | 4.71 | |
| 20/01/2014 | 6 | 10 | 4 | 38 | | | | | | 7 | 8 | 16 | 16.7 | 124 | 208 | 6.20 | 9.90 | 30.3 | 0.14 | 4.24 | 75.35 | | 5.09 | |
| 21/01/2014 | 10 | 15 | 6 | 48 | | | | | | 11 | 10 | 20 | 20.8 | 135 | 218 | 6.43 | 9.91 | 21.7 | 0.12 | 2.60 | 77.95 | | 3.12 | |
| 22/01/2014 | 11 | 18 | 7 | 58 | | | | | | 5 | 10 | 20 | 20.8 | 140 | 228 | 6.36 | 9.91 | 23.3 | 0.13 | 3.03 | 80.98 | | 3.63 | |
| 23/01/2014 | 12 | 18 | 8 | 70 | | | | | | 2 | 12 | 24 | 25.0 | 142 | 240 | 6.17 | 10.00 | 17.8 | 0.14 | 2.49 | 83.47 | | 2.99 | |
| 24/01/2014 | 13 | 25 | 9 | 74 | | | | | | 9 | 4 | 8 | 8.3 | 151 | 244 | 6.29 | 9.76 | 9.1 | 0.16 | 1.46 | 84.93 | | 1.75 | |
| 25/01/2014 | 13 | 29 | 10 | 86 | | | | | | 5 | 12 | 24 | 25.0 | 156 | 256 | 6.24 | 9.85 | 35 | 0.14 | 4.90 | 89.83 | | 5.88 | |
| 26/01/2014 | 14 | 33 | 11 | 98 | | | | | | 6 | 12 | 24 | 25.0 | 162 | 268 | 6.23 | 9.93 | 26.7 | 0.15 | 4.01 | 93.83 | | 4.81 | |
| 27/01/2014 | 14 | 41 | 12 | 110 | | | | | | 9 | 12 | 24 | 25.0 | 171 | 280 | 6.33 | 10.00 | 62.8 | 0.14 | 8.79 | 102.63 | | 10.55 | |
| 28/01/2014 | 15 | 41 | 13 | 123 | | | | | | 2 | 13 | 26 | 27.1 | 173 | 293 | 6.18 | 10.10 | 62.8 | 0.14 | 8.79 | 111.42 | | 10.55 | |
| 29/01/2014 | 16 | 47 | 14 | 133 | | | | | | 8 | 10 | 20 | 20.8 | 181 | 303 | 6.24 | 10.10 | | | | 111.42 | | | |
| 30/01/2014 | 22 | 54 | 16 | 145 | | | | | | 15 | 12 | 24 | 25.0 | 196 | 315 | 6.53 | 10.16 | 60.9 | 0.14 | 9.79 | 121.20 | | 11.74 | |
| 31/01/2014 | 23 | 62 | 17 | 153 | | | | | | 10 | 8 | 16 | 16.7 | 206 | 323 | 6.65 | 10.09 | 42.1 | 0.13 | 5.47 | 126.68 | | 6.57 | |
| 1/02/2014 | 27 | 70 | 18 | 163 | | | | | | 13 | 10 | 20 | 20.8 | 219 | 333 | 6.84 | 10.09 | 54.3 | 0.13 | 7.06 | 133.74 | | 8.47 | |
| 2/02/2014 | 28 | 71 | 20 | 174 | | | | | | 4 | 11 | 22 | 22.9 | 223 | 344 | 6.76 | 10.12 | 70.7 | 0.13 | 9.19 | 142.93 | | 11.03 | |
| 3/02/2014 | 29 | 77 | 21 | 185 | | | | | | 8 | 11 | 22 | 22.9 | 231 | 355 | 6.79 | 10.14 | 46.5 | 0.14 | 6.51 | 149.44 | | 7.81 | |
| 4/02/2014 | 30 | 84 | 23 | 190 | | | | | | 10 | 5 | 10 | 10.4 | 241 | 360 | 6.89 | 10.00 | 47.4 | 0.13 | 6.16 | 155.60 | | 7.39 | |
| 5/02/2014 | 31 | 96 | 28 | 200 | | | | | | 18 | 10 | 20 | 20.8 | 259 | 370 | 7.19 | 10.00 | 78.4 | 0.13 | 10.19 | 165.79 | | 12.23 | |
| 6/02/2014 | 35 | 102 | 29 | 212 | | | | | | 11 | 12 | 24 | 25.0 | 270 | 382 | 7.30 | 10.05 | 88 | 0.13 | 11.44 | 177.23 | | 13.73 | |
| 7/02/2014 | 36 | 111 | 31 | 224 | | | | | | 12 | 12 | 24 | 25.0 | 282 | 394 | 7.42 | 10.10 | 67.9 | 0.13 | 8.83 | 186.06 | | 10.59 | |
| 8/02/2014 | 37 | 116 | 32 | 235 | | | | | | 7 | 11 | 22 | 22.9 | 289 | 405 | 7.41 | 10.13 | 30.2 | 0.14 | 4.23 | 190.29 | | 5.07 | |
| 9/02/2014 | 38 | 122 | 34 | 246 | | | | | | 9 | 11 | 22 | 22.9 | 298 | 416 | 7.45 | 10.15 | 37.7 | 0.13 | 4.90 | 195.19 | | 5.88 | |
| 10/02/2014 | 44 | 126 | 35 | 257 | | | | | | 11 | 11 | 22 | 22.9 | 309 | 427 | 7.54 | 10.17 | 63.7 | 0.13 | 8.28 | 203.47 | | 9.94 | |
| 11/02/2014 | 45 | 136 | 36 | 268 | | | | | | 12 | 11 | 22 | 22.9 | 321 | 438 | 7.64 | 10.19 | 70 | 0.13 | 9.10 | 212.57 | | 10.92 | |
| 12/02/2014 | 45 | 142 | 38 | 278 | | | | | | 8 | 10 | 20 | 20.8 | 329 | 448 | 7.65 | 10.18 | 43.6 | 0.13 | 5.67 | 218.24 | | 6.80 | |
| 13/02/2014 | 46 | 153 | 38 | 284 | | | | | | 12 | 6 | 12 | 12.5 | 341 | 454 | 7.75 | 10.09 | 69.4 | 0.13 | 9.02 | 227.26 | | 10.83 | |
| 14/02/2014 | 47 | 160 | 39 | 290 | | | | | | 9 | 6 | 12 | 12.5 | 350 | 460 | 7.78 | 10.00 | 36.9 | 0.13 | 4.80 | 232.06 | | 5.76 | |
| 15/02/2014 | 53 | 163 | 40 | 292 | | | | | | 10 | 2 | 4 | 4.2 | 360 | 462 | 7.83 | 9.83 | 27.1 | 0.15 | 4.07 | 236.12 | | 4.88 | |
| 16/02/2014 | 55 | 165 | 42 | 297 | | | | | | 6 | 5 | 10 | 10.4 | 366 | 467 | 7.79 | 9.73 | 17.3 | 0.15 | 2.60 | 238.72 | | 3.11 | |
| 17/02/2014 | 59 | 169 | 43 | 308 | | | | | | 9 | 11 | 22 | 22.9 | 375 | 478 | 7.81 | 9.76 | 45.3 | 0.12 | 5.44 | 244.15 | | 6.52 | |
| 18/02/2014 | 60 | 175 | 44 | 317 | | | | | | 8 | 9 | 18 | 18.8 | 383 | 487 | 7.82 | 9.74 | 40.2 | 0.12 | 4.82 | 248.98 | | 5.79 | |
| 19/02/2014 | 61 | 183 | 45 | 322 | | | | | | 10 | 5 | 10 | 10.4 | 393 | 492 | 7.86 | 9.65 | 43.2 | 0.14 | 6.05 | 255.02 | | 7.26 | |
| 20/02/2014 | 62 | 188 | 47 | 334 | | | | | | 8 | 12 | 24 | 25.0 | 401 | 504 | 7.86 | 9.69 | 32.2 | 0.13 | 4.19 | 259.21 | | 5.02 | |
| 21/02/2014 | 64 | 198 | 48 | 346 | | | | | | 13 | 12 | 24 | 25.0 | 414 | 516 | 7.96 | 9.74 | 76.5 | 0.13 | 9.95 | 269.15 | | 11.93 | |
| 22/02/2014 | 65 | 204 | 49 | 357 | | | | | | 8 | 11 | 22 | 22.9 | 422 | 527 | 7.96 | 9.76 | 41.3 | 0.13 | 5.37 | 274.52 | | 6.44 | |
| 23/02/2014 | 66 | 205 | 50 | 367 | | | | | | 3 | 10 | 20 | 20.8 | 425 | 537 | 7.87 | 9.76 | 2.2 | 0.15 | 0.33 | 274.85 | | 0.40 | |
| 24/02/2014 | 73 | 210 | 52 | 378 | 9 | 11 | 11 | 9 | 81.8 | 14 | 22 | 22 | 22.9 | 439 | 559 | 7.98 | 9.98 | 63.2 | 0.13 | 8.22 | 283.07 | | 9.86 | |
| 25/02/2014 | 74 | 211 | 62 | 389 | 19 | 23 | 12 | 10 | 83.3 | 12 | 23 | 23 | 24.0 | 451 | 582 | 8.05 | 10.21 | 55.7 | 0.13 | 7.24 | 290.31 | | 8.69 | |
| 26/02/2014 | 74 | 211 | 74 | 394 | 24 | 29 | 6 | 5 | 83.3 | 12 | 11 | 11 | 11.5 | 463 | 593 | 8.12 | 10.22 | 39.4 | 0.14 | 5.52 | 295.83 | | 6.62 | |
| 27/02/2014 | 76 | 212 | 85 | 399 | 28 | 34 | 5 | 4 | 80.0 | 14 | 10 | 10 | 10.4 | 477 | 603 | 8.22 | 10.22 | 68.6 | 0.14 | 9.60 | 305.43 | | 11.52 | |
| 28/02/2014 | 76 | 219 | 95 | 402 | 30 | 37 | 3 | 2 | 66.7 | 17 | 6 | 6 | 6.3 | 494 | 609 | 8.37 | 10.15 | 81.5 | 0.15 | 12.23 | 317.66 | | 14.67 | |
| 1/03/2014 | 78 | 221 | 100 | 404 | 31 | 41 | 4 | 1 | 25.0 | 9 | 6 | 6 | 6.3 | 503 | 615 | 8.38 | 10.08 | 17.9 | 0.21 | 3.76 | 321.41 | | 4.51 | |
| 2/03/2014 | 79 | 221 | 109 | 413 | 40 | 50 | 9 | 9 | 100.0 | 10 | 18 | 18 | 18.8 | 513 | 633 | 8.41 | 10.21 | 42 | 0.15 | 6.30 | 327.71 | | 7.56 | |
| 3/03/2014 | 79 | 222 | 117 | 424 | 50 | 62 | 12 | 10 | 83.3 | 9 | 23 | 23 | 24.0 | 522 | 656 | 8.42 | 10.41 | 40.2 | 0.13 | 5.23 | 332.94 | | 6.27 | |
| 4/03/2014 | 80 | 223 | 127 | 434 | 59 | 72 | 10 | 9 | 90.0 | 12 | 20 | 20 | 20.8 | 534 | 676 | 8.48 | 10.56 | 58 | 0.12 | 6.96 | 339.90 | | 8.35 | |

