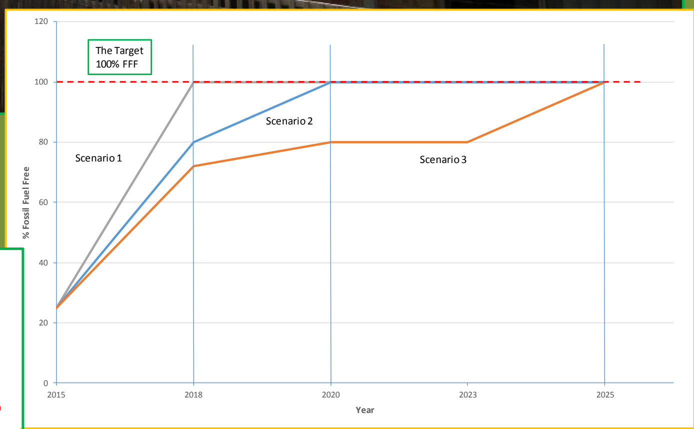
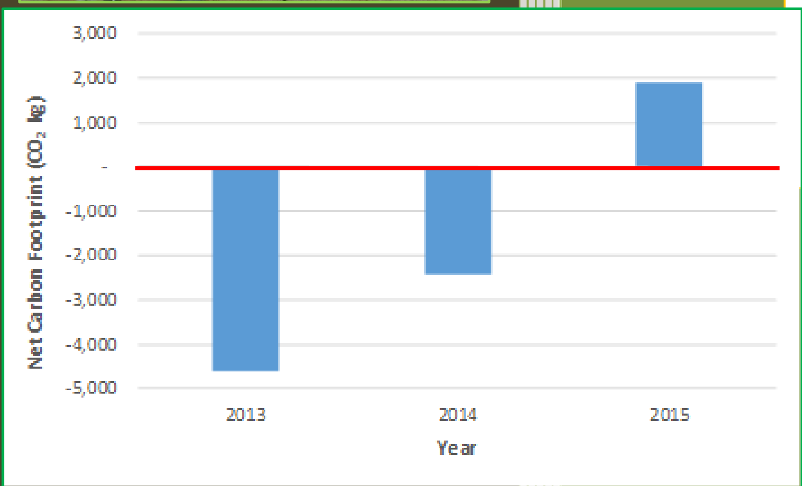
Our Household Energy Transition

Becoming a Fossil Fuel Free Family





Dave Southgate

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Foreword

At the end of 2015 almost all the Nations in the World adopted the Paris Agreement – there was consensus that countries should reach carbon neutrality “in the second half of this century”. This means that humanity will have to end its reliance on fossil fuels within the natural lifespan of my children.

The Paris Agreement is a big step forward. The commitment has been a long time coming but how are we going to wean ourselves off coal, oil and gas?

Over the past twenty years at the national level in Australia we have lurched around like someone in a drunken stupor when it comes to climate change policy. Simply too many people, and too many vested interests, pulling in different directions. At the moment the Federal Government seems to be becalmed on climate action – it has adopted the goal of carbon neutrality but as yet hasn’t demonstrated that it has the confidence to strike out in a new direction.

The standout leaders in Australia have been the State/Territory and Local Governments – irrespective of political persuasion they have not only seen the imperatives to act on climate change but are acutely aware of the economic benefits of adopting new energy paths.

Where does the individual or the household stand in all of this? In my view climate change is a problem where the classic ‘bottom-up’ approaches can really work. So far we have seen the lower levels of government achieving far more than successive Federal Governments – I believe these achievements can be amplified many times over if concerted action is taken at the individual/household level.

Virtually all Australians buy fossil based energy. Petrol to put in our cars; coal in the form of electricity to power our houses; while about 50% of us buy natural gas to heat our water and/or our homes. If millions of households decide they don’t want to buy fossil fuels anymore it will really drive change! Silly thought? Maybe, but already in Australia about 1.5 million households have installed solar systems. Electric vehicles are now rapidly emerging. Change is happening.

This book is about my family’s efforts to become ‘fossil fuel free’ (FFF). We are on a path to no longer buying fossil based electricity; or natural gas; or petrol. We are not cutting ourselves off from the world and adopting an ascetic lifestyle. On the contrary, we are deliberately trying to maintain, or improve, our very ‘normal’ suburban style of living. Over the past three years we have cut our petrol usage by around two thirds; we have disconnected gas from our house; for the last three months of 2015 more than 60% of our electricity usage came directly from the solar PV panels on our roof.

We are not fossil fuel free yet but I believe that we are now set up to be 100%FFF by 2020.

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Transition Essence

The next four pages capture the essence of our family energy transition – the Figures are all extracted from the body of the document.

In summary, the Transition covers a three-year window from 2013 to 2015. We started from a very low base in 2013 - our vision is to stop consuming fossil based electricity, mains gas and petrol within the next few years.

We have already achieved carbon neutrality. I hope that we will be 100% Fossil Fuel Free (100%FFF) within the next 5 years.

Important definition: Our household energy/carbon footprint captures both our **house and our cars**.

The Target

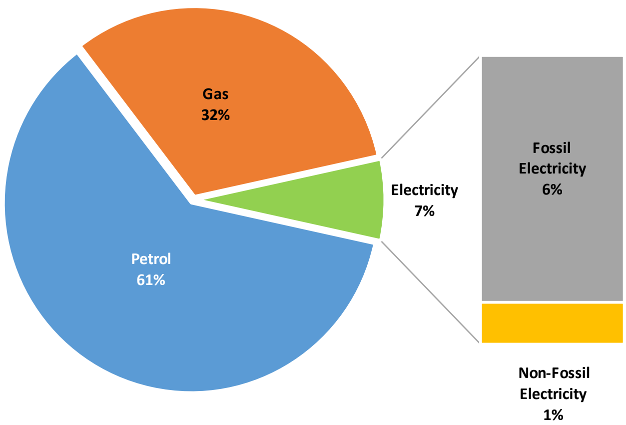
We have a two stage energy transition target for our family:

Stage 1: Net zero CO_2 emissions (carbon neutrality)

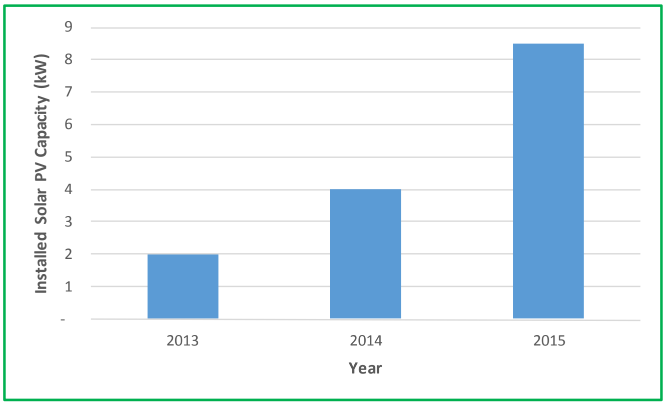
Stage 2: 100% Fossil Fuel Free

The Starting Point

I have selected 2013 as the base year for our household energy transition. We moved into our new house at the end of 2012 and we made no changes to our energy systems until the start of 2014. In the base year petrol dominated our fuel use. Only about 1% of our energy use was fossil fuel free.



Our household energy split by fuel type 2013



Changes in solar PV installed capacity over the period of the Transition

The Actions

Attacking Coal: *Installing Solar PV*

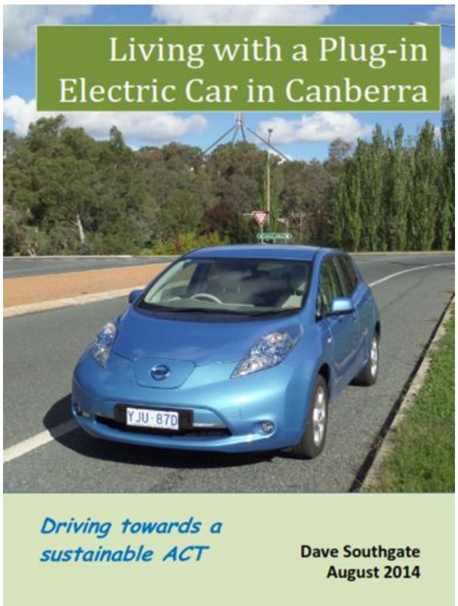
When we moved into our house it already had a 2kW solar PV system installed. We added a second 2kW system in 2014 when we bought our electric car. In 2015, the year we removed gas from the house, we added a 4.5kW solar PV system.

Attacking Petrol: *Buying an electric car*

I bought an electric car (EV) at the start of 2014. This has been wonderful both as a means of transport and as a major step toward our fossil fuel free goal.

We use the EV as our main urban form of transport. We also have another car, a petrol car, which we primarily use for commuting – over the past two years we have travelled about twice as many kilometres in the EV than in our petrol car.

In 2014 I wrote a separate book about our EV experiences (see image).



Our remaining petrol car is the main energy using 'appliance' in the family.

Attacking Gas: *Removing all gas appliances – hot water; space heating; cooking*

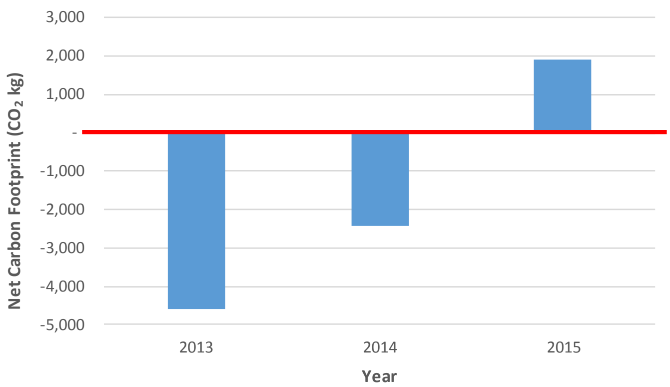
Over 2015 we progressively replaced all our gas appliances with electrical devices. We disconnected gas from the house in early December 2015.

I found myself making some interesting decisions in this area. My research took me down a very different route to the commonly touted heat pumps. In deciding between options I was very conscious of the need to avoid generating noise problems for my neighbours and I was also very keen to explore the incorporation of thermal storage into my solar PV regime. For a long time, I've been intrigued by the role radiant heat plays in the attainment of thermal comfort – my desire to install at least some radiant heat in our house also proved a key decision driver. Our choices:

Hot water - I installed a resistive electric storage heater in combination with an Energy Diversion Device (Immersun). This is delivering about 95%FFF hot water.

Space Heating – I installed a storage heater in combination with a number of Far Infrared (FIR) heating panels. The radiant heat provided by the FIR panels has been a revelation – from a thermal comfort perspective these are a wonderful improvement over heat pumps. 😀

The Outcomes



Net carbon footprint by year

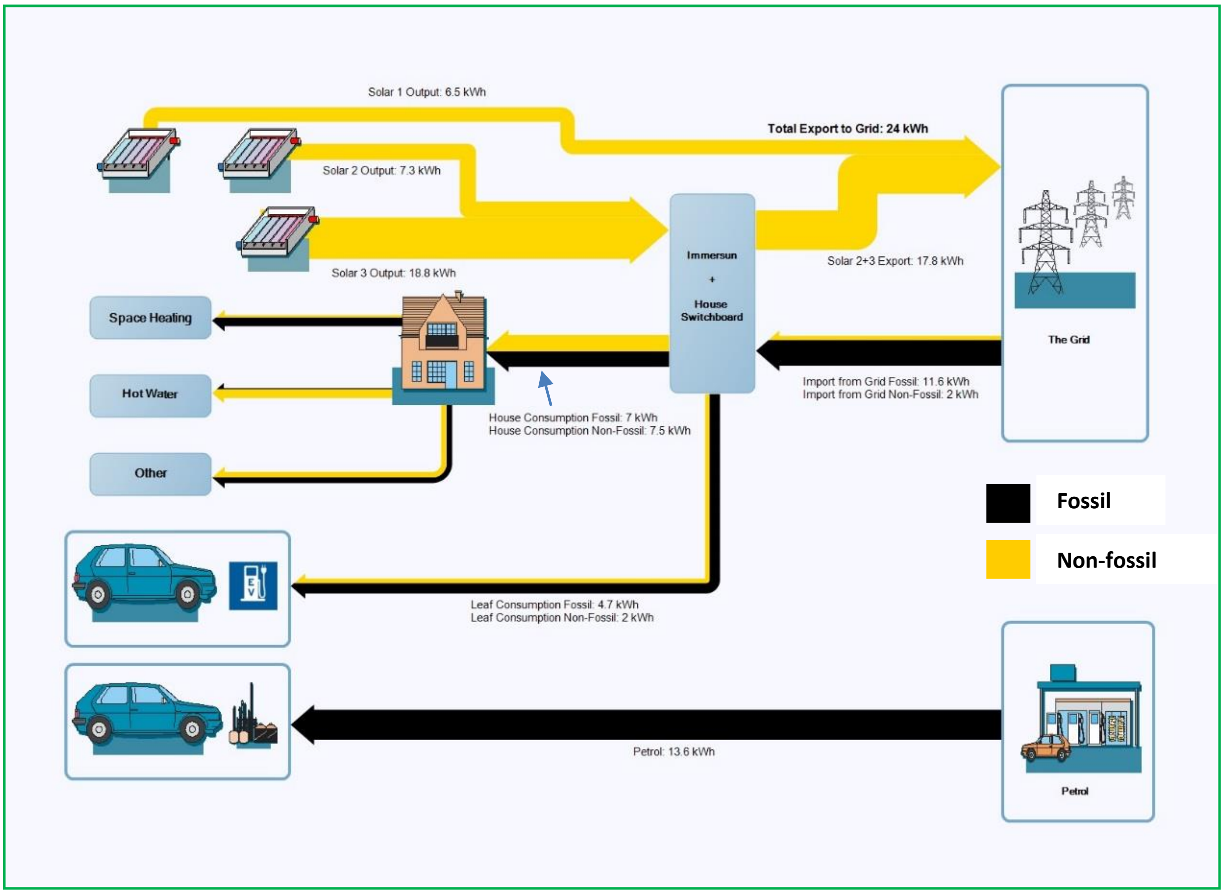
Stage 1 Target: *Carbon neutrality*

Over the three-year period of the Transition we managed to go beyond net zero emissions: our net household carbon footprint went from -4.5 tonnes in 2013 to about +2 tonnes in 2015.

This was essentially achieved by installing sufficient solar PV capacity to generate and export an amount of carbon free electricity that more than offset the carbon footprint of all our energy consumption.

Stage 2 Target: *100% Fossil Fuel Free*

While we have relatively easily become carbon neutral, becoming 100%FFF is much more difficult. The diagram below shows the fossil (black) and non-fossil (yellow) components of the energy flows within our household for an average day over a conceptual year with our current energy systems. I estimate that over the three years of the Transition we have moved from being about 1%FFF to being about 25%FFF.



The Costs

Overall the total costs of the Transition (not including the costs that I would have incurred anyway) to date have amounted to about $30,000. We have an annual return from solar PV income, and savings in fuel costs, of about $2,000 per year. Clearly undertaking the Transition has not been a money-spinner (it was never intended to be); as I say in the text

I look on our energy transition as being a sort of house make-over akin to putting in a new kitchen. So far, our energy transition has cost about the same amount of money as installing a new kitchen. As far as I am concerned, living in a house which is well on the way to being fossil fuel free gives me much greater satisfaction than living in a house with a super flash kitchen.

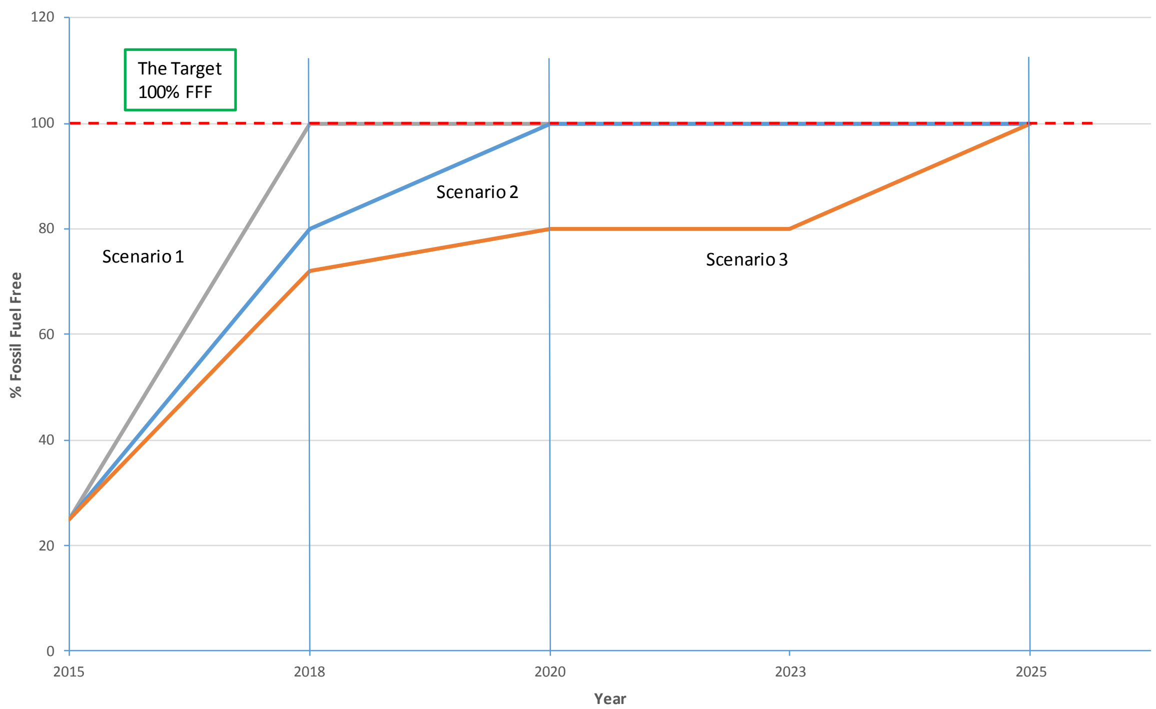
The Future

The outstanding question is – when will we get to 100%FFF? I put forward three possible scenarios:

Scenario 1	*Aggressive action*	*Target: Fossil Fuel Free by 2018*
Scenario 2	*Accelerated action*	*Target: Fossil Fuel Free by 2020*
Scenario 3	*Go with the Flow*	*Target: Fossil Fuel Free by 2025*

I believe all three are achievable – the total timing and cost of reaching the 100%FFF goal is essentially dependent on the development rate and cost of new technology (primarily home battery systems, next generation EVs and smart EV charging systems) and on the rate at which grid electricity is decarbonised.