**Figure A.1: The core datasheet**

| | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5/03/2014 | 81 | 223 | 138 | 441 | 65 | 79 | 7 | 6 | 85.7 | 12 | 14 | 14 | 14.6 | 546 | 690 | 8.53 | 10.62 | 38.5 | 0.13 | 5.01 | 344.91 | | 6.01 | |
| 6/03/2014 | 82 | 224 | 147 | 449 | 73 | 89 | 10 | 8 | 80.0 | 11 | 18 | 18 | 18.8 | 557 | 708 | 8.57 | 10.73 | 67.1 | 0.13 | 8.72 | 353.628 | | 10.47 | |
| 7/03/2014 | 82 | 225 | 158 | 459 | 82 | 100 | 11 | 9 | 81.8 | 12 | 21 | 21 | 21.9 | 569 | 729 | 8.62 | 10.88 | 59.1 | 0.13 | 7.68 | 361.311 | | 9.22 | |
| 8/03/2014 | 84 | 225 | 169 | 465 | 87 | 106 | 6 | 5 | 83.3 | 13 | 12 | 12 | 12.5 | 582 | 741 | 8.69 | 10.90 | 36.8 | 0.15 | 5.52 | 366.831 | | 6.62 | |
| 9/03/2014 | 85 | 229 | 179 | 472 | 92 | 114 | 8 | 5 | 62.5 | 15 | 15 | 15 | 15.6 | 597 | 756 | 8.78 | 10.96 | 119.5 | 0.13 | 15.54 | 382.366 | | 18.64 | |
| 10/03/2014 | 86 | 230 | 186 | 482 | 101 | 125 | 11 | 9 | 81.8 | 9 | 21 | 21 | 21.9 | 606 | 777 | 8.78 | 11.10 | 33.5 | 0.13 | 4.36 | 386.721 | | 5.23 | |
| 11/03/2014 | 87 | 231 | 195 | 489 | 107 | 133 | 8 | 6 | 75.0 | 11 | 15 | 15 | 15.6 | 617 | 792 | 8.81 | 11.15 | 52.4 | 0.12 | 6.29 | 393.009 | | 7.55 | |
| 12/03/2014 | 87 | 232 | 210 | 497 | 114 | 141 | 8 | 7 | 87.5 | 16 | 16 | 16 | 16.7 | 633 | 808 | 8.92 | 11.22 | 67.1 | 0.12 | 8.05 | 401.061 | | 9.66 | |
| 13/03/2014 | 88 | 232 | 217 | 503 | 120 | 149 | 8 | 6 | 75.0 | 8 | 14 | 14 | 14.6 | 641 | 822 | 8.90 | 11.26 | 48.9 | 0.14 | 6.85 | 407.907 | | 8.22 | |
| 14/03/2014 | 89 | 237 | 225 | 511 | 127 | 157 | 8 | 7 | 87.5 | 14 | 16 | 16 | 16.7 | 655 | 838 | 8.97 | 11.32 | 79.9 | 0.13 | 10.39 | 418.294 | | 12.46 | |
| 15/03/2014 | 89 | 237 | 235 | 518 | 132 | 164 | 7 | 5 | 71.4 | 10 | 14 | 14 | 14.6 | 665 | 852 | 8.99 | 11.36 | 48.4 | 0.14 | 6.78 | 425.07 | | 8.13 | |
| 16/03/2014 | 90 | 238 | 236 | 526 | 139 | 172 | 8 | 7 | 87.5 | 3 | 16 | 16 | 16.7 | 668 | 868 | 8.91 | 11.42 | | | | 425.07 | | | |
| 17/03/2014 | 91 | 239 | 247 | 535 | 146 | 182 | 10 | 7 | 70.0 | 13 | 19 | 19 | 19.8 | 681 | 887 | 8.96 | 11.52 | 56.5 | 0.13 | 7.35 | 432.415 | 119.83 | 7.29 | 1.03 |
| 18/03/2014 | 92 | 239 | 254 | 544 | 155 | 192 | 10 | 9 | 90.0 | 8 | 19 | 19 | 19.8 | 689 | 906 | 8.95 | 11.62 | 39.2 | 0.13 | 5.10 | 437.511 | 132.83 | 8.04 | 1.13 |
| 19/03/2014 | 93 | 240 | 269 | 554 | 164 | 202 | 10 | 9 | 90.0 | 17 | 20 | 20 | 20.8 | 706 | 926 | 9.05 | 11.72 | 65.7 | 0.13 | 8.54 | 446.052 | 119.83 | 7.28 | 1.03 |
| 20/03/2014 | 95 | 240 | 272 | 562 | 171 | 210 | 8 | 7 | 87.5 | 5 | 16 | 16 | 16.7 | 711 | 942 | 9.00 | 11.78 | 32.3 | 0.13 | 4.20 | 450.251 | 145.50 | 8.35 | 1.18 |
| 21/03/2014 | 96 | 245 | 277 | 569 | 177 | 219 | 9 | 6 | 66.7 | 11 | 16 | 16 | 16.7 | 722 | 958 | 9.03 | 11.83 | 63.7 | 0.14 | 8.92 | 459.169 | 172.33 | 10.46 | 1.79 |
| 22/03/2014 | 97 | 246 | 285 | 578 | 185 | 228 | 9 | 8 | 88.9 | 10 | 18 | 18 | 18.8 | 732 | 976 | 9.04 | 11.90 | 34 | 0.14 | 4.76 | 463.929 | 100.00 | 6.06 | 0.85 |
| 23/03/2014 | 98 | 247 | 286 | 586 | 192 | 236 | 8 | 7 | 87.5 | 3 | 16 | 16 | 16.7 | 735 | 992 | 8.96 | 11.95 | | | | 463.929 | | | |
| 24/03/2014 | 99 | 248 | 295 | 588 | 193 | 238 | 2 | 1 | 50.0 | 11 | 4 | 4 | 4.2 | 746 | 996 | 8.99 | 11.86 | 40.3 | 0.17 | 6.85 | 470.78 | 120.00 | 7.28 | 1.02 |
| 25/03/2014 | 100 | 249 | 307 | 592 | 196 | 242 | 4 | 3 | 75.0 | 14 | 8 | 8 | 8.3 | 760 | 1004 | 9.05 | 11.81 | 59.1 | 0.14 | 8.27 | 479.054 | 137.83 | 8.33 | 1.17 |
| 26/03/2014 | 101 | 250 | 320 | 593 | 197 | 244 | 2 | 1 | 50.0 | 15 | 3 | 3 | 3.1 | 775 | 1007 | 9.12 | 11.71 | 43.4 | 0.14 | 6.08 | 485.13 | 165.67 | 10.04 | 1.41 |
| 27/03/2014 | 102 | 250 | 326 | 596 | 198 | 247 | 3 | 1 | 33.3 | 7 | 6 | 6 | 6.3 | 782 | 1013 | 9.09 | 11.64 | 47.4 | 0.15 | 7.11 | 492.24 | 150.83 | 9.09 | 1.28 |
| 28/03/2014 | 102 | 252 | 339 | 597 | 199 | 249 | 2 | 1 | 50.0 | 15 | 3 | 3 | 3.1 | 797 | 1016 | 9.16 | 11.55 | 58.3 | 0.16 | 9.33 | 501.568 | 120.00 | 7.29 | 1.03 |
| 29/03/2014 | 104 | 253 | 350 | 603 | 204 | 256 | 7 | 5 | 71.4 | 14 | 13 | 13 | 13.5 | 811 | 1029 | 9.22 | 11.56 | 54.7 | 0.15 | 8.21 | 509.773 | 184.00 | 11.18 | 1.57 |
| 30/03/2014 | 106 | 254 | 357 | 607 | 208 | 260 | 4 | 4 | 100.0 | 10 | 8 | 8 | 8.3 | 821 | 1037 | 9.22 | 11.52 | 25.6 | 0.15 | 3.84 | 513.613 | 130.00 | 7.89 | 1.11 |
| 31/03/2014 | 108 | 255 | 365 | 616 | 215 | 269 | 9 | 7 | 77.8 | 11 | 18 | 18 | 18.8 | 832 | 1055 | 9.24 | 11.59 | 39.3 | 0.13 | 5.11 | 518.722 | 104.33 | 6.33 | 0.89 |
| 1/04/2014 | 109 | 255 | 372 | 622 | 220 | 275 | 6 | 5 | 83.3 | 8 | 12 | 12 | 12.5 | 840 | 1067 | 9.23 | 11.60 | 39 | 0.12 | 4.68 | 523.402 | 100.83 | 6.11 | 0.86 |
| 2/04/2014 | 110 | 256 | 383 | 630 | 227 | 283 | 8 | 7 | 87.5 | 13 | 16 | 16 | 16.7 | 853 | 1083 | 9.27 | 11.65 | 38.8 | 0.12 | 4.66 | 528.058 | 120.17 | 7.29 | 1.03 |
| 3/04/2014 | 110 | 257 | 392 | 634 | 231 | 287 | 4 | 4 | 100.0 | 10 | 8 | 8 | 8.3 | 863 | 1091 | 9.28 | 11.61 | 66.7 | 0.13 | 8.67 | 536.729 | 163.50 | 9.39 | 1.32 |
| 4/04/2014 | 112 | 258 | 403 | 635 | 232 | 288 | 1 | 1 | 100.0 | 14 | 2 | 2 | 2.1 | 877 | 1093 | 9.33 | 11.51 | 45.3 | 0.17 | 7.70 | 544.43 | 127.67 | 7.72 | 1.09 |
| 5/04/2014 | 112 | 259 | 404 | 639 | 235 | 291 | 3 | 3 | 100.0 | 2 | 7 | 7 | 7.3 | 879 | 1100 | 9.25 | 11.46 | | | | 544.43 | 37.67 | 2.27 | 0.32 |
| 6/04/2014 | 113 | 260 | 405 | 644 | 240 | 299 | 8 | 5 | 62.5 | 3 | 13 | 13 | 13.5 | 882 | 1113 | 9.19 | 11.47 | | | | 544.43 | | | |
| 7/04/2014 | 114 | 261 | 415 | 650 | 246 | 307 | 8 | 6 | 75.0 | 12 | 14 | 14 | 14.6 | 894 | 1127 | 9.22 | 11.50 | 50 | 0.14 | 7.00 | 551.43 | 60.17 | 3.65 | 0.51 |
| 8/04/2014 | 117 | 265 | 424 | 657 | 251 | 313 | 6 | 5 | 83.3 | 16 | 13 | 13 | 13.5 | 910 | 1140 | 9.29 | 11.52 | 77.2 | 0.14 | 10.81 | 562.238 | 250.67 | 15.20 | 2.60 |
| 9/04/2014 | 119 | 266 | 435 | 660 | 254 | 316 | 3 | 3 | 100.0 | 14 | 6 | 6 | 6.3 | 924 | 1146 | 9.33 | 11.46 | 38.8 | 0.13 | 5.04 | 567.282 | 119.67 | 7.27 | 1.02 |
| 10/04/2014 | 121 | 267 | 439 | 661 | 254 | 318 | 2 | | | 7 | 3 | 3 | 3.1 | 931 | 1149 | 9.31 | 11.38 | 32.4 | 0.15 | 4.86 | 572.142 | 156.50 | 9.11 | 1.28 |
| 11/04/2014 | 125 | 271 | 446 | 665 | 258 | 323 | 5 | 4 | 80.0 | 15 | 9 | 9 | 9.4 | 946 | 1158 | 9.37 | 11.35 | 64 | 0.15 | 9.60 | 581.742 | 160.33 | 9.72 | 1.88 |