I hope that our household is able to reach the goal by 2020.



Indicative timelines for the three FFF scenarios

Disclaimer

I have no direct commercial interests in any of the fields discussed in this book. I am self-funded and have produced this document purely in pursuit of a personal wish to see society wean itself off fossil fuels as soon as possible.

CONTENTS

Chapter 1

Introduction

1.1 Setting the Scene

Like many Australians I've long had a dream that one day I would be free from fossil fuels.

My dream remained just a dream for years because I couldn't see how it could be done, but then things started to change. Around 2010, people started putting solar PV panels on the roof of their homes in earnest. In 2012 the ACT Government adopted a policy that grid electricity in the Territory will be based on 90% renewables by 2020. Around the same time, serious, affordable, electric vehicles appeared on the Australian market. Tentative steps, but it all began to add up and it became clear that the average Australian household can wean itself off fossil fuels.

This book is about my family putting into practice the vision of setting up a fossil fuel free (FFF) household. It is not about us moving into the bush and going 'off grid'. It is not about us constructing a specially designed 'solar house' or making extensive modifications to an existing house. Our journey to fossil fuel freedom, which I call 'the Transition' throughout this book, simply involves making straightforward changes to the energy systems in a stock standard house in the Canberra suburbs.

The Transition is a simple concept – the aim is for our household to stop buying fossil fuels and to only use electricity based on renewable energy. In essence this means converting all our electricity use over to solar PV; turning off the mains gas; and using plug-in electric cars. Is this feasible? How long will it take? How much will it cost? I hope this book provides some of the answers.

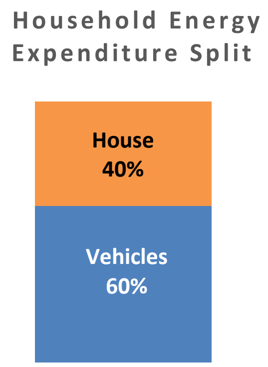


Figure 1.1: The average Australian household spends more on petrol than on electricity/gas

The reader will note that I have included our motor vehicles in our fossil fuel free vision. The car seems to be commonly left out of household energy computations but it can be seen from Figure 1.1 that expenditure on petrol takes up more than half of the average Australian household's total spending on fuel. Ignoring the car would give a very distorted picture of the household carbon footprint. For the purposes of this book, the 'household carbon footprint' covers only the fuels that we buy to directly power our house and our cars – commonly, but not exclusively, electricity, gas and petrol. This is consistent with the fuels captured by the Australian Bureau of Statistics (ABS) in its household energy surveys.[1]

The data in Figure 1.1 is extracted from the ABS Household Energy Consumption Survey 2012 and shows the dwelling/car energy expenditure split for the average Australian household. The differences in average household energy costs between the States and Territories are not massive, but in some parts of the country the major dwelling fuel costs are associated with heating while in

[1] *Household energy consumption survey 2012.* Australian Bureau of Statistics. http://www.abs.gov.au/ausstats/abs@.nsf/Lookup/4670.0main+features132012

others they are associated with cooling. By the same token, the types of fuels used in households for specific end uses (eg space heating) vary significantly between States.[2]

While direct energy purchases comprise the bulk of our household energy use, energy is also indirectly contained in the products we buy – for example, energy is used to make and transport our food, clothing, white goods, and furniture and it fuels our use of public transport. Indirect energy use is not examined in the Transition.

It should be noted that the ABS survey reports **fuel costs** not **energy use**. Figure 1.2 in the next section reports the breakdown of our household **energy use** – it can be seen that it is broadly similar to the average Australian household fuel cost breakdown.

I have found the numerous books, papers and media articles that I have read on the topic of going zero carbon to be very instructive. Reading in this area can rapidly lead to the conclusion that the list of viable options for transitioning to a zero carbon household are narrow: install double glazing and other insulation; drop gas; install solar PV; heat your house and water with heat pumps, buy an electric vehicle.[3,4,5] Finally of course, get ready for installing battery storage in your home. When I started this project I imagined that we would more or less go down this path.

As I delved into the detail of what to do I became increasingly concerned that a sense of 'group think' is beginning to emerge amongst energy specialists. Many viable options for reducing the household carbon footprint rarely get any public scrutiny and promotion. While in the end I did take some of the steps recommended by the pundits, I also came across options that would work better for us. Some of these took us to newer technology; some to well established technology that the energy pundits now tend to treat disparagingly; while some, quite surprisingly to me, led us to adopting technology that has now more or less been abandoned.

The Transition is not about saving money. It is about trying to see whether there are readily available ways to do common things which give a better carbon outcome. Having said that, an awareness of costs is clearly important because ultimately any energy transition will only be widely adopted across society if the costs of 'new energy' are less than, or at least broadly similar to, the current costs of achieving the same lifestyle end (eg feeling warm in your home).

The Transition is also not about changing lifestyle. One of the key aims of the book is to show that a family living a 'normal' life in the suburbs can enjoy all the usual conveniences of modern living and yet still have an extremely small carbon footprint. This is not a book about us sitting around at home in our ski gear munching raw spinach in the dark.

Our house is a relatively standard brick veneer 4-bedroom house in the Belconnen area in the Australian Capital Territory (ACT). It is approximately 220m^2 in floor area and was built around 2005.

When we moved in in late 2012 our house had ceiling insulation, single glazing and no wall insulation. The Energy Efficiency Rating was 3.0 (Low). It had a 2kw solar PV system on a west-northwest facing roof. The space heating, hot water and our cooking top were fuelled by

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[2] *Environmental Issues: Energy Use and Conservation, Mar 2014.* Australian Bureau of Statistics. http://www.abs.gov.au/ausstats/abs@.nsf/mf/4602.0.55.001

[3] *An energy freedom home is a zero emissions home.* RenewEconomy Aug 2015. http://reneweconomy.com.au/2015/an-energy-freedom-home-is-a-zero-emissions-home-23818

[4] *Weaning myself off gas and then the power grid.* Climate Spectator Nov 2015. http://www.businessspectator.com.au/article/2015/11/9/smart-energy/weaning-myself-gas-and-then-power-grid?t=3078fcc9a3d9a7183fb401701ce1e061bd9c05ef

[5] The Energy Freedom Initiative. http://energyfreedom.com.au/

natural gas. The heating was a ducted gas central heating system (supplemented by a heat pump in the main bedroom). The house also had a ducted evaporative central cooling system. The ducted heating/cooling systems, coupled with the many recessed ceiling down lights, meant that in most rooms the ceilings looked pretty much like gruyère cheese – not good for room insulation! We are on an ActewAGL Home time-of-use tariff for our electricity.[6] We are a family of two adults and two children.

To place our household in context, the residential sector in Australia constitutes about 20% of the national carbon footprint.[7]

1.2 The Base Year - 2013

I have chosen 2013 as the baseline year for the Transition since this was the first full year we lived in the house and over this time we made no modifications to the energy systems; we simply used the systems that were in place when we moved in. The gas heating systems worked fine - we had more or less uninterrupted hot water and had good thermal comfort over the winter (which in Canberra is invariably cold by Australian standards). We did not feel the need to use the ducted evaporative cooling in the warmer months. The year 2013 is also a good base year for comparing energy use for our cars since when we moved into the house we owned two medium/small petrol fuelled cars – a Nissan Pulsar and a Hyundai i30. I sold the Nissan Pulsar at the end of 2013 when I took ownership of my electric vehicle (EV) – a Nissan Leaf. I have written separately about my EV experience.[8]

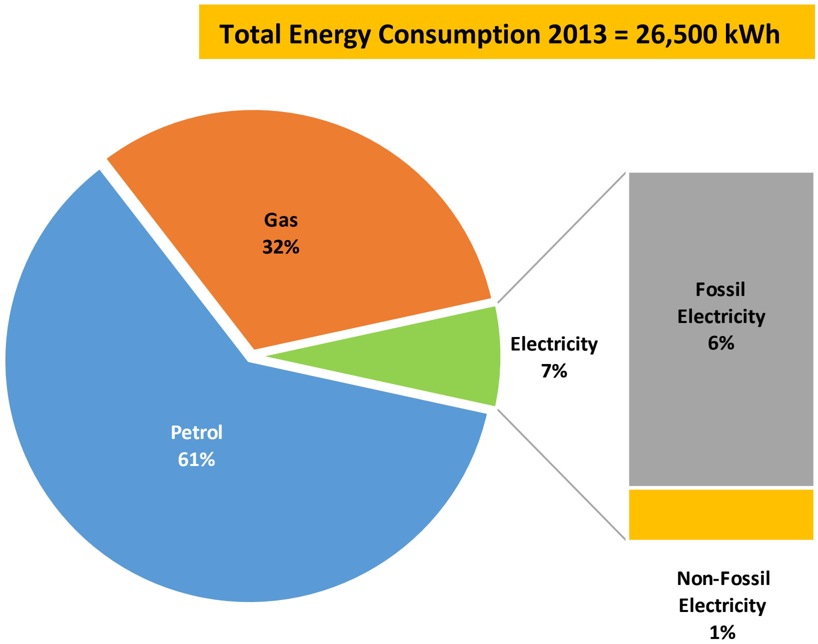

Figure 1.2: Our household energy split by fuel type 2013

Figure 1.2 shows a breakdown of our household energy use by fuel for the base year of 2013. The Figure clearly shows the predominance of gas and petrol as energy sources for our household in 2013. Less than 10% of our energy was delivered in the form of electricity. The cars used about 60% of our energy budget. [I discuss the monitoring of our household energy use in Chapter 8.]

One key figure I try to report throughout the book is the component of our energy usage which is derived from non-fossil fuels. The Figure shows that in 2013 only about 1% of our total household energy use came from non-fossil fuels: this was electricity derived from

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[6] *Our ACT Electricity Prices.* ActewAGL. July 2015. http://www.actewagl.com.au/~/media/ActewAGL/ActewAGL-Files/Products-and-services/Retail-prices/Electricity-retail-prices/ACT-electricity-schedule-of-charges-2015-16.ashx?la=en
[7] *Households and GHG emissions.* EPA Victoria. http://www.epa.vic.gov.au/agc/r_emissions.html#/!
[8] *Living with a plug-in electric car in Canberra.* Dave Southgate. Aug 2014. http://electricvehicleaustralia.com/electric-vehicles/

the renewables component in the electricity delivered to NSW/ACT (in 2013 about 15% of the electricity on the Australian grid derived from renewables[9]).

Care needs to be taken when comparing the usage of petrol and gas with electricity. Petrol and gas are primary sources of energy, electricity is commonly a derived form of energy usually from coal (black and brown) and gas. The amount of primary energy used to generate electricity in Australia, when using fossil fuels, is typically about 3 times the amount of electrical energy consumed at the point of delivery. However, as the electricity generation system is now going through a transition from fossil to non-fossil electricity, throughout this book I deliberately refer to the quantum of energy at point of use (ie at the house + car) when comparing between different fuels.

2013 Household Carbon Footprint = 7t CO_2

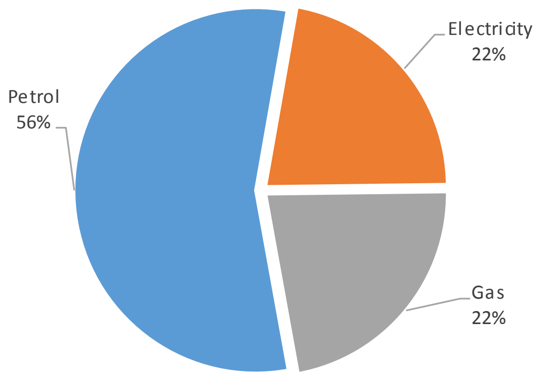
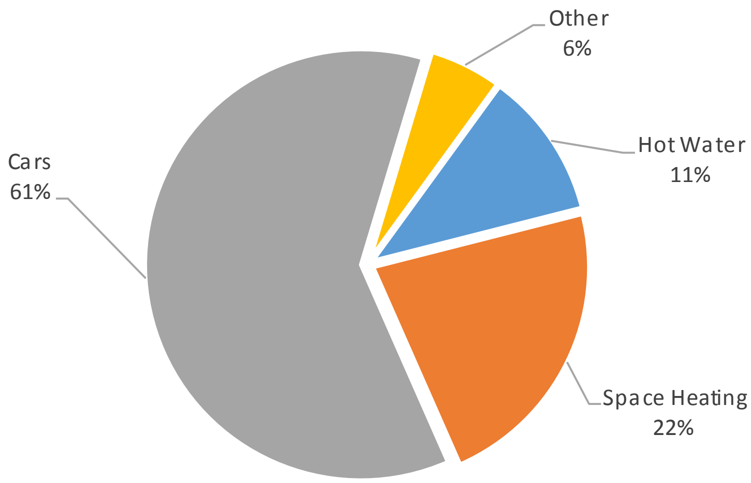


Figure 1.3: Our 2013 household carbon footprint split by fuel type

Figure 1.3 shows the breakdown of our household carbon footprint by fuel type for the base year of 2013. By comparing Figures 1.2 & 1.3 it can be seen that while the proportion of the total carbon footprint taken up by petrol is similar to that taken up by the energy split, the proportion taken up by electricity has more than tripled. This reflects the fact, as discussed in the previous paragraph, that the electricity provided in the ACT at the moment is primarily derived from black coal. The carbon footprint is indicative of the quantum of primary energy that is used by our household.

Figure 1.4 breaks down the household energy use in 2013 by end use. In 2013 we used gas for both hot water and space heating. You can see from the Figure that while we need hot water all year round the energy used for seasonal space heating is about double that for hot water. The heating season in Canberra usually starts rather suddenly at the end of April and runs in anger for about four months until the end of August. Cool evenings requiring at least some heating can persist through to the end of September.

Figure 1.4: Our 2013 household energy split by end use



[9] *Clean Energy Australia Report.* Clean Energy Council. 2014. http://www.cleanenergycouncil.org.au/cleanenergyaustralia

1.3 The Transition Target

I am a great believer in targets. I believe establishing targets provides direction, focuses effort and facilitates transparent tracking, and reporting, of progress toward reaching a goal.

In recent times the whole world has been engaged in a great discussion about climate change targets as part of the Paris COP21 meeting.[10] One hundred and ninety-five nations adopted the 'Paris Agreement' which requires all Parties to produce and report climate change goals.[11]

These national targets simply form the apex of a very large global pyramid of carbon targets. Many nations have multiple sub-national targets relating to climate change. Likewise, many multinational companies have adopted renewable energy targets.[12] In Australia, individual States and Territories have targets[13], cities have targets[14] and small communities are developing targets[15]. I am very happy to slip our household target in as just one extremely small brick at the base of the pyramid.

I have set up a two stage target to help me put in place, and monitor the progress of, the Transition:

- **Stage 1 target is to be a net zero CO_2 emissions household:** *this means that the carbon footprint of the grid electricity we displace (by exporting solar PV electricity) is equal to, or greater than, the carbon footprint of the energy we consume from fossil based sources (ie grid electricity, gas and petrol).*
- **Stage 2 target is to not use any fossil based energy within our household:** *this means not buying any gas, petrol, or non-renewable based electricity (ie 100% fossil fuel free (FFF)).*

Many would argue that the Stage 1 target – carbon neutrality – is the only necessary step. They take the view that society can become fossil fuel free simply by all the individual elements of an economy progressively going carbon neutral over time. Fair enough. However, I'm interested in exploring whether the decarbonisation process can be accelerated in some way by individual households independently going FFF.

I discuss the proposed timeline for reaching our target in the last chapter of the book.

Without going into any detail, I think it is important to understand, and question, our household carbon plans in the context of the bigger picture targets. How do the individual's actions fit in with the plethora of global, national and sub-national government climate change targets and actions? Will actions by governments make individual action unnecessary? For example, do the ACT Government's plans to source 100% of the Territory's electricity from renewable sources by 2025[16] mean that there is no need for Canberrans to install solar PV?

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[10] 21st Conference of the Parties to the United Nations Framework Convention on Climate Change (UNFCCC).
[11] *Article 4. The Paris Agreement.* UNFCCC. http://unfccc.int/resource/docs/2015/cop21/eng/l09r01.pdf
[12] *Renewable Energy.* Google. https://www.google.com.au/green/energy/
[13] *90 percent renewable energy target.* ACT Government. http://www.environment.act.gov.au/energy/cleaner-energy/renewable-energy-target,-legislation-and-reporting/90_percent_renewable
[14] *Carbon Neutral Adelaide.* Government of South Australia. http://www.environment.sa.gov.au/Science/Science_research/climate-change/climate-change-initiatives-in-south-australia/sa-climate-change-strategy/carbon-neutral-adelaide
[15] *Five NSW towns bid to Australia's first zero net energy town.* Reneweconomy. http://reneweconomy.com.au/2014/five-nsw-towns-bid-to-be-australias-first-zero-net-energy-town-16968
[16] *Canberra to be 100% renewable by 2025.* ACT Government. http://www.cmd.act.gov.au/open_government/inform/act_government_media_releases/barr/2015/canberra-to-be-100-renewable-by-2025

Not long ago, if you espoused the idea of the global economy being fuelled by 100% renewable based electricity by 2050 you were treated as if you lived in a fantasy world. Now this concept seems to be gaining wide acceptance. In the period around the Paris COP21 '100% by 2050' became a common theme. This target was touted by a range of bodies and prominent researchers.[17,18,19]

In Australia the opposition Labor Party has recently adopted a target of 50% of Australia's electricity being based on renewable energy by 2030[20] - this target is broadly aligned with a '100% by 2050' target. Not surprisingly it is not hard to find reports which claim that the '100% by 2050' target is lacking ambition and that the world could be at 100% renewable based electricity much earlier.[21,22] The Australian Greens, which have adopted a target of 90% renewable energy by 2030, would appear to be in this latter camp.[23]

The reader may well say 'It's fine for governments and political parties to set grand targets but are they achievable?'; 'Aren't they simply aspirational goals?' No doubt some goals will be aspirational, but in fact that there is a long history of the costs of renewable energy falling much faster than predicted and of renewable goals being achieved ahead of time. Most notably for Australians, over the past two years there has been a very painful debate in the Federal Parliament about cutting back on our legislated Renewable Energy Target (RET) because we were going to achieve more than the anticipated 20% renewable share by 2020.

Overseas there are many examples of substantial progress being made toward '100% by 2050'. For example, Germany is already generating more than 30% of its electricity from renewables[24] and it has legislated a target for renewable energy to account for an 80% share in gross electricity consumption by 2050.[25] In October 2015 the California State Governor signed into law the requirement that 50% of the State's electricity be sourced from renewables by 2030.[26]

As far as I can tell our household target is perfectly consistent with the thrust of global action on climate change.

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[17] *World's vulnerable open gateway to climate safe future at Paris.* Climate Vulnerable Forum. Nov 2015. http://www.thecvf.org/wp-content/uploads/2015/04/High-Level-Meeting-1.pdf

[18] *139 Countries could get all of their power from renewable sources*. Scientific American. Nov 2015. http://www.scientificamerican.com/article/139-countries-could-get-all-of-their-power-from-renewable-sources1/

[19] *Zero emissions needed from electricity by 2050 to hold below 2ºC.* Reneweconomy. Dec 2015. http://reneweconomy.com.au/2015/zero-emissions-from-electricity-by-2050-to-hold-below-2c-stern-40185

[20] *Renewable Energy.* Australian Labor. Jul 2015. http://www.alp.org.au/renewableenergy

[21] *Clean disruption of energy and transportation.* Tony Seba. Jun 2014. http://www.amazon.com/Clean-Disruption-Energy-Transportation-Conventional-ebook/dp/B00L2M7UK8/

[22] *Zero Carbon Australia. Stationary Energy Report.* Beyond Zero Emissions. Jun 2010. http://media.bze.org.au/ZCA2020_Stationary_Energy_Report_v1.pdf

[23] *Clean Energy Roadmap.* The Australian Greens. Nov 2015. http://greens.org.au/clean-energy-roadmap

[24] *Germany reaches new levels of Greendom, gets 31% of its electricity from renewables.* Bloomberg Business. Aug 2014. http://www.bloomberg.com/bw/articles/2014-08-14/germany-reaches-new-levels-of-greendom-gets-31-percent-of-its-electricity-from-renewables

[25] *Renewable Energy Target Setting.* p25. International Renewable Energy Agency. Jun 2015. http://www.irena.org/DocumentDownloads/Publications/IRENA_RE_Target_Setting_2015.pdf

[26] *California's ambitious renewable energy bill signed into law.* Reuters. Oct 2015. http://www.reuters.com/article/us-california-energy-law-idUSKCN0S129M20151008#LEhq0s2OG3rcBVwA.97*50%*

1.4 How do we get to the Target?

Timeline for our Household Target

To be meaningful targets need to specify both a quantum and a date.

In the beginning I had a vague timeline in my mind that we would essentially be a net zero carbon family by 2020 - that is, we would reach our Stage 1 target by this date. In the event we arrived at this point by the end of 2015.

The timing of reaching our final target is much more difficult to predict – when we started out I hoped that lessons from Stage 1 would provide guidance for drawing up the timeline to the ultimate target. At the present time it appears that the ability to reach the final goal will largely be driven by the capacity and cost of yet to be released home battery systems; smart chargers for EVs; and the next generation of electric cars. The rate of decarbonisation of the electricity grid is of course a fundamental factor in the timing of change. I develop a draft timeline for the next stage of the Transition in the final chapter of the book.

A goal without a plan is just a wish.[27]

For an ex-bureaucrat like myself there is a well-established approach to attacking projects such as the Transition. You establish the 'where are we now?' baseline; decide on the proposed destination (the target); and develop an action plan which sets out the way you propose to reach the target. I discuss the development of the Transition Action Plan in the next chapter.

I referred earlier to what now appears to be a widely agreed route to the carbon neutral household: insulate the house, install solar PV, turn off the gas, use heat pumps for space heating and hot water (or maybe install a solar collector hot water system), and finally buy an electric vehicle. When I started out on the project my initial thinking was to more or less follow the recommended steps but possibly not in the order shown. Having said that, I was keen not to slavishly follow a formula and was determined to examine a range of available options for each of the identified steps.

When I began looking at options (eg which is the best way to get hot water?) it readily became apparent that the selection process was not going to be straightforward. Why would I choose option A over option B – am I looking for the smallest carbon footprint; or the least cost; maybe I am trying to use as little electricity as possible from the grid? There are several ways in which each option can be evaluated – these commonly do not lead to the same outcome. In the next chapter I work through my thought processes on deciding which criteria were important for me when deciding between options – this led me to set up an informal selection hierarchy for the implementation steps.

1.5 Report Focus and Structure

The purpose of this book is not to promote any particular route toward a fossil fuel free household. Rather it is aimed at demonstrating what we as a family have done, why we have done it, and what point we have reached with the reduction of our CO_2 footprint. It also identifies the broad costs, and savings, of implementing the Transition. If this serves to encourage others to take a similar route that's fine. Equally, if this warns others to adopt different paths which are more suited to their particular needs then I believe the book will also have made a positive contribution.

It is important in the first instance to emphasise that the target of the transition is not to go 'off grid'. I see networks as being an essential part of our future electricity system. I envisage that we

[27] Quotation. Antoine de Saint-Exupery. http://www.quotationspage.com/quote/34212.html

will have many large scale renewable energy plants around Australia within the next 40 years – solar, wind and wave[28] which will form the backbone of the grid. In addition, I want to be able to sell (or at least share) any surplus electricity my family generates. The 'grids' in the domestic context may well be simple neighbourhood microgrids or local distribution systems.

Many of the steps I have chosen in the Transition are clearly very personal and are closely linked to my own interests and priorities which may be totally inappropriate for others. It also should go without saying that the energy demand patterns of a household in Canberra with its frigid winters are going to be very different to the energy use patterns of most other Australians.

I am very interested in the use of data to underpin understanding and action on climate change and have previously produced four other books relating to this area.[29] I have tried to keep this book in the same style to provide a sense of continuity.

I have divided the core of the book into two parts. Part 1 essentially describes the steps I have taken to bring about the Transition. This includes an explanation on how I arrived at the action options I chose. The individual chapters in this Part examine the individual elements of the Transition in turn.

Part 2 focusses on assessing the outcomes of the Transition actions. This includes computing and reporting energy and CO_2 outcomes (Chapter 8) along with indicative costings (Chapter 9).

This book is only a snapshot of an ongoing process and covers the Transition actions I have taken over the past two years (calendar years 2014 and 2015). Several other key actions will need to be taken before we reach the final fossil fuel free goal – these are discussed in the final chapter of the book.

I use the term '% Fossil Fuel Free' (%FFF) throughout the book to indicate the extent to which we are progressing to the final 'zero carbon' target. This percentage relates to the proportion of the total energy used which is sourced from non-fossil based fuels (ie %renewables). I do this because '% renewables' is a term that generally captures only electricity and I am keen to broaden peoples' horizons so that the carbon footprints of natural gas and petrol, in addition to electricity, become factored into our thinking. While I recognise that different fossil fuels have different CO_2 emission factors, and hence '%FFF' is not as accurate as reporting the carbon footprint, I believe that using physical terms like '%renewables' and '%fossil fuel free' provide the layperson with a more comprehensible, and less confusing, picture of carbon progress than indicators involving terms such as 'net carbon' or 'zero carbon'.

To illustrate this point, there seems to be some discussion about the correct use of the terms 'carbon positive' and 'carbon negative'. Throughout this book I use the term 'carbon positive' to describe the situation where the carbon footprint of our total energy consumption is less than the carbon footprint of the fossil based grid electricity we displace through exporting solar PV electricity. This approach is consistent with that adopted, for example, by the Australian Government 'Your Home' website.[30]

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[28] Some exciting work is going on in Western Australia on wave energy. This is one to watch. http://carnegiewave.com/

[29] *Living with a plug-in electric car in Canberra.* Dave Southgate. Aug 2014. http://electricvehicleaustralia.com/electric-vehicles/

[30] *Carbon zero, carbon positive.* Australian Government – Your Home. http://www.yourhome.gov.au/housing/carbon-zero-carbon-positive

Chapter 2

Transition Action Plan

2.1 Introduction

In the previous chapter I have described our goal of being a fossil fuel free household and have shown in Figure 10.2 an indicative timeline for our achieving that goal. The fundamental question is what are we going to do to get to our goal? The broad thrust of the action I proposed at the start of the Transition has been outlined in Sections 1.3 & 1.4. This chapter attempts to put some detail into those conceptual plans.

At the top level the aim of the Transition is to effectively eliminate the use of gas and electricity sourced from coal within our household within the next few years. While it may take a little longer to totally eliminate the use of petrol the aim is to progressively switch over to plug-in electric vehicles. The aim is to, as far as possible, generate all the electricity we use from our own solar PV systems (while recognizing that the electricity supply for the ACT is being rapidly decarbonised).

In the first instance it is very easy to stop using mains gas in a household. About 30% of the houses in Canberra are not connected to mains gas. My current house is first one that I have lived in in over 50 years that is connected to mains gas. Replacing petrol is more complex. Current electric vehicle technology is providing excellent 'city vehicle' EVs (such as my Nissan Leaf) and very practical plug-in electric/petrol hybrid cars, but battery capacity constraints mean that we are not yet at the point where the EV can replace the petrol engined car on a wide basis. Having said that, I believe that we are much closer to that point than most people realise.

Once my family made the decision to undertake the Transition many other steps logically followed. I have made a list of these in Section 2.2. While the list of actions appears to be straightforward there are a multitude of decisions contained within each step – this part of the process was for me a lot of fun and involved me really having to work out my priorities. Inevitably it meant taking risks as I tried out new concepts and gizmos - something I find totally fascinating!! My thinking on the decision process is captured in Section 2.3.

2.2 Action Menu

In setting up the Transition Action Plan I initially had an informal list in my mind of steps I would need to take to reach the 100%FFF goal. Not surprisingly these were pretty much in line with all the other transition lists I'd come across in my reading (and already mentioned in the previous chapter):

- Improve the house insulation
- Install more solar PV
- Buy an EV
- Change from gas to electric hot water
- Change from gas to electric space heating
- Change from gas to electric induction cooktop for cooking
- Turn off the gas

- Install energy storage – both thermal and battery
- Progressively install more efficient electrical devices (eg LED lights, new fridge, replace the old plasma TV with an LED TV, etc).

I broadly adopted this list of actions as the framework for the Transition action plan.

2.3 Decision Hierarchy

When I started to think about how I would implement each of the steps identified in the previous section it very quickly became apparent that I would have to sort out what my priorities would be during the Transition. Clearly this was not going to be straightforward – many trade-offs would have to be made. To help my thinking I drew up a list of decision criteria which is shown below.

In the context of the list, 'decision' refers to making choices between competing delivery options (eg deciding between a heat pump or resistive heating to generate hot water). The hierarchy is in a loose order of priority but I didn't stick rigidly with this since usually there were multiple boxes to be ticked. While the first two boxes could appear trivial these really underpinned what I was doing – it was fundamental to the Transition that I had the support of my family and that I did not upset my neighbours. When making a decision I roughly gauged how many of the boxes each of the options ticked and then, in my mind, weighted them by importance to come to a decision.

The decisions were always underpinned by the fundamental aim of minimising our household CO_2 footprint and moving off fossil fuels. The decision hierarchy I arrived at was:

- ☐ Maintain comfort levels – the Transition is not about negatively changing lifestyle
- ☐ Avoid adversely affecting neighbours – particularly avoid the emission of disturbing noise
- ☐ Minimise the direct and indirect burning of fossil fuels (gas, petrol, coal/gas fired electricity)
- ☐ Maximise solar generation
- ☐ Maximise self-consumption of solar PV
- ☐ Maximise energy storage - prioritise thermal storage over battery storage
- ☐ Minimise energy use
- ☐ Keep it simple – give priority to options with no moving parts; solid state; electro-chemical
- ☐ Maximise data capture possibilities
- ☐ Support innovative devices (eg energy diversion devices; microinverters)
- ☐ Favour versatility (eg favour an option that can generate electricity as well as provide hot water)
- ☐ Minimise cost

There are a number of conflicting options in the list. For example, 'maximise solar' and 'maximise self-consumption of solar PV' can be in conflict with 'minimise energy use' – this is likely to occur when heating options involving thermal storage (of solar PV electricity) are selected over heat pump based approaches. I discuss how I handled these conflicts in the relevant chapters of Part 1. In my view energy storage is key to the future of solar PV – this is discussed in the next section.

The imperative to 'minimise energy use' appears to lose some of its import when the energy in question is solar PV electricity and, at least at the household level, the CO_2 footprint is not increased if more self-consumption takes place. In addition, as the price of solar PV drops the attractiveness of minimising energy use has to be weighed against the value of generating carbon free electricity. For example, for $10,000 I can now buy a solar PV system that will very conservatively generate 6,000kWh/year when installed in Canberra. Alternatively, if I spend that $10,000 on double glazing for my house I may, if I am very lucky, save about 1,500kWh/year in energy for heating/cooling. Should one therefore just focus on installing solar PV and forget about double glazing?[31]

While minimising our carbon footprint is the aim, it is important to recognise that directly burning gas in the home will, at the present time, very likely generate a lower carbon footprint than using grid based electricity since this electricity is still predominantly sourced from coal. Does this mean I should not have turned off the gas until I could directly replace it with renewable based electricity? This is possibly so, but my reasoning was that this situation will only be transitory as the ACT is now well progressed to reaching its goal of 90% of its grid based electricity deriving from renewables by 2020. Indeed, the ACT Environment Minister has recently indicated that the Territory will be generating 80% of its electricity from renewables by 2018.[32] Given this rapid progress I saw no need to delay action.

As an engineer, I'm very attracted to simple options which involve no moving parts as this will almost certainly result in greater reliability and less maintenance (eg resistive electric heating over heat pumps). Again wearing my engineer's hat, I'm also attracted to options which readily facilitate the generation of data so that I can have an understanding of energy flows within the house.

I have put 'support innovative devices' very close to the bottom of the list – this is not because I'm not interested in innovation (far from it!) rather it's because in reality this is a rather nebulous concept: at what point does one jump in to try out a new gizmo? I tend to be an early adopter and am generally happy to try out new devices for my major projects provided they cost say $2,000 or less (eg see the 'Immersun' in Section 3.2), but I do tend to be more cautious when we are looking at more expensive items and usually wait for prices to drop below my own rather informal price trigger levels before I decide to jump (eg I have yet to enter the home battery field).

The reader will no doubt note that 'Minimise cost' is at the bottom of the list. The Transition is not about costs - the prime aim is about demonstrating technical/user feasibility, though of course it is unlikely that there will be a mainstream household energy transition across society unless the cost savings are compelling.

2.4 Energy Storage

This is an area that probably needs little attention in this book as it has featured very prominently in the energy media for the past year or so.

It goes without saying that the missing link with almost all sources of renewable energy is storage. By its very nature renewable energy tends to be intermittent with distinct diurnal and seasonal patterns (particularly solar and wind) and hence energy storage of some form will generally assist in making renewable energy more useful. Almost inevitably the focus of the media attention has been on batteries; that is electro-chemical storage of electricity, since this form of storage has the widest

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[31] *In an age of cheap solar, does efficiency still matter?* RenewEconomy. Sep 2015. http://reneweconomy.com.au/2015/in-an-age-of-cheap-solar-does-efficiency-still-matter-14204

[32] *Fifteen wind farms vie for ACT contracts as second auction round closes.* The Canberra Times. Oct 2015. http://www.canberratimes.com.au/act-news/fifteen-wind-farms-vie-for-act-contracts-as-second-auction-round-closes-20151014-gk9i1s.html

area of application (particularly in transport). Much less often discussed, but not totally ignored, is thermal storage; that is storing electricity as heat in water and in dense solid material such as rocks and bricks – this form of storage can be very useful for optimising the use of renewable energy in buildings.

When I began considering options for the Transition I was particularly interested in storage. If I had been undertaking the Transition in five years' time, I may well have made different decisions because I imagine by then the price of battery storage will have fallen dramatically. However, in 2015 the installed cost of thermal storage via hot water is about 1/10th of that of battery storage[33] and not surprisingly I was keen to explore whether I could utilise thermal storage in some way. I discuss my thought processes on this in Chapters 3, 5 & 6, but in essence opting to incorporate storage was a very important factor in me ultimately deciding not to use heat pumps for either space heating or hot water (there were also a number of other factors which were pivotal in making this decision).

As long as thermal storage is significantly cheaper than battery storage I envisage that there will be merit in attempting, in the first instance, to store solar PV electricity as heat when the end application is space and water heating and then using battery storage for more specialist end uses (eg lighting, home appliances, etc).

2.5 Monitoring

Any Action Plan lives or dies on the back of its monitoring regime. Clearly there needs to be a way of tracking progress toward the Action Plan target. If the planned implementation steps are not being effective, then the plan needs to be revised.

Throughout the transition period I have been manually taking five readings each day from my electricity meter. In addition, I have been logging the output from two of my solar systems by reading inverter outputs. In my EV each day I zero my meter and record the total distance travelled and the reported EV efficiency (see my EV book for details). My energy diversion device (the Immersun) gives me daily data about how much energy is diverted (to either hot water and/or the space heater). I have also used a datalogger on an ad hoc basis to check the energy used by individual appliances.

In addition, I have gathered information on our overall energy costs from our electricity and gas bills.

I have collated the daily energy data to present the energy use and CO_2 footprint data in Chapter 8. I have combined the energy costs from our utility bills; information on our expenditure for the various pieces of equipment we have purchased and installed as part of the Transition; and the energy use data in Chapter 8 to provide the costing information shown in Chapter 9.

The data is not perfect but I am confident that it is largely robust. Like all data sets there are gaps. I have also had to compute a number of values by inference rather than direct reading. I point out these deficiencies at the relevant points in the text.

I intend to continue this monitoring in the coming years and to produce informal update reports, at least annually, on our progress to becoming 100%FFF.

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[33] A typical household hot water system will store about 10 kWh at an installed cost of about $1,000 (see http://www.engineeringtoolbox.com/energy-storage-water-d_1463.html). A typical home battery system will store 1 kWh for an installed cost of around $1,000.