| 12/04/2014 | 128 | 276 | 447 | 673 | 263 | 331 | 8 | 5 | 62.5 | 9 | 16 | 16 | 16.7 | 955 | 1174 | 9.36 | 11.40 | 40 | 0.15 | 6.00 | 587.742 | 140.33 | 8.44 | 1.52 |
| 13/04/2014 | 130 | 277 | 454 | 681 | 269 | 339 | 8 | 6 | 75.0 | 10 | 16 | 16 | 16.7 | 965 | 1190 | 9.37 | 11.44 | 29.7 | 0.14 | 4.16 | 591.9 | 60.17 | 3.66 | 0.51 |
| 14/04/2014 | 133 | 278 | 462 | 688 | 276 | 346 | 7 | 7 | 100.0 | 12 | 14 | 14 | 14.6 | 977 | 1204 | 9.39 | 11.47 | 42.4 | 0.13 | 5.51 | 597.412 | 103.67 | 6.28 | 0.88 |
| 15/04/2014 | 134 | 280 | 466 | 694 | 281 | 352 | 6 | 5 | 83.3 | 7 | 12 | 12 | 12.5 | 984 | 1216 | 9.37 | 11.47 | 9.1 | 0.16 | 1.46 | 598.868 | 90.67 | 5.50 | 0.77 |
| 16/04/2014 | 137 | 281 | 475 | 701 | 287 | 360 | 8 | 6 | 75.0 | 13 | 15 | 15 | 15.6 | 997 | 1231 | 9.41 | 11.50 | 28.6 | 0.14 | 4.00 | 602.872 | 60.33 | 3.66 | 0.52 |
| 17/04/2014 | 140 | 283 | 480 | 709 | 294 | 368 | 8 | 7 | 87.5 | 10 | 16 | 16 | 16.7 | 1007 | 1247 | 9.41 | 11.55 | 36.1 | 0.14 | 5.05 | 607.926 | 132.67 | 7.43 | 1.05 |
| 18/04/2014 | 141 | 285 | 486 | 715 | 299 | 375 | 7 | 5 | 71.4 | 9 | 13 | 13 | 13.5 | 1016 | 1260 | 9.41 | 11.56 | 28.4 | 0.15 | 4.26 | 612.186 | 60.33 | 3.65 | 0.51 |
| 19/04/2014 | 143 | 287 | 497 | 723 | 306 | 383 | 8 | 7 | 87.5 | 15 | 16 | 16 | 16.7 | 1031 | 1276 | 9.46 | 11.60 | 29.5 | 0.16 | 4.72 | 616.906 | 86.17 | 5.22 | 0.73 |
| 20/04/2014 | 144 | 289 | 510 | 732 | 313 | 391 | 8 | 7 | 87.5 | 16 | 17 | 17 | 17.7 | 1047 | 1293 | 9.52 | 11.65 | 96.2 | 0.13 | 12.51 | 629.412 | 161.67 | 9.34 | 1.31 |
| 21/04/2014 | 148 | 291 | 511 | 738 | 318 | 397 | 6 | 5 | 83.3 | 7 | 12 | 12 | 12.5 | 1054 | 1305 | 9.50 | 11.65 | | | | 629.412 | 132.50 | 8.02 | 1.13 |
| 22/04/2014 | 148 | 292 | 512 | 745 | 324 | 404 | 7 | 6 | 85.7 | 2 | 14 | 14 | 14.6 | 1056 | 1319 | 9.43 | 11.67 | | | | 629.412 | | | |
| 23/04/2014 | 149 | 292 | 513 | 750 | 328 | 409 | 5 | 4 | 80.0 | 2 | 10 | 10 | 10.4 | 1058 | 1329 | 9.36 | 11.66 | | | | 629.412 | | | |
| 24/04/2014 | 149 | 293 | 513 | 757 | 334 | 416 | 7 | 6 | 85.7 | 1 | 14 | 14 | 14.6 | 1059 | 1343 | 9.29 | 11.68 | | | | 629.412 | | | |
| 25/04/2014 | 150 | 294 | 514 | 760 | 338 | 420 | 4 | 4 | 100.0 | 3 | 7 | 7 | 7.3 | 1062 | 1350 | 9.23 | 11.64 | | | | 629.412 | | | |
| 26/04/2014 | 151 | 295 | 521 | 765 | 341 | 425 | 5 | 3 | 60.0 | 9 | 10 | 10 | 10.4 | 1071 | 1360 | 9.23 | 11.62 | 23.6 | 0.17 | 4.01 | 633.424 | 60.50 | 3.68 | 0.52 |
| 27/04/2014 | 153 | 297 | 532 | 767 | 343 | 428 | 3 | 2 | 66.7 | 15 | 5 | 5 | 5.2 | 1086 | 1365 | 9.28 | 11.57 | 52 | 0.14 | 7.28 | 640.704 | 88.67 | 5.39 | 0.76 |
| 28/04/2014 | 155 | 298 | 540 | 774 | 349 | 435 | 7 | 6 | 85.7 | 11 | 14 | 14 | 14.6 | 1097 | 1379 | 9.30 | 11.59 | 38.4 | 0.12 | 4.61 | 645.312 | 151.33 | 9.16 | 1.29 |
| 29/04/2014 | 157 | 300 | 550 | 778 | 352 | 439 | 4 | 3 | 75.0 | 14 | 8 | 8 | 8.3 | 1111 | 1387 | 9.34 | 11.56 | 50.3 | 0.14 | 7.04 | 652.354 | 107.83 | 6.53 | 0.92 |
| 30/04/2014 | 159 | 302 | 562 | 785 | 358 | 446 | 7 | 6 | 85.7 | 16 | 14 | 14 | 14.6 | 1127 | 1401 | 9.39 | 11.58 | 49 | 0.13 | 6.37 | 658.724 | 138.00 | 8.40 | 1.18 |
| 1/05/2014 | 162 | 304 | 573 | 792 | 364 | 453 | 7 | 6 | 85.7 | 16 | 14 | 14 | 14.6 | 1143 | 1415 | 9.45 | 11.60 | 67.2 | 0.14 | 9.41 | 668.132 | 182.33 | 10.78 | 1.52 |
| 2/05/2014 | 164 | 309 | 586 | 797 | 369 | 458 | 5 | 5 | 100.0 | 20 | 10 | 10 | 10.4 | 1163 | 1425 | 9.53 | 11.59 | 78.2 | 0.16 | 12.51 | 680.644 | 219.17 | 13.37 | 2.19 |
| 3/05/2014 | 168 | 313 | 598 | 799 | 370 | 461 | 3 | 1 | 33.3 | 20 | 5 | 5 | 5.2 | 1183 | 1430 | 9.62 | 11.53 | 44.3 | 0.19 | 8.42 | 689.061 | 178.83 | 10.85 | 1.53 |
| 4/05/2014 | 171 | 315 | 605 | 805 | 374 | 466 | 5 | 4 | 80.0 | 12 | 11 | 11 | 11.5 | 1195 | 1441 | 9.64 | 11.53 | 28.6 | 0.15 | 4.29 | 693.351 | 173.33 | 10.52 | 1.48 |
| 5/05/2014 | 174 | 317 | 616 | 812 | 380 | 473 | 7 | 6 | 85.7 | 16 | 14 | 14 | 14.6 | 1211 | 1455 | 9.69 | 11.55 | 53.2 | 0.13 | 6.92 | 700.267 | 92.67 | 5.62 | 0.79 |
| 6/05/2014 | 176 | 318 | 624 | 818 | 385 | 479 | 6 | 5 | 83.3 | 11 | 12 | 12 | 12.5 | 1222 | 1467 | 9.70 | 11.55 | 40.3 | 0.13 | 5.24 | 705.506 | 144.00 | 8.72 | 1.23 |
| 7/05/2014 | 178 | 320 | 635 | 825 | 391 | 485 | 6 | 6 | 100.0 | 15 | 13 | 13 | 13.5 | 1237 | 1480 | 9.74 | 11.56 | 36.2 | 0.13 | 4.71 | 710.212 | 106.83 | 6.48 | 0.91 |
| 8/05/2014 | 180 | 322 | 640 | 832 | 397 | 492 | 7 | 6 | 85.7 | 9 | 14 | 14 | 14.6 | 1246 | 1494 | 9.73 | 11.58 | 38.2 | 0.13 | 4.97 | 715.178 | 154.83 | 8.60 | 1.21 |
| 9/05/2014 | 182 | 324 | 653 | 837 | 402 | 497 | 5 | 5 | 100.0 | 17 | 10 | 10 | 10.4 | 1263 | 1504 | 9.79 | 11.57 | 68.2 | 0.13 | 8.87 | 724.044 | 60.67 | 3.69 | 0.52 |
| 10/05/2014 | 185 | 325 | 664 | 839 | 403 | 499 | 2 | 1 | 50.0 | 15 | 4 | 4 | 4.2 | 1278 | 1508 | 9.83 | 11.51 | 70 | 0.15 | 10.50 | 734.544 | 177.67 | 10.80 | 1.52 |
| 11/05/2014 | 187 | 327 | 670 | 845 | 408 | 505 | 6 | 5 | 83.3 | 10 | 12 | 12 | 12.5 | 1288 | 1520 | 9.83 | 11.52 | 22.4 | 0.15 | 3.36 | 737.904 | 160.83 | 9.80 | 1.38 |
| 12/05/2014 | 189 | 329 | 679 | 851 | 412 | 511 | 6 | 4 | 66.7 | 13 | 12 | 12 | 12.5 | 1301 | 1532 | 9.86 | 11.52 | 40.4 | 0.13 | 5.25 | 743.156 | 74.17 | 4.52 | 0.64 |
| 13/05/2014 | 191 | 331 | 688 | 858 | 418 | 517 | 6 | 6 | 100.0 | 13 | 13 | 13 | 13.5 | 1314 | 1545 | 9.88 | 11.53 | 41 | 0.13 | 5.33 | 748.486 | 107.33 | 6.54 | 0.92 |
| 14/05/2014 | 193 | 333 | 701 | 864 | 423 | 523 | 6 | 5 | 83.3 | 17 | 12 | 12 | 12.5 | 1331 | 1557 | 9.93 | 11.53 | 48.9 | 0.13 | 6.36 | 754.843 | 108.83 | 6.62 | 0.93 |
| 15/05/2014 | 197 | 335 | 705 | 870 | 428 | 529 | 6 | 5 | 83.3 | 10 | 12 | 12 | 12.5 | 1341 | 1569 | 9.93 | 11.54 | 32.3 | 0.13 | 4.20 | 759.042 | 175.50 | 9.98 | 1.40 |
| 16/05/2014 | 198 | 337 | 716 | 877 | 433 | 535 | 6 | 5 | 83.3 | 14 | 13 | 13 | 13.5 | 1355 | 1582 | 9.96 | 11.55 | 58.8 | 0.14 | 8.23 | 767.274 | 60.83 | 3.71 | 0.52 |
| 17/05/2014 | 201 | 339 | 730 | 882 | 437 | 540 | 5 | 4 | 80.0 | 19 | 10 | 10 | 10.4 | 1374 | 1592 | 10.03 | 11.54 | 43.7 | 0.16 | 6.99 | 774.266 | 211.17 | 12.87 | 1.81 |
| 18/05/2014 | 203 | 340 | 744 | 886 | 439 | 544 | 4 | 2 | 50.0 | 17 | 8 | 8 | 8.3 | 1391 | 1600 | 10.08 | 11.51 | 93.6 | 0.14 | 13.10 | 787.37 | 285.00 | 16.62 | 2.55 |