2.6 Implementation Overview

As I have already mentioned a few times, the Transition is not about saving money. Having said that, I do not have unlimited funds and I broadly set myself some informal price trigger levels that I wanted to meet before taking action. Being involved in the renewable energy/innovation space is interesting since there is an almost certain inevitability about the costs of action falling over time, so the trick is often simply just to wait until the price is right. With the electric car I had said to myself that once the price of a real EV (ie an EV with similar features to a 'normal' car) dropped below $40,000 I would enter the market with serious intent. This is what happened in mid-2013. For other elements of the Transition I was looking for a payback time of no more than 10 years for any individual element of the transition - you'll see in Chapter 9 that I certainly didn't achieve this for many of the actions I took.

I decided that I needed to beef up our solar PV capacity as the first step of the Transition. As we were transitioning over to electricity from gas and petrol we would clearly need to be able to produce more carbon free electricity to cover the increased electricity demand.

As things transpired I took possession of the EV in January 2014 about two months before I added our first additional solar PV system. In late 2014 we installed double glazing in our house.

Early in 2015 we installed another solar PV system a month or so before converting our gas based hot water system over to electricity. We did not use our gas central heating system over the 2015 winter but instead heated our home with electrical heaters. The timing of the heating transition did not work out all that well since we were only able to install one part of our new electrical heating system before mid-winter. We did not install the key part of our new electrical heating until late August 2015.

At this point our only gas use was our cooking top. We replaced this with an induction cooktop in November 2015 and we had the gas disconnected from our house a few weeks later in early December.

Part 1 of the report, which follows, gives details of each of the Transition implementation steps. In particular, it sets out the reasoning behind the decisions I made when selecting the key equipment to replace the gas hot water and space heating systems.

PART 1

TRANSITION ACTIONS

Chapter 3

Moving Away from Coal: Solar PV

3.1 Introduction

Clearly installing PV solar had to be the first step in the Transition since the concept is that we progressively take ourselves off gas, petrol and fossil based grid electricity and move over to renewable electricity delivered either by the grid or by solar PV systems on the roof of our house.

When we moved into our current house in late 2012 it already had a PV system installed. This was a 2kW system which was on the ACT Government's gross feed-in tariff. The early feed-in tariffs that were introduced to encourage the up-take of solar give excellent financial returns and we have naturally left this system in place.

We installed the second 2kW system in early 2014 in conjunction with buying our electric car. This system is on the standard ActewAGL net feed-in tariff for the ACT of 7.5c/kWh.[34] While I set this up as part of getting our electric car, initially I was not often able to charge the car directly from this system because I frequently needed to use the car at the time when solar PV production is at its greatest. Over 2014 I almost exclusively charged the car at night using off peak electricity. However, towards the end of 2015, with both the new 2kW system and the latest 4.5kW system (discussed in the next paragraph) in place, I was able to achieve much higher rates of solar PV charging. This is discussed in Chapter 4.

In early 2015 we installed our next solar PV system – a 4.5kW system, also on the net standard feed-in tariff of 7.5c/kWh – as a prelude to going off gas. This is the largest system at our house and it took our total installed capacity to about 8.5kW. I decided to use microinverters[35] for this system rather than the standard central inverter for a number of reasons. To begin with I didn't want any more electrical equipment hanging off our outside wall – too many pieces of electrical equipment (while a beauty to my eyes) can become a bit intrusive. Also as this new solar PV system was filling in the spare space on our roof, it has quite a few disjointed sets of panels, and it may not have been practical to use a central inverter. Probably most important for me, as I love new technology, I was keen to see how microinverters would work out compared to the other inverters we have.

The first two solar systems at the house were on a roof facing west. The third system was split on a number of roof angles which were facing either north or west. In total we now have thirty-three solar PV panels on our roof. If I add additional solar PV capacity in the future this will have to be on

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[34] *Renewable energy generation – ACT customers.* ActewAGL. http://www.actewagl.com.au/Product-and-services/Prices/ACT-residential-prices/Feed-in-schemes.aspx
[35] *Enphase microinverters.* Enphase Energy. https://enphase.com/en-us/products-and-services/microinverters

the east facing roof of the house. Figure 3.1 shows the trend in total solar PV installed capacity at our house over the three years of the Transition.

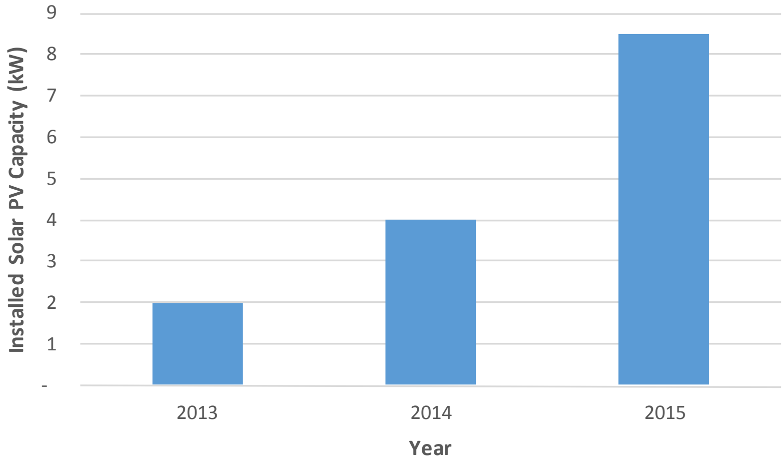

Figure 3.1: Changes in solar PV installed capacity over the period of the Transition

3.2 Managing the PV Output – Storage & Energy Diversion Devices

One of my key interests in putting in place the Transition was to explore ways in which we could maximise self-consumption of the solar PV energy we generate. In essence this meant that we would either have to schedule activities to use electrical devices during the day (say doing laundry) or store the energy in some way so that it could be used at the time it is needed.

Thermal Storage – Hot Water & Space Heating

For us, carrying out electricity consuming activities during the day does not use a lot of electricity and hence, while we try to do this (being retired I am commonly home during the day), it does not have any appreciable impact on the amount of energy we export. Therefore, I had to focus on energy storage. When discussing storage of electricity most people tend to think of batteries – electro-chemical storage – rather than the much simpler and cheaper storage option – thermal storage.

If home battery systems had developed to a truly economic stage at the beginning of 2015 I would probably have simply invested in one of these and not considered thermal storage. Many technically sound battery systems are now on the market in Australia but the costs are still high. As I noted earlier, the cost of storing a kWh of electricity in one of these at the present time is about 10 times that of using thermal storage. On the face of it, it would appear likely that thermal storage will always be an attractive option particularly for hot water, not only on cost grounds but also because of energy efficiency. Solar PV electricity used directly in a hot water system achieves a level of efficiency of 100% (or more with heat pumps), while if the electricity is first stored in a battery and is then subsequently extracted to power an electrical hot water device there are significant energy losses (the process of storing and releasing electricity from a battery is about 80-90% efficient[36]). Having said that, the energy efficiency losses of using a battery for a hot water system would probably only amount to about 1-2 kWh/day for a typical domestic hot water system.

[36] *Car Battery Efficiencies.* Sun J, Stanford University. Oct 2010. http://large.stanford.edu/courses/2010/ph240/sun1/

Thermal storage is of course not new. Most domestic hot water systems capture and store heat generated from either electricity or gas. Solar collector hot water systems store energy in the form of hot water which has been heated directly by the sun. Similarly, passive solar houses are often designed to capture solar heat in large solid mass (eg rocks or walls) during the day which is then released at night when space heating is required. We are certainly not alone in trying to find ways to store our solar PV electricity in the form of hot water. [37]

In recent times instant hot water systems, which bypass the storage stage, have become more popular – these systems have no storage losses but they do require large amounts of energy to be delivered in a short space of time. The high power demand of instant electrical hot water systems is not compatible with the usual domestic solar PV and battery storage systems (see Chapter 5).

Against this background, when I was looking at options for replacing the gas hot water system with an electric one I was keen to examine systems involving hot water storage. Similarly, when looking at options to replace the ducted gas central heating I wanted to explore electric spacing heating systems which involved storing heat generated by solar PV during the day and releasing it in the evening/night when space heating is required. My examination of these options is discussed in Chapters 5 & 6.

Energy Diversion Devices

When looking at water and space heating options involving storage, it rapidly became evident that it would be very useful if I could optimise the allocation of solar PV into my thermal storage devices. In the normal course of events, if devices such as resistive element hot water tanks are wired directly into house electricity circuits the devices will use any available electricity. This may be self-generated solar PV electricity if it is available, but if this is not sufficient to provide the energy required at least some, and possibly a lot of, top up electricity will be taken from the grid. This situation could be improved by using a time switch which turns on the storage devices say between 10am and 3pm – the period of peak solar PV output. While this would give a better capture of solar PV, it would not be an optimum solution since on cloudy days, or even sunny days with broken cloud, much of the energy used to heat the water could derive from grid electricity.

With this in mind my research soon took me to a family of devices which can be termed 'energy diversion devices' (EDDs). EDDs are commonly used in houses in Europe but seem to be rarely used in Australia. In essence these devices sense when excess solar PV electricity is being exported and divert this excess electricity into user specified storage devices (eg hot water cylinders or thermal storage heaters). These devices set up a priority listing for solar PV electricity usage at any given point in time: first priority is given to any appliances in the house which are not linked to the storage systems; second priority is given to the storage devices; the third priority is export to the grid. In this way the hot water system or storage heater can be solely powered by solar PV.

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[37] *Get more out of your solar power system by using water as a battery.* RenewEconomy. Feb 2015. http://reneweconomy.com.au/2015/get-more-out-of-your-solar-power-system-by-using-water-as-a-battery-26228

I examined a number of the EDDs on the market and eventually decided to buy a system called the 'Immersun'.[38] All the systems I studied claimed to achieve the same end – diversion of solar PV – but they appeared to vary greatly in their level of sophistication. I was attracted to the Immersum as it seemed to be the most polished EDD I could find. It also appeared to offer the best system for data capture which was of great interest to me. The purchase decision was sealed for me when I discovered that, as far as I could tell, the Immersun is the only EDD that is certified to meet all Australian electrical standards and it is being imported and supported by a reputable Australasian solar company.[39] The unit was installed for me by a local Canberra solar business.[40] The Immersun is discussed in the box on the next page.

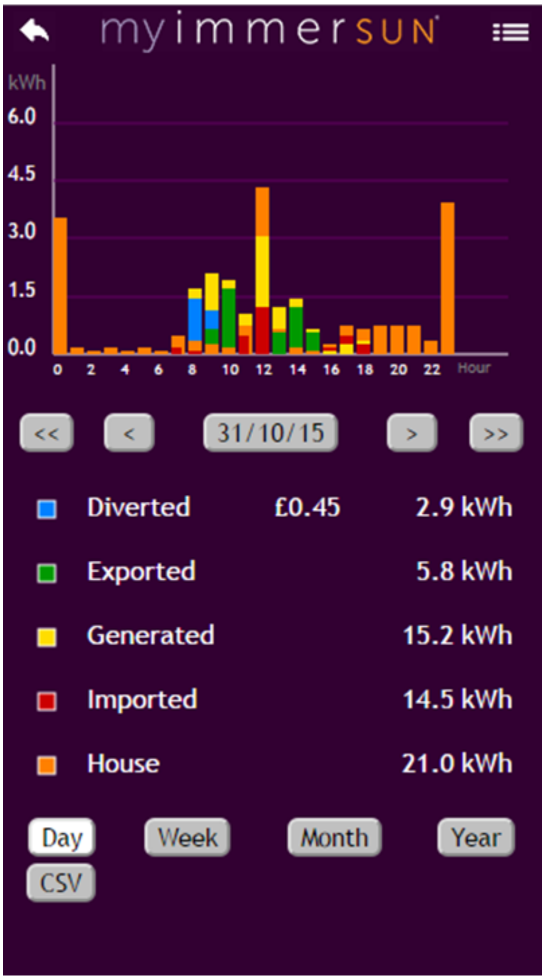

Figure 3.2: Screenshot of data on household energy production/use for one day

Discussion on the Immersun's energy diversion performance is given in Section 8.5. Subjectively I love the Immersun. It has a very neat user interface and it is really easy to monitor and modify its operation (it effectively operates automatically and most users will probably just want to set it up and forget about it). Its data system provides excellent real time information and datalogging capabilities. Figure 3.2 is a screenshot of a day's energy report from the system.

I believe that EDDs have a very important role to play in domestic solar PV systems. For example, solar PV households who are going to lose their generous feed-in tariffs in the next year or so in some Australian States will likely find installing one of these devices to be a very cost effective way of self-consuming some of their solar electricity, particularly if they already have a resistive heating element hot water storage system.

To be fully operational the Immersun needs to divert the solar PV electricity to a device which has a resistive heating element. Resistive heating elements will readily accept a power input which is below the rated power of the device: for example, a 3kW heating element will work totally satisfactorily if it can only draw 1 kW – but of course it will only deliver one third of its rated heat output. In practice the output power from a solar PV system, which fluctuates widely throughout the day, is likely to be below a hot water system's rated power for extended periods (depends on the size of the PV system, amount of cloud, time of day, etc). Devices which have electronic controls will not operate correctly (or be damaged) if they do not receive their rated power input. The Immersun has a feature which enables these latter devices to be hooked up to receive diverted solar PV electricity, but they will only operate when the design amount of power is available.

[38] Immersun. 4eco Ltd. http://www.immersun.co.uk/
[39] *ImmerSUN self-consumption controller.* Enasolar. Christchurch New Zealand. http://www.enasolar.net/Products/immerSUN
[40] Solarhub. Canberra. Australia. http://www.solarhub.net.au/

The Immersun

A photo of the Immersun control unit installed in my office at home is shown in Figure 3.3.

Figure 3.3: The Immersun Control Unit

In essence the Immersun constantly monitors whether a household is importing or exporting electricity. If the house is exporting, the device diverts the excess electricity into nominated devices such as a hot water heater or a storage space heater. Any device in the house not linked to the Immersun unit has priority – the unit does not interfere with these (eg if I turn on an electric kettle during the day this will use any available solar PV electricity before it diverts it to the hot water cylinder). The Immersun must be attached to resistive electrical devices which can happily operate at a power which is below the rated power of the device. The current version of the Immersun cannot operate with a device that has a power rating of greater than 3kW.

The unit has a range of user selectable functions – the most important one for me is that it can be programmed to automatically go into a boost mode at any time. The boost overrides the Immersun diversion process and means that a connected device (eg the hot water system) will be powered by grid electricity if no solar is available. I use the boost mode to ensure that we have hot water even on cloudy days. This is discussed in Chapter 5.

Figure 3.4 is a screenshot of the system's real time data monitoring system which shows the instantaneous key power demand patterns throughout our house. It is refreshed every few seconds. This operates via an internet site so the operation of a house's energy system can be monitored remotely.

The Immersun allows more than one device to receive diverted energy in a user defined priority listing. For example, when the water is hot, the solar PV electricity can be diverted to a storage heater.

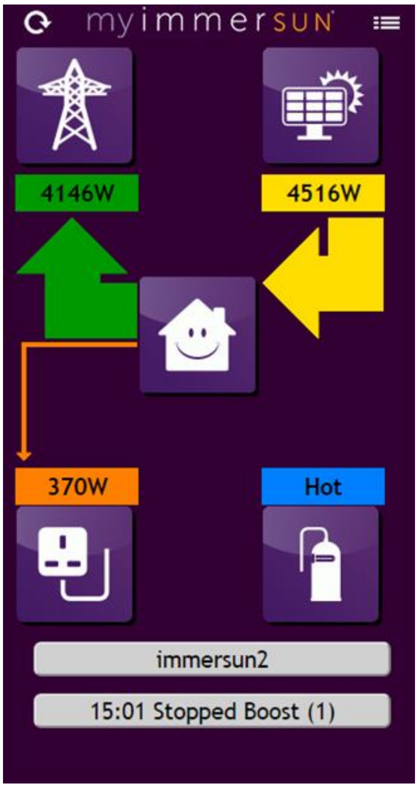

Figure 3.4: Screenshot of report on real time power demand patterns

Chapter 4

Moving away from Petrol: The Electric Car

4.1 Introduction

It was shown in Section 1.2 that in 2013 our cars were the major energy users, and carbon generators, for our household. This would appear to be the case for the average Australian household.

As noted earlier, buying my electric car (EV) was my first transition step in 2014. I changed from my conventional petrol car (a Nissan Pulsar) to an electric car (a Nissan Leaf) at the start of that year. We are a two car family. My wife works, I am retired. We tend to use my EV as the main family car while my wife generally only uses her car (a Hyundai i30) for taking the kids to school and for going to/from work. I typically do about 15,000km/year in my car while my wife goes about 8,000km/year in hers.

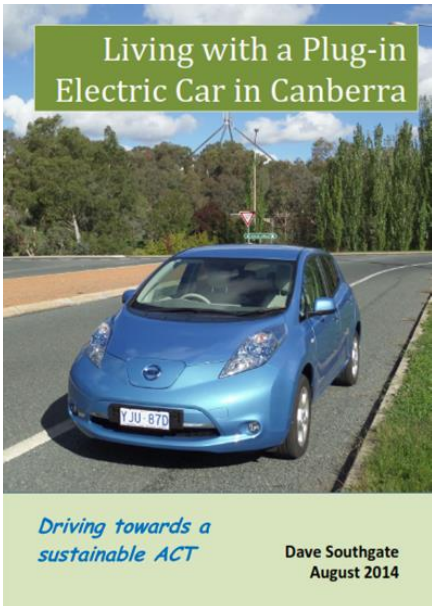

Figure 4.1: Front cover of my EV book

It can be seen from Figure 1.2 that petrol made up about 60% of our household energy use in 2013 – this figure dropped to around 45% in 2015. In 2014 I produced a book about my experiences with owning the EV - *Living with a Plug-in electric car in Canberra* - and would recommend that the reader look at this book if they would like to get further information about owning an EV.[41]

As the Transition is aimed at minimising our household carbon footprint, some may well say why not go the next step and do away with the cars and just walk, cycle and/or take public transport? This is fair comment – we do use simpler forms of transport when we can - but a key part of the project is to demonstrate that a big difference can be made in a family's carbon footprint without making major lifestyle changes.

Moving to an EV is the transition step with the greatest capital outlay (though the significant fuel cost savings made by using an EV mean a payback period of around 10 years) and we have no plans to attack our petrol usage further at this stage. We want to tackle the other big household energy areas before we put more money into EVs.

I started to focus on EVs in mid-2013. At that time the price of EVs dropped below my informal price trigger point for buying an EV of $40,000. In the second half of 2013 I began to keep data on my

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[41] *Living with a plug-in electric car in Canberra.* Dave Southgate. Aug 2014. http://electricvehicleaustralia.com/electric-vehicles/

daily car travel patterns to ascertain whether the EVs then on the market had the capacity to meet my daily travel needs. In fact, they very easily met my needs and I set up the purchase of my Nissan Leaf to take ownership right at the beginning of 2014.