**Figure A.1 (continued): The core datasheet**

| | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 19/05/2014 | 206 | 343 | 753 | 891 | 444 | 549 | 5 | 5 | 100.0 | 15 | 10 | 10 | 10.4 | 1406 | 1610 | 10.12 | 11.50 | 38.5 | 0.13 | 5.01 | 792.375 | 141.00 | 8.56 | 1.39 |
| 20/05/2014 | 208 | 345 | 762 | 896 | 448 | 554 | 5 | 4 | 80.0 | 13 | 10 | 10 | 10.4 | 1419 | 1620 | 10.14 | 11.49 | 40.2 | 0.13 | 5.23 | 797.601 | 110.33 | 6.70 | 1.13 |
| 21/05/2014 | 210 | 346 | 774 | 902 | 452 | 559 | 5 | 4 | 80.0 | 15 | 11 | 11 | 11.5 | 1434 | 1631 | 10.17 | 11.49 | 39.9 | 0.14 | 5.59 | 803.187 | 175.17 | 9.94 | 1.59 |
| 22/05/2014 | 213 | 348 | 786 | 907 | 457 | 564 | 5 | 5 | 100.0 | 17 | 10 | 10 | 10.4 | 1451 | 1641 | 10.22 | 11.48 | 72 | 0.14 | 10.08 | 813.267 | 158.67 | 9.68 | 1.55 |
| 23/05/2014 | 215 | 350 | 796 | 914 | 462 | 570 | 6 | 5 | 83.3 | 14 | 13 | 13 | 13.5 | 1465 | 1654 | 10.24 | 11.49 | 50.2 | 0.13 | 6.53 | 819.793 | 135.50 | 8.23 | 1.35 |
| 24/05/2014 | 219 | 353 | 805 | 917 | 465 | 574 | 4 | 3 | 75.0 | 16 | 7 | 7 | 7.3 | 1481 | 1661 | 10.28 | 11.46 | 41.8 | 0.15 | 6.27 | 826.063 | 128.83 | 7.81 | 1.29 |
| 25/05/2014 | 220 | 355 | 807 | 921 | 467 | 577 | 3 | 2 | 66.7 | 5 | 7 | 7 | 7.3 | 1486 | 1668 | 10.25 | 11.42 | | | | 826.063 | | | |
| 26/05/2014 | 223 | 356 | 815 | 926 | 471 | 583 | 6 | 4 | 66.7 | 12 | 11 | 11 | 11.46 | 1498 | 1679 | 10.26 | 11.42 | 40.2 | 0.12 | 4.82 | 830.887 | 105.17 | 6.39 | 1.09 |
| 27/05/2014 | 226 | 359 | 823 | 929 | 473 | 585 | 2 | 2 | 100.0 | 14 | 5 | 5 | 5.21 | 1512 | 1684 | 10.29 | 11.38 | 39.4 | 0.14 | 5.52 | 836.403 | 113.50 | 6.94 | 1.17 |
| 28/05/2014 | 229 | 360 | 841 | 932 | 476 | 588 | 3 | 3 | 100.0 | 22 | 6 | 6 | 6.25 | 1534 | 1690 | 10.36 | 11.34 | 63.5 | 0.16 | 10.16 | 846.563 | 180.00 | 10.89 | 1.72 |
| 29/05/2014 | 233 | 362 | 853 | 937 | 480 | 593 | 5 | 4 | 80.0 | 18 | 10 | 10 | 10.42 | 1552 | 1700 | 10.42 | 11.33 | 71.3 | 0.15 | 10.70 | 857.258 | 250.67 | 14.44 | 2.22 |
| 30/05/2014 | 234 | 365 | 864 | 943 | 484 | 599 | 6 | 4 | 66.7 | 15 | 12 | 12 | 12.50 | 1567 | 1712 | 10.45 | 11.34 | 52.8 | 0.14 | 7.39 | 864.65 | 150.83 | 9.16 | 1.48 |
| 31/05/2014 | 237 | 368 | 873 | 946 | 486 | 602 | 3 | 2 | 66.7 | 15 | 6 | 6 | 6.25 | 1582 | 1718 | 10.48 | 11.30 | 42.4 | 0.16 | 6.78 | 871.434 | 136.00 | 8.26 | 1.35 |
| 1/06/2014 | 240 | 372 | 885 | 947 | 487 | 603 | 1 | 1 | 100.0 | 19 | 2 | 2 | 2.08 | 1601 | 1720 | 10.53 | 11.24 | 42.1 | 0.17 | 7.16 | 878.591 | 151.00 | 9.16 | 1.48 |
| 2/06/2014 | 243 | 373 | 895 | 949 | 488 | 605 | 2 | 1 | 50.0 | 14 | 4 | 4 | 4.17 | 1615 | 1724 | 10.56 | 11.19 | 40.2 | 0.16 | 6.43 | 885.023 | 130.83 | 7.94 | 1.31 |
| 3/06/2014 | 245 | 376 | 905 | 953 | 491 | 609 | 4 | 3 | 75.0 | 15 | 8 | 8 | 8.33 | 1630 | 1732 | 10.58 | 11.17 | 39.3 | 0.16 | 6.29 | 891.311 | 129.17 | 7.87 | 1.30 |
| 4/06/2014 | 248 | 378 | 918 | 956 | 493 | 612 | 3 | 2 | 66.7 | 18 | 6 | 6 | 6.25 | 1648 | 1738 | 10.63 | 11.14 | 43.8 | 0.16 | 7.01 | 898.319 | 180.17 | 10.95 | 1.73 |
| 5/06/2014 | 249 | 380 | 932 | 959 | 496 | 615 | 3 | 3 | 100.0 | 17 | 6 | 6 | 6.25 | 1665 | 1744 | 10.67 | 11.11 | 84.7 | 0.14 | 11.86 | 910.177 | 187.83 | 11.26 | 1.78 |
| 6/06/2014 | 250 | 383 | 946 | 965 | 500 | 621 | 6 | 4 | 66.7 | 18 | 12 | 12 | 12.50 | 1683 | 1756 | 10.72 | 11.11 | 62 | 0.16 | 9.92 | 920.097 | 198.83 | 12.11 | 1.90 |
| 7/06/2014 | 254 | 385 | 955 | 970 | 503 | 626 | 5 | 3 | 60.0 | 15 | 10 | 10 | 10.42 | 1698 | 1766 | 10.75 | 11.11 | 40.1 | 0.16 | 6.42 | 926.513 | 155.17 | 9.44 | 1.52 |
| 8/06/2014 | 257 | 387 | 956 | 976 | 508 | 631 | 5 | 5 | 100.0 | 6 | 11 | 11 | 11.46 | 1704 | 1777 | 10.72 | 11.11 | | | | 926.513 | | | |
| 9/06/2014 | 259 | 391 | 963 | 979 | 509 | 634 | 3 | 1 | 33.3 | 13 | 6 | 6 | 6.25 | 1717 | 1783 | 10.73 | 11.07 | 21.2 | 0.16 | 3.39 | 929.905 | 73.00 | 4.42 | 0.81 |
| 10/06/2014 | 263 | 393 | 973 | 981 | 511 | 636 | 2 | 2 | 100.0 | 16 | 4 | 4 | 4.17 | 1733 | 1787 | 10.76 | 11.03 | 40.2 | 0.15 | 6.03 | 935.935 | 120.17 | 7.30 | 1.22 |
| 11/06/2014 | 265 | 396 | 986 | 985 | 514 | 640 | 4 | 3 | 75.0 | 18 | 8 | 8 | 8.33 | 1751 | 1795 | 10.81 | 11.01 | 44.9 | 0.16 | 7.18 | 943.119 | 180.33 | 10.98 | 1.74 |
| 12/06/2014 | 269 | 397 | 996 | 989 | 517 | 644 | 4 | 3 | 75.0 | 15 | 8 | 8 | 8.33 | 1766 | 1803 | 10.83 | 10.99 | 55.6 | 0.18 | 10.01 | 953.127 | 151.00 | 8.94 | 1.45 |
| 13/06/2014 | 273 | 404 | 1003 | 990 | 518 | 645 | 1 | 1 | 100.0 | 18 | 2 | 2 | 2.08 | 1784 | 1805 | 10.88 | 10.94 | 50.7 | 0.18 | 9.13 | 962.253 | 183.50 | 11.21 | 2.06 |
| 14/06/2014 | 276 | 410 | 1012 | 994 | 520 | 649 | 4 | 2 | 50.0 | 18 | 8 | 8 | 8.33 | 1802 | 1813 | 10.92 | 10.92 | 108.7 | 0.18 | 19.57 | 981.819 | 214.83 | 13.05 | 2.28 |
| 15/06/2014 | 280 | 413 | 1019 | 998 | 523 | 653 | 4 | 3 | 75.0 | 14 | 8 | 8 | 8.33 | 1816 | 1821 | 10.94 | 10.90 | 23.2 | 0.18 | 4.18 | 985.995 | 83.00 | 5.01 | 0.90 |
| 16/06/2014 | 283 | 415 | 1026 | 1004 | 528 | 659 | 6 | 5 | 83.3 | 12 | 12 | 12 | 12.50 | 1828 | 1833 | 10.95 | 10.91 | 21.8 | 0.20 | 4.36 | 990.355 | 87.17 | 5.27 | 0.93 |
| 17/06/2014 | 286 | 417 | 1035 | 1008 | 531 | 662 | 3 | 3 | 100.0 | 14 | 7 | 7 | 7.29 | 1842 | 1840 | 10.96 | 10.89 | 31.8 | 0.19 | 6.04 | 996.397 | 122.67 | 7.46 | 1.24 |
| 18/06/2014 | 289 | 419 | 1049 | 1013 | 535 | 667 | 5 | 4 | 80.0 | 19 | 10 | 10 | 10.42 | 1861 | 1850 | 11.01 | 10.88 | 40.6 | 0.16 | 6.50 | 1002.893 | 180.50 | 10.86 | 1.72 |
| 19/06/2014 | 293 | 422 | 1054 | 1017 | 538 | 671 | 4 | 3 | 75.0 | 12 | 8 | 8 | 8.33 | 1873 | 1858 | 11.02 | 10.87 | 31.8 | 0.17 | 5.41 | 1008.299 | 69.33 | 4.17 | 0.78 |
| 20/06/2014 | 294 | 425 | 1067 | 1021 | 541 | 675 | 4 | 3 | 75.0 | 17 | 8 | 8 | 8.33 | 1890 | 1866 | 11.05 | 10.85 | 57.5 | 0.17 | 9.78 | 1018.074 | 180.50 | 10.99 | 1.74 |
| 21/06/2014 | 297 | 432 | 1073 | 1026 | 544 | 679 | 4 | 3 | 75.0 | 16 | 9 | 9 | 9.38 | 1906 | 1875 | 11.08 | 10.84 | 42.2 | 0.19 | 8.02 | 1026.092 | 180.67 | 10.97 | 2.18 |
| 22/06/2014 | 300 | 435 | 1079 | 1031 | 547 | 684 | 5 | 3 | 60.0 | 12 | 10 | 10 | 10.42 | 1918 | 1885 | 11.09 | 10.83 | 21.3 | 0.18 | 3.83 | 1029.926 | 80.67 | 4.89 | 0.88 |
| 23/06/2014 | 304 | 438 | 1091 | 1032 | 547 | 685 | | | | 19 | 1 | 1 | 1.04 | 1937 | 1886 | 11.13 | 10.78 | 38.6 | 0.20 | 7.72 | 1037.646 | 152.17 | 9.22 | 1.49 |