4.2 The EV Experience

I give details of my experience with the electric car in my EV book but in a word it has been 'wonderful'! As of 31 Dec 2015 we had done just over 28,000 km in the Nissan Leaf. Its operation has been flawless and there have been no mechanical or electrical problems. It is beautiful to drive – smooth, quiet and has fantastic acceleration compared to my previous cars.

In the media it is common to see negative comments about EVs relating to 'range anxiety' and the lack of public chargers. In my experience these fears are totally misplaced. I have never had any 'range anxiety' when using my EV as a day to day city car – I know where I'm going and how much energy I'll need. I've never needed to use a public charger when using the car as a city car. In fact, charging has been one of the delights of owning an EV. Subject to the comments in the next section; I get home, plug in the car, it charges overnight on the off-peak rate and in the morning there it is fuelled up ready for the next day!! I find this much easier, and much more convenient, than going to a petrol station (and considerably cheaper – the fuel costs are approximately 25% of those of an equivalent petrol car).

For me, the need for public chargers will only become an issue if/when I want to turn my EV from a 'city car' into a 'regional car' or maybe even a 'highway car'. In the meantime, we just use our petrol car when we need to go places that are outside the range of the EV. [During the school holidays when my wife doesn't need to ferry the kids to school she uses public transport or an electric bike to commute].

4.3 Charging the EV with Solar PV – Smarter Chargers

In the previous section I've said that the charging side of owning an EV is a delight. The EV has a very simple user interface which lets the user set up the times at which the car charges – once this information has been entered the computer takes over the charging process without human intervention. This is terrific, but very often I can see missed opportunities during the day where the car could have taken on board some of our solar PV electricity which instead has been exported. Unfortunately, the EV chargers commonly used today are not as smart as they need to be when it comes to using solar PV.

I mentioned in Section 3.1 that towards the end of 2015 I was beginning to increase the proportion of our home grown solar PV electricity that I used to charge the car. In essence I did this simply by manually monitoring how much solar PV electricity we were exporting in real time (I get the data from my Immersun interface) and, if this was greater than the power demand of the EV charger, I plugged in the charger and left it there until either the car battery was full or the EV started to draw significant levels of power from the grid (due say to cloud cover or the approaching end of the day). While this was reasonably effective it was certainly not perfect – this meant that on many occasions I was drawing some energy from the grid at a higher tariff than the off-peak rate or that I was exporting some solar PV electricity that could have gone into the car.

The most straightforward solution would probably be to buy the right size home battery system, charge this up with solar electricity during the day and then transfer this to my EV battery at night. However, this is not a particularly elegant solution. Charging and discharging batteries has inefficiencies and inverting electrical current from AC to DC and back again also has inefficiencies so options which minimise the number of these steps are likely to be a much better approach.

I envisage the next version of my home EV charger being much smarter. There is no shortage of references to 'smart charging' on the internet but it appears these concepts usually involve some form of integration with electricity grids (see for example [42,43]). I am more interested in having a smart standalone charger. It is not hard to visualise some form of domestic smart charger which lets you select the amount of the battery you want to charge overnight from the grid based on your planned EV usage for the next day. For example, I normally travel about 40-50km each day and therefore I like to start the day with at least 80km range so that I have a good travel buffer. So I would like to be able to tell my charger before I go to bed 'make sure at the end of the night I have 80 km range and we will try to top up the battery tomorrow with solar PV'. Ideally the next day will be sunny and I will have enough spare solar PV electricity (after having heated up the household water) to fill up any remaining capacity in my EV battery using some form of EDD during the periods when I'm not using the car. If it is not possible to add any electricity to the battery the next day due, say, to lack of time or cloudy weather, it will still hold enough energy for my planned level of use for that day and can be subsequently charged up using the same approach the next night.

This type of 'smart charger' concept will presumably be much easier to introduce when car battery sizes increase and there is a lot more spare capacity in EV batteries. In coming years, when EVs have significantly larger batteries it is not hard to visualise a very high proportion of the day to day charging being carried out using home generated solar PV electricity.

Presumably the end game for EV charging is the adoption of concepts such as that now being floated by Nissan which enable the EV owner to use the car's battery to power the house as well as the car.[44,45] On the face of it, this would be a relatively straightforward development – I envisage that these types of systems will become commonplace when the average EV has a battery capacity of +60kWh (the battery in the soon to be released Chevrolet Bolt discussed in the next section and in the mooted next generation Nissan Leaf are going to be this size).[46]

4.4 Potential next moves

Things are moving very rapidly in the EV field. Most major car manufacturers are now producing some form of plug-in electric vehicle. Very few of these have appeared on the market in Australia but in some countries EVs have achieved significant market penetration. Norway is the leading example – in 2015 EVs made up approximately 23 % of new vehicle registrations.[47] Several manufacturers are promising new, significantly improved, EV models in the next year or so. 'Significantly improved' in this context generally means greater range and reduced price. For example, General Motors has recently announced a new EV (The Chevrolet Bolt) due to be available

[42] *Demand management of electric vehicle charging using Victoria's smart grid.* DiUS computing. May 3013. http://percepscion.com/wp-content/uploads/sites/3/2014/01/Demand-management-of-EV-charging-using-Victorias-Smart-Grid_May-2013.pdf

[43] *Smart charging: steering the charge, driving the change.* Eurelectric. Mar 2015. http://www.eurelectric.org/media/169888/20032015_paper_on_smart_charging_of_electric_vehicles_finalpsf-2015-2301-0001-01-e.pdf

[44] *"Vehicle to Home" Electricity Supply System.* Nissan Motor Company. http://www.nissan-global.com/EN/TECHNOLOGY/OVERVIEW/vehicle_to_home.html

[45] *Nissan Teams with ENEL to Transform Electric Cars into Mobile Energy Source.* InsideEVs. Dec 2015. http://insideevs.com/nissan-teams-enel-transform-electric-cars-mobile-energy-source/

[46] *"The Future Nissan LEAF In Drag", 60 kWh NMC Battery Inside.* InsideEVS. Nov 2016. http://insideevs.com/nissan-ids-concept-future-nissan-leaf-drag-report/

[47] *23% of new cars in Norway now electric cars.* Clean Technica. Jul 2015. http://cleantechnica.com/2015/07/16/23-of-new-cars-in-norway-now-electric-cars/

in the US at the end of 2016 which breaks two major barriers – range greater than 300km and price below $30,000 USD.[48]

At this stage I think our family's next move on reducing our petrol usage will be when it comes time to replace my wife's petrol car (though of course, in the meantime, I might be tempted to update my Nissan Leaf to a new generation EV if the price is right!). I imagine that getting a replacement for the petrol car will be a toss-up between buying a new generation EV or getting some form of plug-in hybrid EV. I envisage the plug-in hybrid is likely to be the petrol/electricity transition vehicle for most one-car families. A well selected plug-in hybrid car will let the user run on electricity for normal day to day commuting while cutting in to petrol for longer out of city trips.

Even though these days I am only an occasional bus user, I would feel much more positive about taking public transport if it were run on electricity rather than diesel. I am heartened by the very strong take up of battery electric buses overseas and just hope that Australian public transport agencies are ready to move in this direction.

[48] *Introducing the All-Electric 2017 Chevrolet Bolt EV.* Chevrolet. Jan 2016. http://www.chevrolet.com/bolt-ev-electric-vehicle.html#*:*

Chapter 5

Moving away from Gas: Hot Water

5.1 Introduction

There are many different types of domestic hot water system in use in Australia. These are usually fuelled by electricity, gas or solar. For each fuel there are various system types and a multiplicity of manufacturers. ABS data shows that about 50% of Australian homes use electricity for hot water, 40% use gas and 10% use solar.[49] The broad families of hot water systems in use by fuel type are:

Electricity: (i) resistive element and storage tank; (ii) heat pump; and (iii) instant

Gas: (i) storage tank; and (ii) instant

Solar: (i) collector - many forms of heating panels/tubes (with gas and/or electric boost); and (ii) solar PV powering either resistive element or heat pump electric systems.

When we moved into our house it had a 170 litre gas storage hot water system. As one of the key aims of the Transition was to remove gas usage from the house, this effectively left us with a choice between electricity or solar collector for our new hot water system. My thinking as I considered the different options is discussed in the next Section.

5.2 Consideration of the Alternatives

Instant Solar PV Electric

I put this option first because it was the one that proved the easiest to reject.

Whole of house instant how water systems (as opposed to appliances just set up for one washbasin) typically have a significant power draw which far exceeds the output of the normal domestic solar PV system (these systems can have a power demand of around 20kW and require a 3 phase electricity supply).[50] In addition, even if we had a PV system which was large enough to provide the necessary power output this would only likely be met during a few hours each day around noon - I think restricting the family to taking showers in the middle of the day would definitely break the first rule of the Transition (no degradation of lifestyle)!

The timing incompatibility could possibly be managed by installing a home battery system. However, the power demands of instant hot water systems will almost certainly exceed the capacity of near term domestic battery systems (for example, the Tesla Powerwall is advertised as being able to deliver a peak power of 3.3kW[51]).

Conclusion: Not suitable.

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[49] *Environmental Issues: Energy Use and Conservation, Mar 2014.* Australian Bureau of Statistics. http://www.abs.gov.au/ausstats/abs@.nsf/mf/4602.0.55.001

[50] Stiebel Eltron. Water Heaters. http://www.stiebel.com.au/water-heating

[51] Powerwall. Tesla Home Battery. Tesla Motors. http://www.teslamotors.com/en_AU/powerwall

Solar Collectors

I gave a little thought to possibly installing a pure solar hot water system – there are certainly lots of different types and designs on the market - but as far as I could tell they would not offer our family any benefits over the electricity options. Overall it would appear that hot water systems based on solar PV are a better option for our family.

As far as I can ascertain, solar collector hot water systems require less roof area than solar PV panels to deliver the same quantity of hot water and they therefore may be a good choice for houses where there is limited roof area – this is not our situation. When I looked at solar collector systems against my decision hierarchy (Section2.3) I found they ticked very few of my boxes:

(i) they are relatively complex systems involving pumps, heat exchangers, etc

(ii) compared to a solar PV option they are not versatile; they only produce hot water

(iii) with the falling price of solar PV, solar collector hot water systems now tend to be more expensive than solar PV options

(iv) solar collector systems have inherent energy efficiency limitations. On a clear sunny day the household water may well be hot by 10am – for the rest of the day after this all the solar energy falling on the collector panels is not used (assuming usual family hot water demand patterns). If a family goes away on holiday the energy falling on the solar collector may be unused for weeks. This compares to a solar PV system which produces useful carbon free electricity irrespective of the state of the hot water system – once the water is hot the PV electricity can be used elsewhere in the house or be exported to the grid.

Given my reservations I did not delve at any depth into the merits of the various types of solar collector hot water systems.

Conclusion: ***Not an attractive option for us given that we are already exporting solar PV electricity which could be used to heat water.***

Solar PV + Heat Pump

This is the alternative I was initially most attracted to. As I've mentioned a number of times before in the book it is the option widely recommended by the energy pundits.

Modern heat pump hot water systems are very special. These heat pumps received two very big ticks in boxes on my decision hierarchy – they are super efficient (eg some have a Coefficient of Performance (COP) of 4.5[52]) and they are new technology. I looked into these in some detail and received a quote from a supplier but in the end I did not go down this route primarily, but not exclusively, because of fears about criteria number two on my decision hierarchy – don't disturb the neighbours!

I was an environmental bureaucrat for more than thirty years and for all of this time I was involved in managing environmental noise. While I was only directly involved in domestic noise for a short period at the start of my public service career, I was certainly fully aware of the noise problems

[52] *Why consider an air-sourced hot water heat pump system?* Sanden International. http://www.sanden.com.au/iS_admin/files/Sanden%206pp%20Brochure%20210512%20FIN%20AW_web.pdf

generated by equipment such as domestic air conditioners, pool pumps, heat pumps, etc. These problems can lead to some very unpleasant disputes between neighbours.

In modern Canberra suburbs the houses are very close to each other and the potential for noise problems is high. The location where I would have had to put the heat pump at our house is at a point which is less than a metre from my neighbours' fence and about 5 metres from their house. This point is also in an area where there are overhanging eaves and a right angle wall – conditions where enhancement of noise is quite likely. I didn't want to take the risk of becoming a noise nuisance.

Another factor in deciding not to go down the heat pump route is that they are not totally compatible with solar PV. If I had gone down this route I envisage that I would have put the heat pump on a time switch to operate only during the period 11am to 3pm. The model I looked into had a power draw of about 1kW. I estimate that we would need the input of around 1-2kWh/day of electrical energy from the heat pump to provide the hot water for our family (2 adults + 2 children). On a sunny day, with our 6.5kW solar PV capacity (net tariff), all our hot water would very easily come from solar. However, on a day when it is cloudy between say 11am to 1pm (even if it is sunny for the rest of the day) a high proportion of our hot water would likely have come from grid electricity. I could improve the performance to some extent, but not totally, by the use of an EDD (there are limitations since the heat pump is not a resistive heating device (see Section 3.2)). When home battery storage systems become available the stored energy could be used for producing hot water via a heat pump but this would involve some inefficiencies.

A less important negative was the fact that heat pumps are relatively complex devices which generally need regular maintenance if they are to keep performing well.

Conclusion: ***An attractive option but not taken up primarily because of potential noise problems and the relative attractiveness of resistive thermal storage heaters.***

Solar PV + Storage tank/resistive element

For me this was one of the more surprising elements of the Transition. Initially I was not at all attracted to this option. Resistive element hot water storage systems are much less efficient than the heat pump (by a factor of 3 or 4) and they are old technology. Here I was, carrying out a project where new technology is super important and I find myself selecting a hot water system that we used in my childhood home more than sixty years ago! I was also aware that there are moves to no longer allow the installation of these devices in Australian houses due to their relative inefficiency.[53]

Putting those negatives aside, the resistive element system ticked lots of other boxes in my decision hierarchy: simple with no moving parts; no maintenance; no noise; and the cheapest option. Of course the biggest tick goes to the fact that, being a resistive device, it enabled the unconstrained use of an EDD (see Section 3.2). This marriage of new and old technology also opened up the possibility of using thermal storage for my space heating (see the next chapter).

Conclusion: ***The option I chose. This system provides simplicity and opens up the use of thermal storage for both hot water and space heating via the use of an Energy Diversion Device.***

[53] *Hot water system regulations.* BUILD. http://www.build.com.au/hot-water-system-regulations

5.3 Installation and Operation of the Resistive Element System

Prior to the Transition we had a 170 litre gas storage hot water system**.** We replaced this with a 250 litre electric hot water storage system which was installed with a 3 kW heating element. We used a 3 kW element because this is the maximum power capacity of the current version of our EDD (the Immersun) (resistive hot water systems in Australia usually have a 3.6 kW heating element). We set the thermostat in the storage tank at 60 degrees – the minimum temperature recommended for Legionella control.

I set hot water as the first priority on the Immersun. This means that at the beginning of each day the unit starts diverting all excess solar PV to the hot water system. The unit's interface (see the box in Section 3.2) gives an excellent indication of the energy flows in the house – it shows the amount of instantaneous solar PV power being generated and the amount, if any, being diverted into the hot water system. It also shows the total amount of energy that has been put into the hot water tank since the beginning of the day. On most days it takes about 4-5 kWh to get the water hot. Once the water is 'hot' the Immersun diverts the solar PV electricity to the second priority heater – in our case this is a storage heater. This is discussed in Chapter 6.

In order to ensure my family has hot water when they come in the evening, I set the Immersun to automatically 'Boost' every day between 3pm and 4.30pm. The 'Boost' function overrides the normal solar diversion operation mode and connects the hot water system directly to the electricity mains. This means that even if we have a totally cloudy day we end up with hot water at the time we take our showers. In practice at 3pm each day the system attempts to deliver electricity to the heating element; on almost all days the water is hot at this time and the thermostat is open, therefore the solar PV being generated at the time is either used by any other devices in the house or is exported to the grid. In fact, on almost all days (even quite cloudy ones in winter) the water is 'hot' (ie the temp reaches 60 degrees) before noon, in summer this usually happens before 10am.

5.4 Subjective Assessment

Overall I am very happy with the option I chose for the hot water system. It works; it is a simple solution and I feel I am breaking new ground by using an EDD. Hot water is a critical component in the Transition since, unlike space heating, we have no backup for heating our water - if the family has no, or intermittent, hot water the Transition (and I!!) will be in real trouble.

One attraction for me going down the resistive heating element route was that it would allow me to test what is likely to be a solar PV solution for thousands of Australian households. As noted in Section 5.1, about 50% of Australian households have electric hot water systems. I imagine that a high proportion of these are resistive element systems. This means that for very little expenditure they can divert solar PV electricity into their hot water systems. This is likely to be particularly attractive for those households installing their first solar PV systems or for those solar PV households who are being phased off high feed-in-tariff rates.

Without going into great detail there are interesting questions around the merits of placing too much emphasis on energy efficiency when this has no direct impact on the household carbon footprint.[54] I touched on this topic in Section 2.3. For example, how important is it if I use 5 kWh/day rather than 1.5 kWh/day for hot water if all the electricity involved is solar PV? This is the approximate difference in energy use for heating our household hot water from a resistive

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[54] *In an age of cheap solar, does efficiency still matter?* RenewEconomy. Sep 2015. http://reneweconomy.com.au/2015/in-an-age-of-cheap-solar-does-efficiency-still-matter-14204

element rather than a heat pump hot water system. In my view I have made the right environmental decision when balancing all the competing issues. I am sure others will disagree.

I cannot finish this Chapter without commenting on the moves to restrict the installation of resistive element hot water systems in an effort to force households to use solar collector, heat pumps or gas hot water systems. This decision was made some years ago before the price of solar PV plummeted; when the importance of thermal storage of solar PV energy was not well understood; and in the days when gas was seen as a positive alternative fuel to electricity derived from coal. An enormous amount has changed since these restrictions were initiated. In my view any moves to totally ban the use of resistive hot water systems should be abandoned – indeed some very superficial research on this topic indicates that there is already some retreat from the original hard line position.[55,56] At the very least any proposed restrictions should be refined so that they do not apply to integrated solar PV/resistive element hot water installations. Clearly resistive element hot water systems have a very important role to play in an energy system based on renewables.

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[55] *Ask Environment Line.* Environment and Heritage. NSW Government. http://www.environment.nsw.gov.au/en/questions/when-will-the-electric-hot-water-heater-phase-out-occur-in-nsw

[56] *Hot water system requirements amended - 1 Feb 2013.* Fallon Solutions. http://www.fallonsolutions.com.au/latest-news/hot-water-system-requirements-amended-1-feb-2013

Chapter 6

Moving away from Gas: Space Heating

6.1 Introduction

Making decisions in this area was probably the most complex, and ultimately the most rewarding, part of the Transition. Heating is by far the greatest use of energy in our dwelling (ie the house apart from the cars) (see Figure 1.4). When we moved into our house it had a fully operational ducted gas central heating system. These are very common in Canberra.

The starting point when looking at our heating was to examine whether our house had sufficient insulation. When we moved into our house it had a low energy rating (EER=3). It had 200mm thick thermal batts in the roof but, as noted earlier, it had a large number of ceiling penetrations for vents and it only had single glazing. It was therefore somewhat of a no brainer that we would put in some form of window insulation before we began putting in a new heating system. This is discussed in Section 6.2.

As I have indicated earlier, when it came to the point of choosing the heating system to replace our gas ducted system, my initial thinking was that we would install heat pumps (reverse cycle air conditioners) in our main living areas – after all that is the recommendation of nearly all the energy pundits. However, in the end my research took me down a very different path.

While I had my preconceived ideas of what we would do, right at the start I was somewhat nervous about going down the heat pump route as we already have one of these in one of our rooms and my wife has been loath to use it. Even though it rapidly heats the room to a comfortable (to me) 19^{o}C she said that it does not make her feel warm; for her thermal comfort is provided by having a fan heater extremely close to her body (about 200mm away). In fact, she very happily more or less sits on the fan heater (intermittently turning it on/off) for hours in a room that is about 15/16^{o}C – for her this is 'comfort' (the fan heater is very ineffective at heating the room when she is using it as a personal heater in this way!). Very clearly there is a complex relationship between room air temperature and thermal comfort for a human!

Room air temperature v thermal comfort

It has long been recognised that air temperature only tells a part of the story of a person's thermal comfort. For example, it is now common around the world for meteorological agencies to report both air temperature and 'apparent temperature'. In Australia the Bureau of Meteorology publishes 'thermal comfort observations' which take into account effects such as wind chill.[57] Radiant heat, such as that provided by the sun is particularly important. On a cold day moving from a shaded spot into the sunlight makes one feel much more comfortable even though the air temperature is the same. Similarly, on a hot day moving out of the sun and into the shade improves thermal comfort at the same air temperature.

[57] *Thermal comfort observations.* Australian Government Bureau of Meteorology. http://www.bom.gov.au/products/IDN65179.shtml

While 'apparent temperature' effects are self-evident, it is interesting that we almost always manage the thermal comfort level within a house simply by reference to the air temperature. This is presumably because air temperature can be easily measured and used as a value to control heating devices via thermostats.

These very simple concepts/questions raised the warning flags in my mind about automatically installing heat pumps without further research. Very quickly I started to question what are we trying to do with space heating in houses – are we trying to heat the air inside the house or are we aiming to give the occupants thermal comfort? Are these one and the same thing? Why are we so fixated on centrally heating our homes?

Need for central heating

If the purpose of our heating systems is purely to provide personal thermal comfort, why do we choose to heat the large mass of air inside our houses (to indirectly heat the persons) rather than just to directly heat each person? Why do we need to continually warm the air in areas in our houses where the occupants rarely spend time (eg corridors) or would never sit (eg broom cupboards)? These are particularly pertinent questions in a house like ours which has poor thermal sealing and where much of the air we heat simply escapes outside.

Following this to its logical conclusion quickly led me to deciding that in the Transition I would not just try to replace the gas burner in our central heating system with some form of central electric heater (eg a heat pump) but would move away from central heating. We decided that the best approach for us would be to heat each room independently to get the greatest control and to allow individual family members to more easily achieve their own comfort level. I also envisaged that this would be a much more energy efficient approach.

Opting for an approach based on providing direct personal thermal comfort rather than on central heating obviously raises the question of how do we achieve this?

Convection versus radiant heat

When I was a child growing up in post-World War 2 England all the heating in our house was radiant. We huddled around a coal fire at night in our main living room – we got nicely warmed on the front, via the radiant heat, while all the heated air went up the chimney. In other rooms we used the iconic 'one (or two) bar radiator' – this was effectively a red hot stick that did very little to warm the person and achieved even less in warming a room. I find it interesting that I am now living in a world where we almost exclusively rely on convected heat to warm our houses - we generally heat the air in our houses with central heating systems or use some form of blow heater to heat and circulate the air within individual rooms.

I would be the last person to hanker after the freezing houses of my childhood but I'm not convinced we have taken the right step by almost totally moving away from radiant heat. For some reason our home heating technology development effort over the past half century seems to have been focussed on convection, rather than radiant, heating. If we are looking at attaining direct personal thermal comfort in our houses, using at least some radiant heat, either alone or in combination with convected heat, would appear to be essential.[58]

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[58] I was disappointed when I tried to find independent research papers comparing different methods of home heating – the standard Google searches generally brought up papers/articles produced by companies promoting their own heating devices or methods. I found the link below especially useful as it introduced me to a heating concept I was not aware of, far infrared heating panels, but it is not independent https://www.herschel-infrared.com/heater-fundamentals/how-it-works/

After all, in the outside environment radiant heat from the sun is the key factor determining our thermal comfort. My thought processes as I mulled over alternative heating systems led me to search for ways in which we could effectively bring the sun inside our house on a cold dark Canberra night. I discuss my search for the perfect heating system in Section 6.3.

6.2 Window Insulation

This is one direction we would have gone irrespective of the Transition. As I've indicated earlier, when we moved into our house it had a low energy rating (EER=3). When buying the house, we were aware that we would need to install some form of improved window insulation, not only for our own comfort but also to enhance the market value of the property. It made sense to take this step before we changed our heating system.

While this is considered a no-brainer step in all the literature, I was very surprised by the economics of installing window insulation. My experience did not seem to accord with the usual upbeat positioning on window insulation adopted by the pundits – the economic benefits for us were marginal at best. When I searched the internet I soon found that we were not alone. I discuss this issue in Section 9.8.

I seriously looked a three options for improving the energy performance of the window areas of our house; waffle blinds; full double glazing; and secondary glazing.

Waffle Blinds

These blinds are also commonly called honeycomb or cellular blinds. These are insulating blinds which have a honeycombed structure which traps air.[59] I had some of these in my previous house and they do work.

I had a quote for fitting out the house with these blinds and the price was about half that of installing secondary glazing. After considering the other options, I decided not to go down this route primarily because they are not particularly flexible. I like to have light in the house during the day and this means the blinds have to be lifted; the consequence is that there is no window insulating effect during daylight hours. As a retired person I am commonly at home during the day so I really wanted an option that works 24/7.

Full Double Glazing

While I do like double (or even triple) glazed window units I did not get quotes for installing new double glazed windows in our house simply due to the fact that the window frames are only about ten years old and I believe it would have been wasteful to throw these out. If I were building a new house, or my current windows needed replacement, I could easily end up with this option.

While I did not seek a quote for full double glazing, looking at prices quoted on the Internet I estimated that retro-fitting out the house with full double glazing would cost about twice the price of installing secondary glazing.

[59] *Pros and cons of honeycomb shades.* A Little Design Help. http://alittledesignhelp.com/pros-and-cons-of-honeycomb-shades/

Secondary Glazing

This option simply involves installing a second window frame inside the existing frames. There are many ways in which this can be done. In the end I chose to go for a product called Magnetite which seemed to offer a very neat way to get a well-sealed window unit which, at the same time, also offers easy access for opening/closing the original windows.[60] When installed the secondary windows blend in very well with the existing window frames and are barely noticeable.

We changed our heating system at more or less the same time as we installed our secondary glazing. This unfortunately meant that I could not carry out even an informal assessment of how well the windows have performed thermally since it was not possible to isolate the impact of the added insulation from the change in the heating system. Subjectively after we installed the secondary windows the house seemed much warmer. There was also a clearly noticeable reduction in road traffic noise.

6.3 Consideration of the Heating Options

When looking at alternative heating systems to replace our ducted gas central heating system I naturally only considered electricity based approaches since the final heating choice had to fit in with a solar PV solution.

The best option for home heating is probably to build a very well insulated passive solar house which relies on capturing daytime heat in large masses of brick/stone walls and/or floors. Any small supplementary heating requirements can be met, or at least offset, by solar PV electricity. However, this option is really only of interest when building a new house or making major modification to an existing house and this did not apply in our case.

There is a wide range of available options for electrically heating homes in Australia. I had to do some initial culling to get down to a small number of options which I looked at in more detail. I noted in Section 6.1 that I wanted to move on from central heating and to install a heating option that can be applied room by room. To be specific I wanted to install fixed electrical heating appliances in each of our two large living areas, while I planned to heat our smaller rooms with some form of portable supplementary heating.

I eliminated some options, such as underfloor electrical heating, because they are not really a feasible option for an existing house. Eventually after going through an informal elimination process loosely based on my decision hierarchy I came down to three broad categories of heater I wanted to examine more closely: heat pumps; storage heaters; radiant heaters.

Heat pumps – reverse cycle air conditioners

As I have noted a number of times already, heat pumps seem to be the darling of the energy pundits. Over the past year when reading the 'green energy literature' I have found it rare for other retrofit heating options to be given any serious consideration. Heat pumps are an attractive option. I love clever new technology and the concept of getting 'something for nothing' is intriguing – I find the idea that you put in 1kW of electrical power to get a heat flow of around of 3 or 4 kWs very exciting. They are also an attractive option since a heat pump unit can be used for both heating and cooling – an extremely big plus. However, in the end I did not go down this route simply because I came across a heating option which suited us much better (we did not need to install a cooling system). What were the negatives I perceived with choosing heat pumps?

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[60] Magnetite retrofit double glazing. http://www.magnetite.com.au/

Primarily, as I noted in Section 6.1, my wife doesn't get any great thermal comfort from the type of heat our current heat pump unit (in our bedroom) puts out. For me one of the main points of the Transition was to test out new ideas and I could see little value in installing a type of heating system that we already have, and that has not worked out all that well, simply because it is energy efficient.

Another very important reason for not installing heat pumps was that I was keen to explore options which involved the storage of heat. Having decided to install an EDD to provide hot water, I was very focussed on finding a form of resistive electrical heater that could also use the EDD to store energy for space heating. My research led me to the storage heater which I discuss in the next sub-section.

Other downsides of having multiple heat pumps can be noise disputes with neighbours (I raised this issue in Section 5.2) and ending up with a house which externally looks like some form of industrial complex. While noise problems from space heating heat pumps would have been unlikely for our situation given where the compressor units would have been located at our house, I was conscious of the latter issue - we already have two big solar inverters plus one heat pump compressor unit on one side of our house: I was afraid that adding another two compressor units to the same side of the house would make the mechanical services equipment become visually intrusive.

Finally, an issue that I know is important to some people. Canberra has some very cold evenings/nights in winter and I know from personal experience that air sourced heat pumps can struggle when it is really cold outside: they can give blasts of what feels like fairly cold air when they are going through a de-icing cycle. Heat pumps are relatively complex pieces of equipment and do need ongoing maintenance to ensure optimum performance. Annual professional servicing is recommended in addition to regular cleaning of filters every few months.[61] I suspect the aforementioned blasts of cold air I have experienced may be related, at least in part, to a lack of maintenance.

Conclusion: ***An attractive option, particularly if you are looking for a device that cools as well as heats, but heat pumps do not compare favourably with other options when it comes to thermal comfort or thermal energy storage.***

Storage Heaters

Storage heaters respond to one of the major deficiencies of heat pumps – they facilitate energy storage in the form of thermal energy. As I have discussed earlier, storage is the recognised missing link with solar energy. When battery storage is affordable, solar PV will become a 24/7 flexible energy source. In the meantime, if the output of solar PV systems can be cheaply stored as heat, and if this heat can be efficiently delivered for space heating, we will have a very affordable energy source for heating the inside of buildings. Enter the storage heater.

I am sure that many Australians will not be aware of storage heaters. These heaters were very popular when I was growing up in England. They were commonly called 'off-peak' heaters or 'heatbanks' and were designed to take advantage of the low electricity tariffs at night. They are a very simple (some would say crude) concept – the heater simply contains a stack of firebricks within an insulated chamber; and a number of resistive electrical heating elements are embedded within the firebricks. In operation electricity is passed through the elements; the elements heat up and, in turn, heat the bricks which have a high thermal mass and therefore store the heat. When heat output is required (usually in the evening) the user (or a thermostat) turns on a fan which blows air

[61] *Operating and maintaining your heat pump.* US Government Department of Energy. http://energy.gov/energysaver/operating-and-maintaining-your-heat-pump

Figure 6.1: The storage heater in our main living area

across the heated bricks thus releasing the stored heat into the room. These heaters look like some form of 'normal' convection panel heater – see the photo of the storage heater in the main living area in our house (Figure 6.1).

These appeared to be a perfect fit with a solar PV system so it was not hard to decide that I needed to try them out.

Deciding to install a storage heater was the easy part; buying one was much harder. I could not find these in any shops in Canberra and had to do a fair bit of hunting around in order to buy one. I eventually found two companies supplying storage heaters to the Australian market and in the end I more or less chose one based on price[62] – I could not find detailed technical specifications and/or advice which would separate them on function or quality. The heater I chose has a thermal storage capacity of 15.4kWh. I have to say that the price of the heater was much more than I had expected (a sentiment also expressed by the representative of the company in Canberra through which I bought my heater). I discuss storage heater costs in Section 9.7.

Conclusion: ***I chose to buy one of these heaters to test out how well solar PV couples with thermal storage for space heating. I was aware that the one heater I bought would in no way meet all our heating demands and that I would therefore have to also select another heating option.***

Radiant Heat - Far Infrared (FIR) Panels

Consistent with my comments earlier in the Chapter about convection versus radiant heat, after having bought the storage heater (a form of convection heater) I was keen to add some radiant heat to our heating mix. I didn't really know where to start but quite by chance I stumbled across a reference to far infrared panel heaters[63] (**NOT** to be confused with normal panel heaters which are basically a form of convection heater).

I had never heard of far infrared (FIR) panel heaters before. In essence these heaters emit energy in the far infrared (ie non visible) area of the electromagnetic spectrum. This energy does not directly heat the air in a room, only objects such as people, furniture, floors, etc. Any heating of the air occurs indirectly when air in contact with objects gets warmed. These panels are being promoted as an environmentally friendly form of heating because it is claimed they use significantly less energy than a conventional convection/blow heater to obtain the same level of thermal comfort. It is also claimed they have many other advantages compared to convection heaters – no moving parts, no

[62] QM100 Storage Heater. Dimplex. http://www.dimplex.com.au/product/qm100-storage-heater
[63] *How Herschel far infrared heating works.* Herschel. https://www.herschel-infrared.com/heater-fundamentals/how-it-works/

noise, easy to install, no maintenance, take up little space, can be disguised as pictures, no draughts or blowing of dust, etc.

I do not wish to come across as a convert to some whacky cause and would urge the reader to do their own research on far infrared heaters if they are interested - there are many references on the internet to this topic. At this stage I must say that if you go to some of the energy/heating blogs you'll find that far infrared panels seem to generate a strong negative reaction in some people – they see far infrared heating as some form of scam perpetrated by snake-oil salesmen. This is certainly buyer beware territory but as my discussion in the earlier part of this chapter suggests, thermal comfort is a very personal issue and what works for one person won't necessarily work for the next.

When I first came across far infrared heating I was naturally extremely interested but also highly sceptical. New technology yes, but I've also read a lot of wonderful, and unbelievable, claims by purveyors of all sorts of heating equipment. Reading the vigorous debates on the pros and cons of far infrared panels on the energy blogs only heightened both my interest and my scepticism.

Figure 6.2: The 600W FIR panel on the wall in my office

I could not resist putting my toe into the far infrared water and I bought, as a trial, a low wattage (600W) DIY far infrared heating panel from an Australian supplier.[64] I attached it to the wall in my office at home (a room of about $14m^2$) - see Figure 6.2. The panels are not heavy and installing the heater was a process akin to hanging a picture. As you can see, the panel I bought looks like a whiteboard (it does not change colour when turned on) – much more sophisticated designs incorporating mirrors, pictures or plain vivid colours are available. You can see from the Figure that the DIY panel, with its dangling electrical cord, is not particularly pretty but as a heater I was extremely impressed! The panel emitted a gentle low level heat which I found gave very rapid thermal comfort. It heated the room very effectively while using little energy. In fact, after I had used the panel for a few days I had to buy a thermostat since the room was getting too hot.

On the basis of this trial I had four higher capacity panels hard wired into the ceilings of the two main living areas in our house (see Figure 6.3).

Conclusion:	***Far infrared panels seemed to tick so many of the boxes in my selection hierarchy. New technology, energy efficient, no moving parts, no noise, totally contained within the house. Most importantly they provide radiant heat – the missing ingredient in thermal comfort compared to heat pumps and conventional convection/blow heaters.***

[64] *DIY FIR heating panel.* Heat On heating systems. http://heat-on.com.au/DIY.asp

6.4 Operation and Assessment of the Chosen Heaters

I have deliberately confined the text in this section to subjective issues. I give an assessment of the energy/CO_2 performance and the costs of the heating systems in Chapters 8 & 9.

Storage Heater

Overall I would rate our experience with the storage heater as totally acceptable but not something I could get too enthusiastic about. I think it would be best described as a background heater – it takes and keeps the chill off the room but it is performing a function most occupants of the room are not aware of; it provides a heat source which is much like an oil filled radiator.

When I bought it I was aware that it would not be able to keep our 50m^2 main living area warm as it only has a heat output of around 2kW – the calculators tell me we need about 5kW of heat input to keep a room of this size warm. If it were placed in a smaller room, I would not be surprised if the heater could perform a role akin to a fan heater.

Its integration with the EDD worked very well. During the real depth of Canberra's winter I found it very convenient to top up the solar input by automatically inputting heat into the thermal bricks during the last two off-peak hours (4am to 6am) via the EDD's boost function. We had no thermal comfort problems living through the winter with only the storage heater charged in this way working in combination with our Dyson fan heater (see the end of this Section).