| 24/06/2014 | 307 | 441 | 1103 | 1034 | 548 | 687 | 2 | 1 | 50.0 | 18 | 4 | 4 | 4.17 | 1955 | 1890 | 11.17 | 10.74 | 40.3 | 0.21 | 8.46 | 1046.109 | 173.17 | 10.51 | 1.67 |
| 25/06/2014 | 310 | 443 | 1118 | 1036 | 550 | 689 | 2 | 2 | 100.0 | 20 | 4 | 4 | 4.17 | 1975 | 1894 | 11.22 | 10.70 | 39.8 | 0.18 | 7.16 | 1053.273 | 180.67 | 10.93 | 1.73 |
| 26/06/2014 | 314 | 445 | 1129 | 1040 | 553 | 693 | 4 | 3 | 75.0 | 17 | 8 | 8 | 8.33 | 1992 | 1902 | 11.25 | 10.69 | 53 | 0.18 | 9.54 | 1062.813 | 185.00 | 10.51 | 1.67 |
| 27/06/2014 | 316 | 452 | 1136 | 1043 | 556 | 696 | 3 | 3 | 100.0 | 16 | 6 | 6 | 6.25 | 2008 | 1908 | 11.28 | 10.66 | 52.9 | 0.15 | 7.94 | 1070.748 | 164.67 | 10.05 | 1.80 |
| 28/06/2014 | 321 | 454 | 1144 | 1044 | 556 | 697 | 1 | | | 15 | 2 | 2 | 2.08 | 2023 | 1910 | 11.30 | 10.61 | 23 | 0.24 | 5.52 | 1076.268 | 110.83 | 6.75 | 1.14 |
| 29/06/2014 | 324 | 458 | 1159 | 1046 | 557 | 699 | 2 | 1 | 50.0 | 22 | 4 | 4 | 4.17 | 2045 | 1914 | 11.36 | 10.57 | 60.4 | 0.18 | 10.87 | 1087.14 | 180.83 | 10.98 | 1.74 |
| 30/06/2014 | 328 | 461 | 1164 | 1052 | 561 | 705 | 6 | 4 | 66.7 | 12 | 12 | 12 | 12.50 | 2057 | 1926 | 11.36 | 10.58 | 9.2 | 0.17 | 1.56 | 1088.704 | 73.50 | 4.49 | 0.76 |
| 1/07/2014 | 332 | 464 | 1172 | 1057 | 565 | 710 | 5 | 4 | 80.0 | 15 | 10 | 10 | 10.42 | 2072 | 1936 | 11.38 | 10.58 | 32 | 0.14 | 4.48 | 1093.184 | 93.00 | 5.64 | 0.99 |
| 2/07/2014 | 337 | 467 | 1178 | 1059 | 566 | 711 | 1 | 1 | 100.0 | 14 | 3 | 3 | 3.13 | 2086 | 1939 | 11.40 | 10.54 | 9.1 | 0.17 | 1.55 | 1094.731 | 81.33 | 4.52 | 0.83 |
| 3/07/2014 | 340 | 470 | 1181 | 1063 | 570 | 715 | 4 | 4 | 100.0 | 9 | 8 | 8 | 8.33 | 2095 | 1947 | 11.39 | 10.52 | 19.7 | 0.15 | 2.96 | 1097.686 | 26.33 | 1.60 | 0.31 |
| 4/07/2014 | 342 | 470 | 1190 | 1069 | 574 | 721 | 6 | 4 | 66.7 | 11 | 12 | 12 | 12.50 | 2106 | 1959 | 11.38 | 10.53 | 30.4 | 0.19 | 5.78 | 1103.462 | 111.67 | 6.80 | 1.15 |
| 5/07/2014 | 346 | 473 | 1195 | 1075 | 578 | 726 | 5 | 4 | 80.0 | 12 | 11 | 11 | 11.46 | 2118 | 1970 | 11.39 | 10.53 | 12.5 | 0.20 | 2.50 | 1105.962 | 51.83 | 3.17 | 0.61 |
| 6/07/2014 | 349 | 475 | 1196 | 1079 | 581 | 730 | 4 | 3 | 75.0 | 6 | 8 | 8 | 8.33 | 2124 | 1978 | 11.36 | 10.52 | 45.9 | 0.19 | 8.72 | 1114.683 | | | |
| 7/07/2014 | 349 | 476 | 1205 | 1083 | 584 | 734 | 4 | 3 | 75.0 | 10 | 8 | 8 | 8.33 | 2134 | 1986 | 11.35 | 10.51 | 58.4 | 0.18 | 10.51 | 1125.195 | 165.17 | 10.02 | 1.60 |
| 8/07/2014 | 350 | 476 | 1206 | 1087 | 588 | 738 | 4 | 4 | 100.0 | 2 | 8 | 8 | 8.33 | 2136 | 1994 | 11.30 | 10.49 | | | | 1125.195 | | | |
| 9/07/2014 | 350 | 477 | 1207 | 1091 | 592 | 742 | 4 | 4 | 100.0 | 2 | 8 | 8 | 8.33 | 2138 | 2002 | 11.25 | 10.48 | | | | 1125.195 | | | |
| 10/07/2014 | 350 | 477 | 1208 | 1095 | 596 | 746 | 4 | 4 | 100.0 | 1 | 8 | 8 | 8.33 | 2139 | 2010 | 11.20 | 10.47 | | | | 1125.195 | | | |
| 11/07/2014 | 351 | 478 | 1209 | 1099 | 600 | 750 | 4 | 4 | 100.0 | 3 | 8 | 8 | 8.33 | 2142 | 2018 | 11.16 | 10.46 | | | | 1125.195 | | | |
| 12/07/2014 | 351 | 478 | 1210 | 1105 | 604 | 756 | 6 | 4 | 66.7 | 1 | 12 | 12 | 12.50 | 2143 | 2030 | 11.10 | 10.46 | | | | 1125.195 | | | |
| 13/07/2014 | 351 | 479 | 1211 | 1109 | 607 | 760 | 4 | 3 | 75.0 | 2 | 8 | 8 | 8.33 | 2145 | 2038 | 11.06 | 10.45 | | | | 1125.195 | | | |
| 14/07/2014 | 351 | 479 | 1212 | 1113 | 609 | 763 | 3 | 2 | 66.7 | 1 | 7 | 7 | 7.29 | 2146 | 2045 | 11.01 | 10.43 | | | | 1125.195 | | | |
| 15/07/2014 | 354 | 484 | 1219 | 1114 | 609 | 764 | 1 | | | 15 | 2 | 2 | 2.08 | 2161 | 2047 | 11.03 | 10.39 | 18.3 | 0.24 | 4.39 | 1129.587 | 98.67 | 5.99 | 1.04 |
| 16/07/2014 | 357 | 488 | 1231 | 1116 | 610 | 766 | 2 | 1 | 50.0 | 19 | 4 | 4 | 4.17 | 2180 | 2051 | 11.07 | 10.36 | 20.9 | 0.19 | 5.68 | 1135.268 | 180.50 | 10.33 | 1.65 |
| 17/07/2014 | 360 | 491 | 1236 | 1120 | 612 | 770 | 4 | 2 | 50.0 | 11 | 8 | 8 | 8.33 | 2191 | 2059 | 11.07 | 10.35 | 28.9 | 0.18 | 5.20 | 1140.47 | 63.50 | 3.63 | 0.69 |
| 18/07/2014 | 362 | 496 | 1254 | 1125 | 614 | 775 | 5 | 2 | 40.0 | 25 | 10 | 10 | 10.42 | 2216 | 2069 | 11.14 | 10.35 | 72.5 | 0.17 | 12.33 | 1152.795 | 279.00 | 17.01 | 2.90 |
| 19/07/2014 | 367 | 498 | 1268 | 1131 | 618 | 781 | 6 | 4 | 66.7 | 21 | 12 | 12 | 12.50 | 2237 | 2081 | 11.19 | 10.35 | 84.1 | 0.15 | 12.62 | 1165.41 | 211.00 | 12.56 | 1.96 |
| 20/07/2014 | 370 | 501 | 1269 | 1137 | 622 | 787 | 6 | 4 | 66.7 | 7 | 12 | 12 | 13 | 2244 | 2093 | 11.16 | 10.36 | | | | 1165.41 | 18.50 | 1.13 | 0.16 |
| 21/07/2014 | 373 | 507 | 1281 | 1142 | 625 | 791 | 4 | 3 | 75.0 | 21 | 9 | 9 | 9 | 2265 | 2102 | 11.21 | 10.35 | 80.3 | 0.17 | 13.65 | 1179.061 | 287.50 | 17.52 | 3.24 |
| 22/07/2014 | 376 | 509 | 1290 | 1148 | 629 | 796 | 5 | 4 | 80.0 | 14 | 11 | 11 | 11 | 2279 | 2113 | 11.23 | 10.36 | 34 | 0.16 | 5.44 | 1184.501 | 117.17 | 7.15 | 1.20 |
| 23/07/2014 | 380 | 512 | 1303 | 1153 | 634 | 801 | 5 | 5 | 100.0 | 20 | 10 | 10 | 10 | 2299 | 2123 | 11.27 | 10.36 | 39.7 | 0.16 | 6.35 | 1190.853 | 181.33 | 10.85 | 1.72 |
| 24/07/2014 | 384 | 514 | 1314 | 1156 | 636 | 804 | 3 | 2 | 66.7 | 17 | 6 | 6 | 6 | 2316 | 2129 | 11.30 | 10.33 | 55.5 | 0.17 | 9.44 | 1200.288 | 159.67 | 9.09 | 1.47 |
| 25/07/2014 | 385 | 516 | 1328 | 1162 | 641 | 810 | 6 | 5 | 83.3 | 17 | 12 | 12 | 13 | 2333 | 2141 | 11.33 | 10.34 | 65 | 0.15 | 9.75 | 1210.038 | 181.50 | 11.07 | 1.79 |
| 26/07/2014 | 390 | 520 | 1342 | 1166 | 643 | 814 | 4 | 2 | 50.0 | 23 | 8 | 8 | 8 | 2356 | 2149 | 11.38 | 10.33 | 41.9 | 0.18 | 7.54 | 1217.58 | 202.00 | 12.31 | 1.95 |
| 27/07/2014 | 392 | 523 | 1355 | 1172 | 647 | 820 | 6 | 4 | 66.7 | 18 | 12 | 12 | 13 | 2374 | 2161 | 11.41 | 10.34 | 76.3 | 0.15 | 11.45 | 1229.025 | 202.67 | 11.53 | 1.82 |
| 28/07/2014 | 395 | 525 | 1365 | 1175 | 650 | 823 | 3 | 3 | 100.0 | 15 | 6 | 6 | 6 | 2389 | 2167 | 11.43 | 10.32 | 42.7 | 0.14 | 5.98 | 1235.003 | 124.67 | 7.59 | 1.26 |
| 29/07/2014 | 407 | 531 | 1367 | 1182 | 656 | 830 | 7 | 6 | 85.7 | 20 | 14 | 14 | 15 | 2409 | 2181 | 11.47 | 10.34 | 50.5 | 0.14 | 7.07 | 1242.073 | 201.33 | 12.02 | 2.39 |
| 30/07/2014 | 410 | 533 | 1377 | 1186 | 658 | 834 | 4 | 2 | 50.0 | 15 | 8 | 8 | 8 | 2424 | 2189 | 11.40 | 10.33 | 42.9 | 0.14 | 6.01 | 1248.079 | 141.33 | 7.78 | 1.29 |
| 31/07/2014 | 413 | 538 | 1387 | 1193 | 662 | 840 | 6 | 4 | 66.7 | 18 | 13 | 13 | 14 | 2442 | 2202 | 11.52 | 10.34 | 98.3 | 0.14 | 13.76 | 1261.841 | 109.00 | 6.55 | 1.26 |