Do storage heaters have a future as part of solar PV systems?

I think they could have if two important things could be improved.

Firstly, the price. When looked on simply as a heater they appear to be expensive - the price range to buy one in Australia is about $1,200 to $1,800 for a 2kW heater. However, if looked on as a storage device they provide cheap storage of solar PV electricity (about $100/kWh) compared to batteries. I believe storage heaters will need to be re-branded and re-marketed for the solar PV field if they are to gain significant acceptance.

Putting price issues aside, the most important deficiency of the heater as far as I am concerned is the lack of control. In particular, the heater gives the user no feedback on how much heat is contained in the bricks – without this knowledge it is difficult to know how to control both the output and the input. This might not be so much of a problem if the heater is solely being used as a conventional 'off-peak' heater since it has smarts which optimise overnight heat input based on heating energy used the night before. However, it does not work so well when being used in combination with solar – it's all a bit hit and miss; I would be much more upbeat about using storage heaters in combination with solar PV if they had smarter control systems.

Far Infrared (FIR) Panels

For me FIR heating was the revelation of the Transition. I have found FIR heaters to be quite remarkable. I cannot understand why they are not used more widely. Having said that, I must point out that my comments are based on our experience of using the panels for one month at the end of the Canberra winter. While most Australians would probably find the evenings at this time of the year in Canberra pretty frigid, they are not as cold as in early and mid-winter and I may have to revise my views when we use the panels in anger for the first time over the full 2016 winter.

As I mentioned earlier, I was very sceptical when I bought my first far infrared panel. I imagined that at best it might work OK for personal heat if you were sitting quite close to the panel but would not do a great job of heating a room. I was way off the mark.

While the heating effect of using the panel fixed on the wall in my office encouraged me to go further, the best place for them in my view is to have them attached to the ceiling. We had two large panels (1200W) fixed to the ceiling in our main living room over the areas where we normally eat and where we watch the TV. The best way I can describe it is that when the panels are on it feels like you are sitting in the warm sun on a cool autumn day (without the harmful UV rays). Thermal Nirvana!

Figure 6.3 shows one of the large FIR panels fixed to the ceiling in our front room. Three people can easily sit under one panel and get the same pleasant heating effect. When you consider how effective this heating is, it is hard to believe that one of these panels is drawing only a little bit more power than was drawn by the old one bar radiator of my childhood (which seemed to deliver much more light than heat)!

Figure 6.3: A 1200W FIR panel fixed to the ceiling in our front room

I have focussed on the personal thermal comfort of the direct radiant heat but in many ways it is the ability of the FIR heater to warm a room that has surprised me the most. They do not warm a room anything like as fast as a good fan heater (this is not a problem if you are sitting under a panel – the direct heating effect only takes a minute or so) but once a room is warm it seems to retain the heat much longer than a room heated by a conventional convection heater. This makes sense as the FIR heater is heating objects (furniture, floor, walls, etc) which retain heat rather than heating air which has very little thermal mass and which quickly escapes from a thermally leaky room. I have included data about FIR energy use in Section 8.6 and FIR cost in Section 9.7.

As far as I am concerned, the main weakness of the FIR panel set up that we have is the control system. We have panels in three rooms, each room is controlled by a separate thermostat which turns the FIR system on or off (it does not vary the temperature of the panels), while each panel can be separately switched on or off manually. As things have turned out this is a bit crude. Given the nature of the heating, when the thermostat turns the heater(s) off it can take quite a while for it/them to come on again because of the long thermal retention time of an FIR heated room (compared to a convection heated room). This means that the beautiful feeling of the infrared heat can disappear for what seems like a long time. I believe a better set up would be to have controllers which incorporate both a thermostat and a means for varying the heat output of the individual panels (say high, medium, low). This type of controller would presumably allow the room occupants to more closely match room heat input with room heat losses which in turn would improve the (already excellent) levels of thermal comfort generated by the FIR system.

Do far infrared heaters have a future as part of solar PV systems?

Absolutely! Two issues here.

Firstly, they could integrate with solar PV systems in the same way as heat pumps: they are both low energy heating systems and could easily be driven off a moderately sized home battery system which is integrated into the solar PV system. Probably more interesting is the concept of an FIR heating system acting like a thermal storage heater.

I first came across FIR heaters via the producer of my EDD – the Immersun. The Immersun company has linked with Herschel, a major UK player in the FIR industry. [65] Herschel is promoting the idea that FIR panels be driven off a solar PV system using an EDD during the day to heat up rooms – this heat is retained in the fabric of the rooms and is then slowly released in the evening as it gets cold outside.[66] I think this sounds interesting, but while I am an unashamed fan of FIR, and recognise that FIR heat is retained in objects in a room for some time, I'm not convinced that the heat is retained for a long enough time for the system to have anything other than a very minor effect in reducing evening heating requirements. Maybe the energy savings would be significant in an extremely well insulated house, but I don't believe our FIR panels could be used in this way to any great effect with our house's current insulation configuration. Anyway I'll watch this space with interest.

Supplementary Heaters

While this sub-section does not relate directly to the operation and assessment of the chosen heaters, I have included it for completeness since I did need some supplementary heating during the Transition as we phased in the new electrical heating systems.

I guess most families have a collection of small electric heaters of some form or other which they use to supplement their main heating – blow heaters, convection panel heaters, oil filled column heaters, (visible) infrared heaters in bathrooms and on patios, etc. There is a very wide range of electric heaters on the market. I commonly read comments on the internet to the effect that 'if you deliver a 2kW flow of heat to a room it doesn't matter how you do it – you get the same heating effect – so just buy the cheapest heater'. Without getting into a long debate all I can say is that that statement does not accord with my experience.

When implementing the Transition we decided not to use the gas heating from the beginning of 2015. This meant that we needed to use some form of temporary heating until we installed the storage heater in late June and then needed to use some form of supplementary heating until the far infrared panels were installed in late August. After assessing our fairly large stock of old and cheap fan heaters I decided to purchase a Dyson fan heater to act as our transitional space heater. Not cheap, quite noisy, not very good as a personal heater, but extremely impressive for warming up a large cold area quickly (our large living area is about 50m^2). Its performance seemed to belie it's 2kW power rating.

We successfully used our storage heater in combination with the Dyson fan heater to heat our main living area over the major part of the cold Canberra winter – these were not used again once the far infrared panels were installed in late August. We used a combination of fan heaters, a heat pump (in the main bedroom), the small DIY far infrared panel mentioned before in the office and (visible) infrared heaters in the ceilings of our bathrooms to heat the rest of the house over the winter.

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[65] *Complementary Technologies - Herschel Infrared.* 4eco Ltd. http://www.immersun.co.uk/herschel-infrared/

[66] *Increase return on Solar Investment using ImmerSUN with Herschel Infrared.* Herschel Infrared Ltd. http://www.herschel-infrared.com/heater-fundamentals/solar-integration/

6.5 Overall Comments on our New Heating Regime

I believe our new heating regime gives us much better thermal comfort at a much reduced carbon footprint. I have never been all that comfortable with the concept of pouring energy into unoccupied areas of buildings, so moving away from central heating to a focus on giving individuals thermal comfort is a direction I am extremely happy with. I am so impressed with the far infrared heating panels that I envisage installing these in the remaining two bedrooms in our house.

The main outstanding question for me is why do all the energy pundits focus so much attention on heat pumps? I certainly agree that the figure of say 400% efficiency for a heat pump is incredibly impressive, but I think the examination of heating performance has to be looked at holistically. Questions must be asked if the heat pump is simply (albeit very efficiently) generating hot air that:

- provides little thermal comfort (compared to radiant heat);
- rapidly escapes from a room; or
- just sits in areas of rooms where there is no need for warm air.

Maybe the answer lies in the fact that a heat pump is a compromise device that can both heat and cool – and for many parts of Australia cooling is much more important than heating.

The energy use, and carbon footprint, of our space heating for 2015 is discussed in Section 8.6.

Chapter 7

Moving away from Gas: Cooking

I have included this short Chapter solely for completeness.

We replaced our gas cooktop with an electric induction top. Induction tops now seem to becoming the norm. This is not a cookbook, and the reader can find many articles on the internet comparing the merits of different types of cooktops from a culinary perspective, but as far as we are concerned the induction top is terrific – fast, clean, easy to use.

We only consumed a very small amount of energy using our gas cooktop. We were able to get a reasonably accurate handle on how much energy the cooktop consumed since in the last six months of 2015, after we had changed our hot water system over to electricity, the cooktop was the only appliance in our house using gas. Over this time, our gas consumption was around 0.4kWh/day.

I have not done an energy audit on the induction top due to the small amount of energy we use for cooking with a cooktop. Nevertheless, all the references I have been able to find indicate that an induction top consumes less energy than a gas cooktop. For example, the Wikipedia page for induction cooking suggests the cooking efficiency of induction cooktops is around 70% compared to around 45% for gas cooktops.[67]

Our bill for gas, not including the service charge, over the last six months of 2015 was about $6. However, the service charge for the privilege of being connected to gas was in the order of $250/year. Therefore, once we had stopped using gas for space heating and hot water, it made perfect economic sense to totally remove our gas connection irrespective of our commitment to being fossil fuel free.

Figure 7.1 is my favourite photo of the book. Gas is gone!! The meter was removed by our gas provider during the first week in December 2015. The photo on the front cover of the book shows what this space looked like before the gas meter was taken away. You can see that the supply gas pipes have been left in place. If in the future someone wants to reinstate gas this can be done very easily. None of the gas pipes within the house have been removed.

Figure 7.1: Gas is gone – the meter has been removed!

[67] *Induction Cooking.* Wikipedia. https://en.wikipedia.org/wiki/Induction_cooking

PART 2

TRANSITION ASSESSMENT

Chapter 8

Energy Use & Carbon Footprint

8.1 Introduction

This is the crux of the Transition. To this point in the book I have described what I have done and why I have done it. What has this achieved in terms of both energy use and carbon footprint?

The Transition is in no way a controlled scientific study. In some areas I have been able to gather high quality data; in others my numbers are no more than indicative estimates. Essentially, every day for the past three years I have recorded my electricity use and solar generation from our household electricity meter and/or good quality monitoring devices. Likewise, I have read our gas meter every day and have computed the energy used by my electric car on a daily basis. This information underpins the figures that are reported in this Chapter. I have converted all the energy data to kWh and kg of CO_2 using conversion factors specified in the Australian Government's national greenhouse accounts.[68] I have used the Australian Government's Green Vehicle Guide to compute the CO_2 generated by our motor vehicles.[69] I have shown the details of my computations in the Appendix and these are individually referenced at the appropriate points in the text.

As indicated earlier, the Transition covers the three years 2013-2015 and the data in this Chapter relates to those years. While this enables the reader to see what we have achieved so far it is important to realise that this period is just a small window on what is likely to be a longish journey.

In the following Sections I have broken down the data both by fuel and activity type. This necessarily means making a number of assumptions. I point these out in the text but I have attempted to be conservative and overstate, rather than understate, our energy use and carbon footprint.

8.2 Overall Trends in Energy Use + Carbon Footprint

(i) Energy Consumption and Carbon Footprint by Fuel Type

Year	Grid Electricity		Gas		Petrol		Total	
	kWh	CO_2 (kg)	kWh	CO_2 (kg)	kWh	CO_2 (kg)	**kWh**	**CO_2 (kg)**
2013	1,790	1,539	8,466	1,559	16,206	3,888	**26,462**	**6,986**
2014	4,128	3,550	8,426	1,552	4,964	1,191	**17,518**	**6,293**
2015	4,945	4,249	1,460	269	4,964	1,191	**11,369**	**5,709**

Figure 8.1: Breakdown of household energy use and carbon footprint by fuel type

[68] *National Greenhouse Accounts Factors.* Australian Government Department of the Environment. Dec 2014. http://www.environment.gov.au/system/files/resources/b24f8db4-e55a-4deb-a0b3-32cf763a5dab/files/national-greenhouse-accounts-factors-dec-2014.pdf

[69] GreenVehicleGuide. Australian Government. http://www.greenvehicleguide.gov.au/

Figure 8.1 shows the household energy and carbon footprint breakdown by energy source for the three years of the Transition. This figure only shows externally sourced energy and does not include self-consumed solar PV electricity – this is discussed in Section 8.3. The conversion factors used in the computations are contained in Appendix A.1.

As noted earlier, caution needs to be used when comparing energy use between different energy types. Gas and petrol are primary fossil fuels and the energy consumption can be easily directly computed. On the other hand, electricity is a derived energy source which is produced by a number of routes. If the electricity is generated by burning coal this process typically has an efficiency of about 30%, so the overall amount of fossil fuel input into an electrical device is usually much greater than it first appears. However, this is a complex picture because while the majority of electricity supplied to the NSW/ACT grid market derives from black coal, electricity is also produced from gas, hydro, wind and solar. With current trends, over time the proportion of renewables will increase. In the ACT the Government has indicated that it expects about 80% of its electricity to be sourced from renewables by 2018 and it has a target for 100% of the grid electricity to be sourced from renewables by 2025.[70,71]

Figure 8.1 shows a significant increase in electricity use between 2013 and 2014 and a similar significant decrease in petrol use – this is showing the fuel use impact of changing over from a petrol car to an EV at the beginning of 2014. The carbon footprint for electricity shows a commensurate marked increase between the non-EV and EV years. It is interesting to note that overall the total household carbon footprint has not varied greatly over the three years even though there has been a significant shift in the types of fuels used. This is primarily because, at the present time, the electricity used in the ACT is primarily derived from coal. However, if all other things remain constant it would be expected that the carbon footprint of electricity, and hence the total, will progressively fall due to the ongoing increase in the use of renewables.

As noted in Chapter 7, our house was disconnected from mains gas in early December 2015 – the gas use for 2015 shown in the Figure was for hot water for the first six months of the year and for the cooking top for about 11 months.

(ii) Energy Consumption by End Use (kWh)

Figure 8.2 on the next page provides an overview of the breakdown of energy consumption by end use. Details of the energy consumption and carbon footprint for each end use are given in Sections 8.4 to 8.6.

This is the area where I have the least confidence in my data and the splits in energy use shown in Figure 8.2 should be treated as being purely indicative. In particular I was not able to obtain high quality data on the split in energy use between hot water and space heating. For example, in 2013 and 2014 we were using gas for both space heating and producing hot water but we were not able to separately monitor the gas use for these two activities. I have therefore had to make a number of assumptions in allocating energy between those two end uses. These assumptions are discussed in Appendices A2 & A3. [The differences in the data between Figure 8.1 and Figure 8.2 primarily relate to Figure 8.2 capturing self-use solar PV electricity.]

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[70] *Canberra to be 100% renewable by 2025.* ACT Government. Aug 2015. http://www.cmd.act.gov.au/open_government/inform/act_government_media_releases/barr/2015/canberra-to-be-100-renewable-by-2025
[71] *Strong bids received in second ACT wind auction.* ACT Government. Nov 2015. http://www.cmd.act.gov.au/open_government/inform/act_government_media_releases/corbell/2015/strong-bids-received-in-second-act-wind-auction

Year	Hot Water (kWh)	Space Heating (kWh)	Cars (kWh)	Other (kWh)	Total (kWh)
2013	2,920	6,194	16,206	1,142	**26,462**
2014	2,555	6,463	7,581	1,338	**17,937**
2015	2,213	1,995	7,396	2,109	**13,713**

Figure 8.2: Breakdown of household energy consumption by end use

The 'Cars' data covers petrol used in our Hyundai i30 and in our Nissan Pulsar (in 2013) and electricity consumed by the Nissan Leaf. The breakdown of the electricity and petrol used in the respective cars is shown later in Figure 8.7 and discussed in Section 8.4. The 'Other' column in Figure 8.2 relates to electricity used for electrical appliances, lights, etc. This data was obtained by difference and I have low confidence in its accuracy.

It is interesting to note that the Figure indicates that an almost equal amount of energy was used for space heating and hot water during 2015 - this relates to the change from gas to grid electricity as the heating fuel and I do not do believe any significance should be placed on this. I envisage in the future that the total energy use for hot water will be significantly less than that for space heating (and that the energy for hot water will be almost totally derived from solar PV).

8.3 Solar PV trends – generation and self-consumption

Figure 8.3 shows how our solar PV output progressively increased over the three years of the Transition as we incrementally increased the size of our PV system. This increase in solar PV production enabled us to move from a strongly negative to a strongly positive household carbon footprint. Comparing the data with Figure 8.1 shows that for each of the three years our production of solar PV electricity exceeded our consumption of grid electricity.

Year	Solar PV Total Production (kWh)	Total Energy Consumed		Exported Electricity		Net CO_2 Footprint (kg)
		kWh	CO_2 (kg)	kWh	CO_2 (kg)*	
2013	2,772	26,462	6,986	2,772	2,384	**-4,602**
2014	4,906	17,518	6,293	4,476	3,849	**-2,444**
2015	10,980	11,369	5,709	8,863	7,622	**1,913**

Figure 8.3: Trends in the household net carbon footprint

***Note:** *It is assumed that each kWh of solar PV (ie carbon zero electricity) which we export displaces one kWh of grid electricity (ie predominantly coal based electricity) somewhere in the generation/transmission system.*

The solar production data is broken down by month in Figure 8.4. This figure shows the dramatic increase in solar production when we installed our third PV system at the end of February 2015 and also the significant variation between summer and winter PV output.