**Figure A.1 (continued): The core datasheet**

## A.3 EV Charger Data

I noted in the body of the report (Section 3.3) that I was disappointed when I first got my EV because I was not able to get any information on how much energy I was using in the car or get any information on how much it was costing me to fuel the car. After exploring a number of options I finally decided to buy a good quality datalogger (with compatible sensors) to log the current on my EV battery charger. [118]

I set the logger to sample at ten second intervals. *Figure A.2* is an extract from the dataset I built up using the data recorded by the datalogger. You can see that I have converted AC current into kW simply by multiplying the measured current by 240 (the nominal voltage is 240V). This is not as accurate as using a dedicated energy logger but for my purposes it seemed to work fine – I was able to check the reliability of the readings with the instantaneous kW readings provided on the display of my charger; they showed an extremely good level of agreement.

The logger provided me with an accurate picture of 'time on' and 'time off' for the charging current – this enabled me to confidently work out the amount of energy I used in each of the time-of-use tariff bands (and hence the cost of fuelling my vehicle) over the period of the project.

I computed the energy input into the car, and the electricity cost, simply by aggregating the 10sec energy/cost increments for each day. I transferred the daily data from the charger data sheet to the core datasheet (*Figure A.1*).

*Simulated Charger Data*

As can be seen in *Figure A.*1 I had no data for energy put into the car until 17 March when I began the datalogging and therefore, in order to create a full dataset I simulated the missing data.

In order to simulate the energy used by the car for the period 1 January to 17 March I summed values of the daily charger energy input over the period 17 March to 31 July (Total = 1,008 kWh) and compared this with the total EV energy usage over same period as derived by the EV's instrument panel (Total = 837 kWh). This gave me a value for the relationship between the two columns (1008/837=1.20) and I then used this factor to simulate the EV charger readings for the period up to 17 March by multiplying the EV data use by 1.2. This simulated data is shown in *Figure A.1.*

*Charging Inefficiency*

The 'Data from Car Instrument Panel' group in *Figure A.1* shows the daily energy use of the EV over the time of the project period as computed from information on the car's instrument panel (Total = 1262 kWh). The 'EV Charger – Data from the Datalogger' group in *Figure A.1* shows the energy that the charger delivered to the car over the project period – including the simulated data just discussed (Total = 1518 kWh) . The relationship between these two numbers is simply 1.2 as the data has been set up using this factor (discussed in the previous paragraph).

The 20% difference between these two figures represents the energy lost in the charging process. As discussed in Section 3.4, I consider the energy delivered to the car as the true figure for the energy the car uses (after all this is the amount of electricity I have to pay for).

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[118] Hobo UX120-006M data logger. OneTemp: http://www.onetemp.com.au/p/1953/hobo-ux120-4-channel-analogue-data-logger-ux120-006m

| Date | Time | Amps | Fraction of Day | Mins from Day Start (Formula) | Mins from Day Start (Value) | kW | kW clean | kWsec | TOU Tariff (c/kWh) | Charge ($) | Charging Time (Mins) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 11/04/2014 | 22:58:22 | 0.0282 | 0.957199074 | 1378.37 | 1378.366667 | 0.006768 | 0 | 0 | 14.08 | 0 | 0 |
| 11/04/2014 | 22:58:32 | 0.0282 | 0.957314815 | 1378.53 | 1378.533333 | 0.006768 | 0 | 0 | 14.08 | 0 | 0 |
| 11/04/2014 | 22:58:42 | 0.0282 | 0.957430556 | 1378.70 | 1378.7 | 0.006768 | 0 | 0 | 14.08 | 0 | 0 |
| 11/04/2014 | 22:58:52 | 0.0282 | 0.957546296 | 1378.87 | 1378.866667 | 0.006768 | 0 | 0 | 14.08 | 0 | 0 |
| 11/04/2014 | 22:59:02 | 0.0282 | 0.957662037 | 1379.03 | 1379.033333 | 0.006768 | 0 | 0 | 14.08 | 0 | 0 |
| 11/04/2014 | 22:59:12 | 0.0282 | 0.957777778 | 1379.20 | 1379.2 | 0.006768 | 0 | 0 | 14.08 | 0 | 0 |
| 11/04/2014 | 22:59:22 | 0.0282 | 0.957893519 | 1379.37 | 1379.366667 | 0.006768 | 0 | 0 | 14.08 | 0 | 0 |
| 11/04/2014 | 22:59:32 | 0.0282 | 0.958009259 | 1379.53 | 1379.533333 | 0.006768 | 0 | 0 | 14.08 | 0 | 0 |
| 11/04/2014 | 22:59:42 | 0.8354 | 0.958125 | 1379.70 | 1379.7 | 0.200496 | 0 | 0 | 14.08 | 0 | 0 |
| 11/04/2014 | 22:59:52 | 15.2514 | 0.958240741 | 1379.87 | 1379.866667 | 3.660336 | 3.660336 | 36.60336 | 14.08 | 0.001431598 | 0.166666667 |
| 11/04/2014 | 23:00:02 | 15.2468 | 0.958356481 | 1380.03 | 1380.033333 | 3.659232 | 3.659232 | 36.59232 | 14.08 | 0.001431166 | 0.166666667 |
| 11/04/2014 | 23:00:12 | 15.2689 | 0.958472222 | 1380.20 | 1380.2 | 3.664536 | 3.664536 | 36.64536 | 14.08 | 0.001433241 | 0.166666667 |
| 11/04/2014 | 23:00:22 | 15.2674 | 0.958587963 | 1380.37 | 1380.366667 | 3.664176 | 3.664176 | 36.64176 | 14.08 | 0.0014331 | 0.166666667 |
| 11/04/2014 | 23:00:32 | 15.304 | 0.958703704 | 1380.53 | 1380.533333 | 3.67296 | 3.67296 | 36.7296 | 14.08 | 0.001436535 | 0.166666667 |
| 11/04/2014 | 23:00:42 | 15.3193 | 0.958819444 | 1380.70 | 1380.7 | 3.676632 | 3.676632 | 36.76632 | 14.08 | 0.001437972 | 0.166666667 |
| 11/04/2014 | 23:00:52 | 15.3071 | 0.958935185 | 1380.87 | 1380.866667 | 3.673704 | 3.673704 | 36.73704 | 14.08 | 0.001436826 | 0.166666667 |
| 11/04/2014 | 23:01:02 | 15.3025 | 0.959050926 | 1381.03 | 1381.033333 | 3.6726 | 3.6726 | 36.726 | 14.08 | 0.001436395 | 0.166666667 |
| 11/04/2014 | 23:01:12 | 15.3407 | 0.959166667 | 1381.20 | 1381.2 | 3.681768 | 3.681768 | 36.81768 | 14.08 | 0.00143998 | 0.166666667 |
| 11/04/2014 | 23:01:22 | 15.3353 | 0.959282407 | 1381.37 | 1381.366667 | 3.680472 | 3.680472 | 36.80472 | 14.08 | 0.001439473 | 0.166666667 |
| 11/04/2014 | 23:01:32 | 15.3277 | 0.959398148 | 1381.53 | 1381.533333 | 3.678648 | 3.678648 | 36.78648 | 14.08 | 0.00143876 | 0.166666667 |
| 11/04/2014 | 23:01:42 | 15.3254 | 0.959513889 | 1381.70 | 1381.7 | 3.678096 | 3.678096 | 36.78096 | 14.08 | 0.001438544 | 0.166666667 |
| 11/04/2014 | 23:01:52 | 15.3079 | 0.95962963 | 1381.87 | 1381.866667 | 3.673896 | 3.673896 | 36.73896 | 14.08 | 0.001436902 | 0.166666667 |
| 11/04/2014 | 23:02:02 | 15.2941 | 0.95974537 | 1382.03 | 1382.033333 | 3.670584 | 3.670584 | 36.70584 | 14.08 | 0.001435606 | 0.166666667 |

**Figure A.2: Extract from output of datalogging my EV charger circuit**

*Time Profile for session charging current*

While not directly relevant for the information in the body of the book, when looking at the data from my datalogger I found it interesting to see the differences in the amps time profile when the car is charged to 80% full as opposed to 100% full. This comparison is shown in *Figures A.3* and *A.4.*

The days of the profiles shown in the figures are randomly selected – looking at these it is easy to understand why fast chargers go to 80% and not 100% charge. It can be seen that when giving the car an '80% charge' the current drops immediately to zero when the 80% level is reached. On the other hand when charging to 100% there is a gradual tail-off period of about 20-30 minutes where the current drops from around 15 amps to 5 amps before cutting off totally.

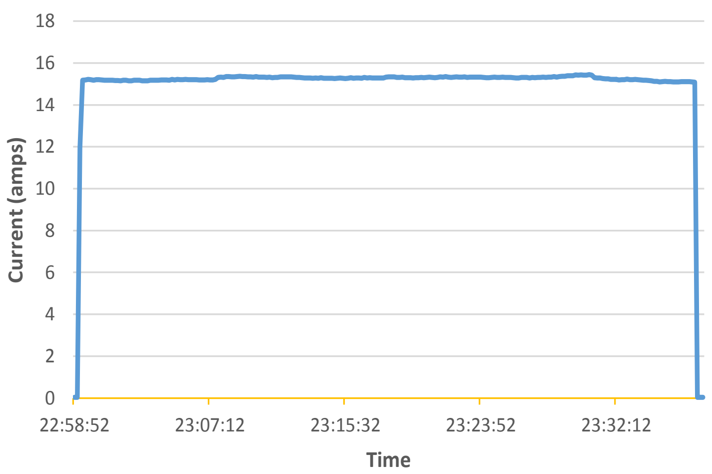



**Figure A.3: Amps time profile for 80% full charge**

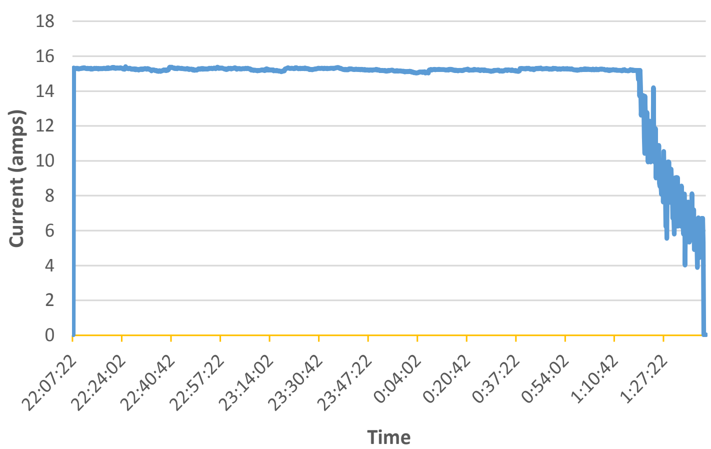



**Figure A.4: Amps time profile for 100% full charge**

## A.4 Net Metered Solar PV System Data

My data logger has four channels. I have one channel logging the circuit on my EV charger as described in Appendix A.3 and another logging the AC output from my net metered solar PV system. I set the PV output logger to take a sample every 10 seconds in parallel with the EV charger channel. An extract of the PV log dataset is shown in *Figure A.5.* I have used this dataset to construct the solar output time profiles shown in *Figures 4.4 & 4.5*.

In a similar manner to the data for the EV charger I have converted amps into power by multiplying by 240. This may be inducing errors but it seems to be giving acceptable quality data for my purposes. The maximum power value in my dataset is 1.87 kW which appears reasonable for a 2 kW peak system operating in autumn.

| Date | Time | Solar Current (Amps) | Solar Power (kW) | Solar Energy (kWh) |
|---|---|---|---|---|
| 26/03/2014 | 11:33:32 | 0.2969 | 0.071256 | 0.000198 |
| 26/03/2014 | 11:33:42 | 0.2972 | 0.071328 | 0.000198 |
| 26/03/2014 | 11:33:52 | 0.3027 | 0.072648 | 0.000202 |
| 26/03/2014 | 11:34:02 | 0.3082 | 0.073968 | 0.000205 |
| 26/03/2014 | 11:34:12 | 0.3177 | 0.076248 | 0.000212 |
| 26/03/2014 | 11:34:22 | 0.3253 | 0.078072 | 0.000217 |
| 26/03/2014 | 11:34:32 | 0.3311 | 0.079464 | 0.000221 |
| 26/03/2014 | 11:34:42 | 0.3439 | 0.082536 | 0.000229 |
| 26/03/2014 | 11:34:52 | 0.3522 | 0.084528 | 0.000235 |
| 26/03/2014 | 11:35:02 | 0.3626 | 0.087024 | 0.000242 |
| 26/03/2014 | 11:35:12 | 0.3696 | 0.088704 | 0.000246 |
| 26/03/2014 | 11:35:22 | 0.3775 | 0.0906 | 0.000252 |
| 26/03/2014 | 11:35:32 | 0.3861 | 0.092664 | 0.000257 |
| 26/03/2014 | 11:35:42 | 0.3937 | 0.094488 | 0.000262 |
| 26/03/2014 | 11:35:52 | 0.4001 | 0.096024 | 0.000267 |
| 26/03/2014 | 11:36:02 | 0.401 | 0.09624 | 0.000267 |
| 26/03/2014 | 11:36:12 | 0.4089 | 0.098136 | 0.000273 |

**Figure A.5: Extract from output of datalogging my net metered solar PV system**

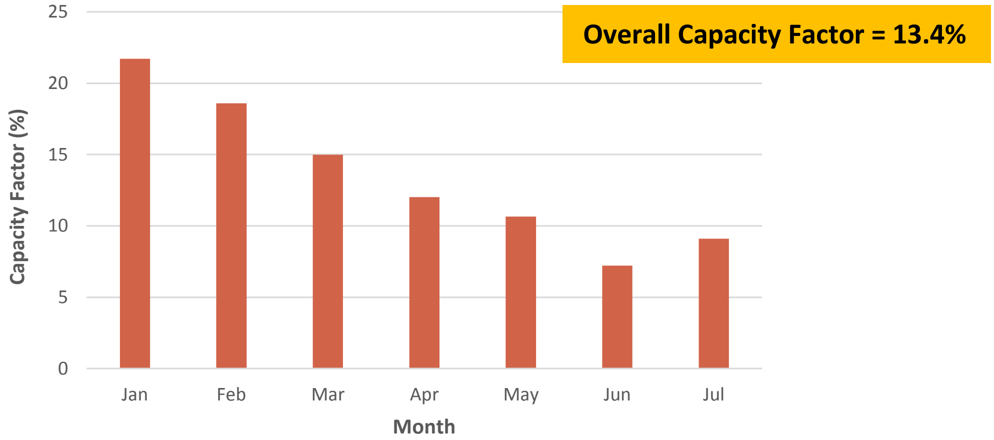
*Simulated Solar Data*

I indicated in Section 4.1 that I simulated data for solar generation for January and February to take account of the fact that we installed an additional 2kW solar PV system at our house in late February. I did this simply by assuming that the daily kWh output for each of our 2kW systems is equal – you can see from *Figure A.1* that this is a solid assumption. Therefore for the period 1 January to 24 February, I simply took the reading of the daily output of the gross metered solar PV system (our original PV system) and doubled this to give a value for the simulated total PV output for the house – this is shown in the 'Simulated Daily Generation' column in *Figure A.1*.

*Capacity Factor*

For completeness I have included the graphic *Figure A.6* which shows how the solar system capacity factor varied during the project. This Figure is derived from the data in *Figure A.1.*

The capacity factor (CF) is simply the ratio between the actual output of an energy generating system and the theoretical maximum output. In the case of my 4kW system the theoretical maximum output per day is 96kWh. The monthly variation in the CF follows the normal seasonal patterns and the overall capacity factor of 13.4% is within the expected range (I would expect a higher CF if our panels were oriented due north). The Figure suggests that my PV system was operating normally during the project period.




## A.5 $CO_2$ Savings

Despite my strong interest in carbon footprinting I have deliberately avoided any reference to personal $CO_2$ savings in the body of the report so that the focus is not diverted from the broader issues. Nevertheless I found it useful to have an appreciation of the magnitude of the reduction in my personal carbon footprint by going EV.

The Australian Government Green Vehicle Guide provides advice on $CO_2$ emissions by cars in use in Australia.[119] According to the Green Vehicle Guide, my previous car, a Nissan Pulsar, would have generated about 2.8 tonnes of $CO_2$ when travelling 15,000km (the approximate distance I expect to travel this year in my EV). The average distance travelled by a car in the ACT is also around 15,000km. The Nissan Leaf is rated as zero emissions and hence, if only the $CO_2$ emissions from the car itself are taken into account, by going EV I have reduced my carbon footprint by around 3 tonnes of $CO_2$/year.

I pointed out in Section 1.2 that the $CO_2$ impacts of the 'non-road' components of a transport mode cannot be ignored. This is particularly important when discussing EVs since the electricity powering the vehicles may have been generated from a carbon intensive source such as a coal fired power station. 'Non-road $CO_2$ Emissions' are discussed in the Green Vehicle Guide.[120] In my case, where my fuel is effectively sourced from my solar PV system (ie I am generating more electricity from my PV system than I am using in both my house and car) I consider that the carbon footprint reduction of about 3 tonnes of $CO_2$/year holds true. Given that the ACT will be fuelled by 90% renewables by 2020 within a few years, savings of this magnitude are likely to be accrued in the Territory on average every time a petrol car is replaced by an EV irrespective of whether the owners have home PV systems.

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[119] Green Vehicle Guide. Australian Government: http://www.greenvehicleguide.gov.au
[120] *Estimating Non-road $CO_2$ Emissions.* Green Vehicle Guide. Australian Government: http://www.greenvehicleguide.gov.au/GVGPublicUI/Information.aspx?type=Nonroademissions

## A.7 Useful Links

I like to get an up-date on news about EVs and renewable energy each day. I have found that keeping an eye on say two or three sites in any given topic area seems to work well since articles and/or commentary on events are commonly shared across multiple sites. The following is a listing of the sites that I like to look at on a reasonably regular basis:

***Electric Vehicles***

*Inside EVs:* This is a US site which is very active and updates each day with interesting EV articles. http://insideevs.com/

*Fully Charged:* A somewhat quirky UK site which is a must see. It is described as 'a weekly video podcast' about EVs; be entertained while keeping up to date on EV developments. http://blip.tv/fullycharged

*Australian LEAF Owners Forum:* This is an interesting and useful site for learning about the hot issues among Australian Nissan Leaf owners. http://ozleaf.proboards.com/

***Renewable Energy***

*RenewEconomy:* An Australian site which updates every working day with interesting articles about developments in renewable energy. http://reneweconomy.com.au/

*Climate Spectator:* An active Australian site with informative articles on energy and climate change (but be prepared to be disrupted with annoying pop-ups). http://www.businessspectator.com.au/climate

*The Community Power Report:* Simple but inspiring site giving updates on global examples of community owned renewable energy projects. http://www.communitypowerreport.com

***General Sustainability***

*The Conversation:* A good quality independent electronic daily news site (articles primarily written by Australian academics) – has an excellent 'Environment + Energy' page. https://theconversation.com/au/environment

*The Guardian:* An icon of global media. Also has an excellent up-to-date environment section. http://www.theguardian.com/environment/

*ACT Government Environment and Sustainable Development Directorate:* Not the sexiest site in the world but a good place to access some far reaching climate change policy documents. http://www.environment.act.gov.au/cc

# About the Author

Dave Southgate retired from the Australian Government Public Service in July 2012 after a 31 year career as an 'environmental bureaucrat'. After working for 8 years in government environmental agencies at both the State and Federal levels he joined the Australian Government Transport Department in late 1989 and stayed there until he retired. Throughout his time in Transport he specialised in aircraft noise; in the latter years he also became involved in aviation climate change issues and developed a particular interest in carbon footprinting.

Dave has a longstanding interest in sustainable transport. He was President of Pedal Power ACT in the late 1980s and was a daily bike commuter from southern Woden to Civic for 27 years. As a public servant he strongly believed in promoting transparency and in involving communities in environmental decision making. In 2008 Dave was awarded the Australian Government Public Service Medal (PSM) for his work on incorporating transparency concepts into aircraft noise management.[121]

Since his retirement Dave has written three books reporting on the carbon footprint of aviation.[122] He has a strong interest in renewable energy and is a volunteer with SolarShare, a Canberra based group which has been set up to facilitate community ownership of renewable energy projects. [123]

The Nissan Leaf became part of Dave's family at the start of 2014. His family has recently expanded the electrification of its transport fleet by acquiring an electric bike. Dave is particularly excited by current developments in the incorporation of battery storage into solar PV systems and will almost certainly become an early adopter when battery prices start to fall.

Dave has a science/engineering background and has degrees from the Universities of Liverpool, London (Imperial College) and Tasmania.

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121 Public Service Medal: http://www.itsanhonour.gov.au/honours/honour_roll/search.cfm?aus_award_id=1137899&search_type=quick&showInd=true

122 Dave Southgate's website: http://southgateaviation.wordpress.com/

123 SolarShare Canberra: http://solarshare.com.au/