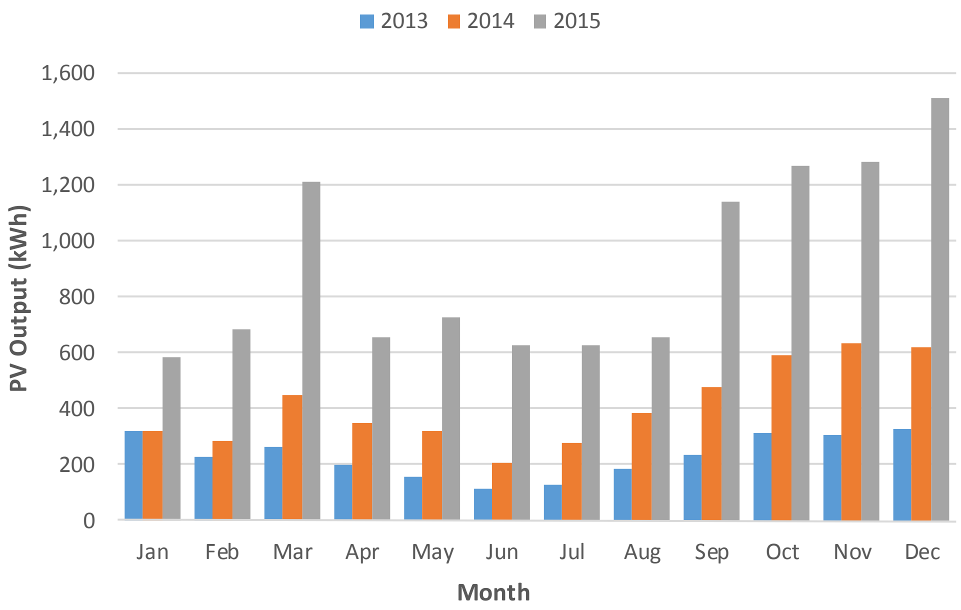

Figure 8.4: Solar PV output by month for the three years of the Transition

Self-consumption of solar PV electricity

Figure 8.5 sheds light on self-consumption by looking at the % of our solar PV electricity which is exported. This was one of the key areas for me in carrying out the Transition – I was keen to explore ways to maximise self-consumption since this will be fundamental if we are to become a Fossil Fuel Free Family in advance of a totally decarbonised electricity grid. Significant self-consumption was not possible until mid-2015 after we had converted from gas to electricity for both hot water and

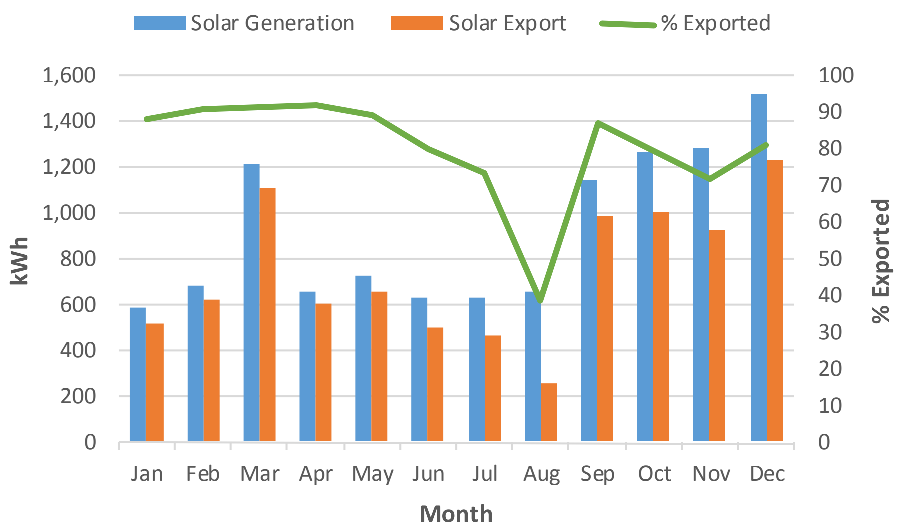

Figure 8.5: Solar PV electricity export patterns for 2015

space heating and hence the Figure just relates to that year. Prior to installing the electric hot water system we were exporting about 90% of our solar PV electricity. We installed the EDD and the new heating regimes in late June and the % of our solar PV output which was exported fell dramatically when this system became fully operational (we were away on holiday for most of July).

As things turned out, August was the high point for the % self-consumption for a number of reasons:

- solar production began to ramp up quite rapidly in September as we moved toward the equinox (and this gave us a big increase in the amount of solar PV electricity available for self-consumption);
- we no longer needed the storage heater because we were getting close to the end of the heating season and had just installed the FIR panels (thus closing off one of the two devices into which we had been diverting our solar PV electricity);
- our Immersun EDD was off line for all of September due to a difficult to diagnose technical problem – during this time we heated all of our water using peak tariff electricity.

When the Immersun came back into service in early October we resumed diverting solar PV electricity into our hot water. However, this was only taking about 4.4kWh/day and by that time we were producing on average around 45Wh/day of solar PV electricity, so we had a large surplus of electricity which we were exporting.

In order to use some of this self-produced electricity I manually diverted excess PV solar generation to top up the battery in my EV on an opportunistic basis. In essence, I simply turned on the EV battery charger at times when solar PV was being generated at a power which exceeded that of the demand of the EV charger. You can see from Figure 8.5 that despite this we were still exporting about 75% of our solar PV production at the end of the year (at this time we were generating up to 60kWh/day).

It is inevitable in summer, when solar PV production is at its height and there is no longer any heating demand, there is going to be a large surplus of electricity. Therefore, when considering self-consumption, it is useful to examine what proportion of energy or electricity used by the household is provided by solar PV – this information for 2015 is shown in Figure 8.6. During 2013 we only had the gross solar PV system in place and therefore we had no self-consumption. We installed our first net solar PV system in Feb 2014 and we began self-consumption. The total amount of

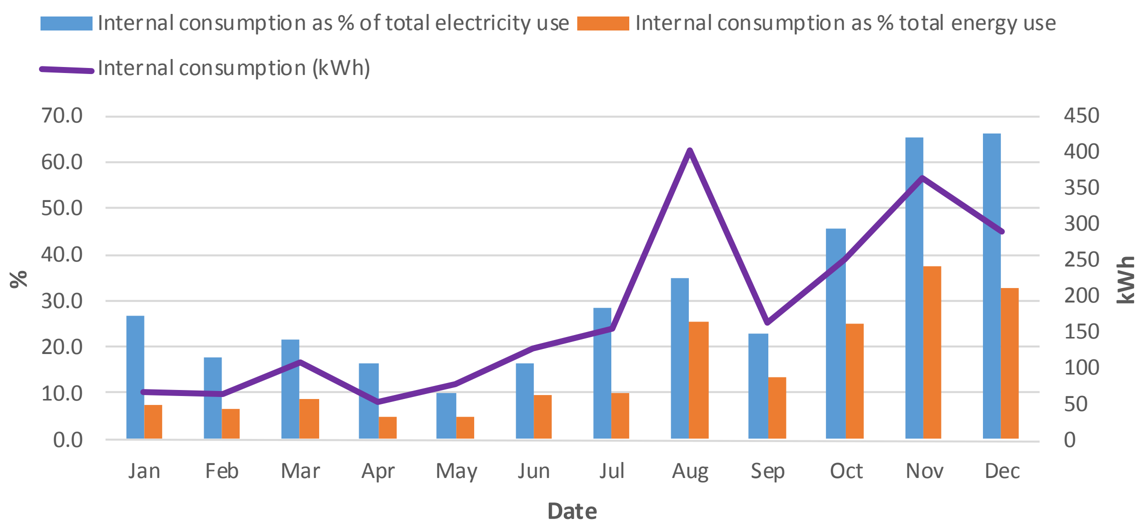

Figure 8.6: Self-consumption data for 2015

self-consumption remained relatively low until we installed the next solar PV system in Feb 2015. It can be seen that up until Aug 2015 the monthly self-consumption varied between about 5% and 25% of the total electricity consumed. In Aug 2015, the first full month where the Immersun was in full operation and we were diverting the solar PV for both hot water and space heating, the rate of self-consumption of our solar PV electricity reached 35%. This dropped back in September 2015 for the reasons noted above but then rose to a level of about 65% toward the end of the year.

8.4 Car - Energy Use + Carbon Footprint

Figure 8.7 shows the breakdown between electricity and petrol for fuelling our two family cars for the three years of the Transition. The data in the Figure for the petrol use is based on estimates - notes on the derivation of the numbers are given in Appendix A.4.

Year	Electricity		Petrol		Total	
	kWh	CO_2 (kg)	kWh	CO_2 (kg)	kWh	CO_2 (kg)
2013	0	0	16,206	3,888	16,206	3,888
2014	2,617	2,251	4,964	1,191	7,581	3,442
2015	2,432	2,092	4,964	1,191	7,396	3,283

Figure 8.7: Breakdown of car energy use and carbon footprint

You can see that the change from petrol to EV at the end of 2013 led to a significant fall (about 50% drop) in the use of energy at the point of use but not a great change in the carbon footprint. As discussed earlier, this is consistent with the expected outcome when the electricity is predominantly sourced from coal (in Figure 8.6 I have assumed that all the energy used by the EV is from the grid). As also noted earlier, as the ACT grid is progressively decarbonised, the carbon footprint for our EV will tend to zero. The carbon footprint data for 2015 shown in the Figure is somewhat exaggerated since it does not take account of the opportunistic solar PV charging of the EV which I carried out toward the end of the year. My indicative calculations suggest that approaching 70% of the electricity input into our EV over the last three months of 2015 came from our solar PV system (see Appendix A6). [I must admit that I was surprised that I was able to achieve such a high rate of solar PV electricity use for charging the car using a manual method – I'm sure this rate of solar usage could be significantly improved across the year with a well-designed EDD.]

I have provided a detailed assessment of the energy use of my EV in my companion book referenced earlier and the reader may wish to look at this for additional information. [72]

Figure 8.8 shows a histogram of the EV daily travel distances during 2015. The pattern of the distribution is very similar to that of 2014. The average distance travelled per day in 2014 was 40.3 km, in 2015 this figure was 36.6 km.

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[72] *Living with a plug-in electric car in Canberra*. Dave Southgate. Aug 2014. http://electricvehicleaustralia.com/electric-vehicles/

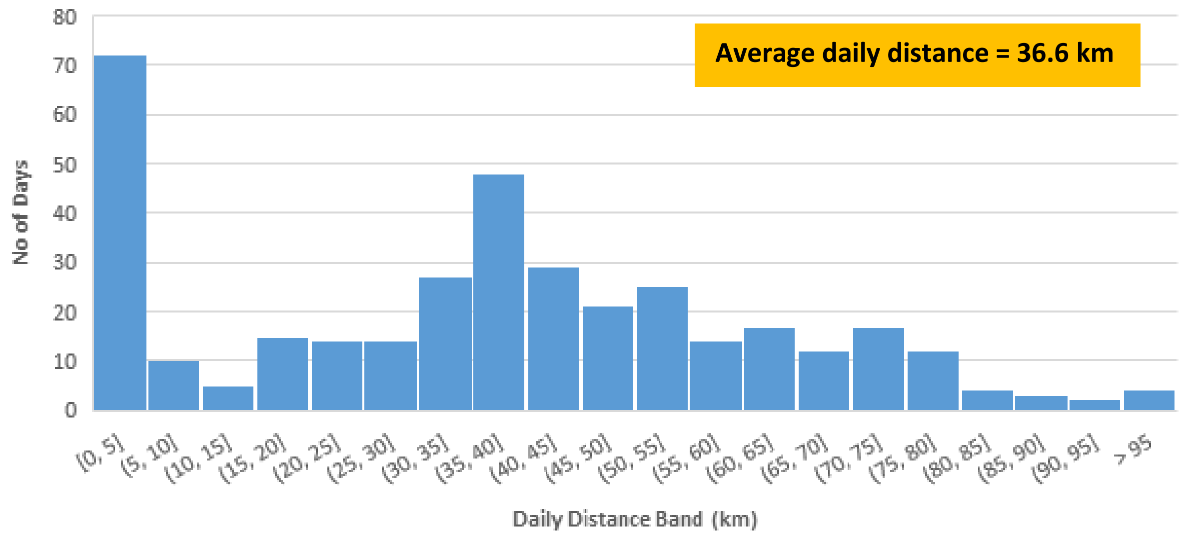

Figure 8.8: Frequency distribution of EV daily travel distances in 2015

In 2014 on average I put 7.3 kWh/day into the EV. In 2015 this figure was 6.7 kWh/day for the same period. The efficiency for the EV in both years was around 18 kWh/100km. Therefore, there was no significant degradation in the vehicle performance over the two years. The routine checking carried out during the Nissan programmed car services did not reveal any deterioration of the battery.

8.5 Hot Water – Energy Use + Carbon Footprint

As indicated in Section 8.2 a number of assumptions had to be made to separate out the energy use and carbon footprint between hot water and space heating. I give details of the way in which I have computed the energy and CO_2 footprint for hot water in Appendix A.2. Figure 8.9 gives a breakdown of the energy sources and carbon footprint for hot water for the three years of the Transition. The quantum of energy for hot water ranged from about 8kWh/day in 2013 (estimated gas consumption) down to about 3.7kWh/day for the last three months of 2015 (monitored solar PV electricity).

Year	Electricity Consumed (kWh)		Gas (kWh)	Carbon Footprint (CO_2 (kg))
	Grid Sourced (kWh)	Solar PV		
2013	0	0	2,920	538
2014	0	0	2,555	470
2015	207	544	1,394	435

Figure 8.9: Breakdown of hot water energy and carbon footprint

When the EDD was installed in mid 2015 the device indicated that household hot water was consuming about 5kWh/day – this figure dropped down to less than 4kWh/day in the warmer months of the year. This marked ‘winter to summer’ drop in energy use could be due to a number of factors such as: warmer temperature of the cold water feed; taking less hot and/or shorter showers in hot weather; and lower energy losses from the hot water storage tank. Even in the middle of winter on almost all days the water in the hot water storage tank, heated solely by solar PV electricity, reached the control temperature (60°C) before noon. I was surprised that this occurred even on heavily cloudy days.

The hot water carbon footprint for 2015 shown in Figure 8.9 reflects the fact that gas was used to produce the hot water for the first six months of the year and for the month of September when the EDD was out of service. It is expected that in future years the hot water carbon footprint will be very close to zero. The basis for this claim is shown in Figure 8.10. This is a histogram showing the distribution of the solar PV output from the net systems in 5 kWh steps for 2015. This shows that on 17 days of the year the PV output was less than 6 kWh. In computing the hot water carbon footprint for 2015, I assumed that on the days when the total net system PV output was less than 6kWh the hot water was totally heated by grid electricity and on all the other days the hot water was heated by solar PV. Even this somewhat conservative approach indicates that more than 95% of the electricity used to produce hot water over a year will be derived from solar PV.

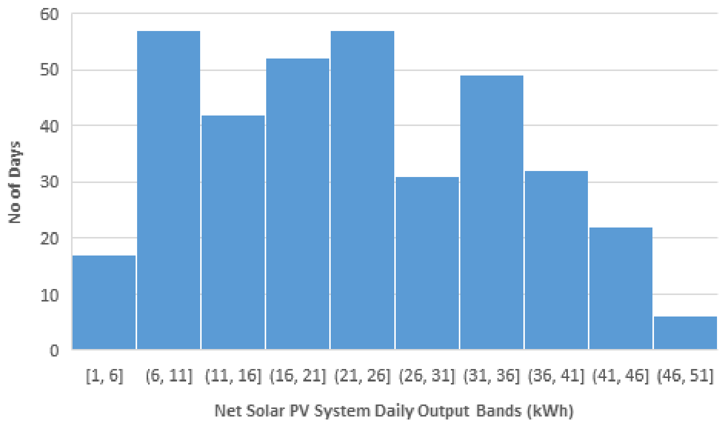

Figure 8.10: Distribution of no of days versus available solar PV in 5 kWh bands for 2015

8.6 Space Heating – Energy Use + Carbon Footprint

Figure 8.11 shows the breakdown of the energy sources and the carbon footprint for space heating for the three years of the Transition. As indicated earlier, deriving these figures involved a number of assumptions and the numbers should only be considered indicative. Details of the derivation of the numbers in the Figure are shown in Appendix A.3. Given the complexity of working out the energy use/carbon footprint for space heating, I've broken this Section down into a number of sub-sections.

Year	Electricity Consumed (kWh)		Gas (kWh)	Carbon Footprint (CO_2 (kg))
	Grid Sourced (kWh)	Solar PV		
2013	274	0	5,920	1,326
2014	274	0	6,189	1,376
2015	1,853	142	0	1,594

Figure 8.11: Breakdown of space heating energy and carbon footprint

Overview

The figures for electrical heating in 2013 and 2104 are estimates of the amount of supplementary heating used in those years (274 = 1.5kWh/day for the 6 month Canberra heating season). The solar PV figure for 2015 relates to the electricity stored (as heat) in the storage heater.

It can be seen from Figure 8.11 that over the three years the quantity of (point of use) energy used for heating dropped dramatically while the carbon footprint was marginally higher. This simply reflects a transition from gas to electricity which is primarily sourced from coal – if the electricity were sourced from renewables the carbon footprint would be zero. It is anticipated that this will happen over the next few years as the ACT grid electricity is decarbonised.

Storage Heater

The storage heater is located in our main living area (area 50m^2) and was used for about six weeks over the 2015 winter (we were away on holiday for the majority of July). Over that time, I set up the Immersun to put 4.4kWh into the storage heater each night using the off-peak tariff. In addition, the

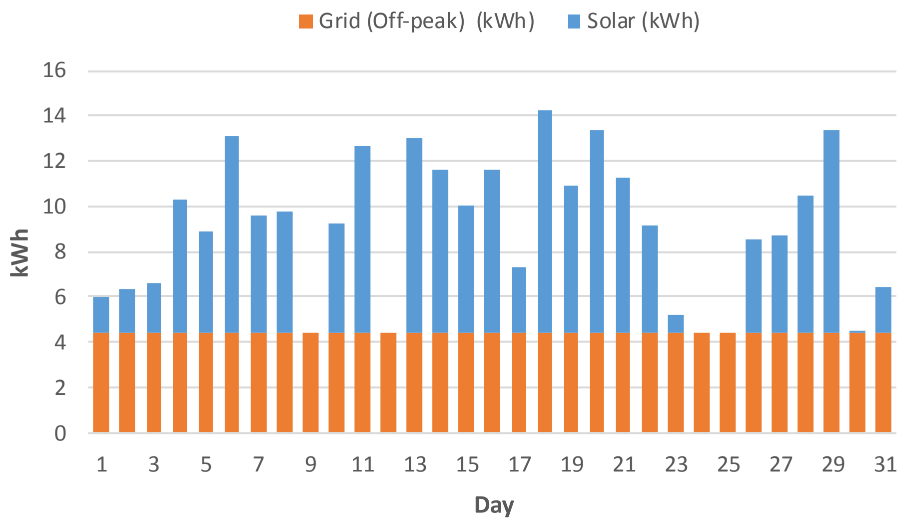

Figure 8.12: Daily energy input into the storage heater during August 2015

storage heater was set up as my second choice device on the Immersun (after hot water) (see Section 3.2) and on most days at least some solar PV electricity was injected into the storage heater during the day. Figure 8.12 shows the results of the one months' monitoring I was able to capture for August – this shows an indicative amount of solar electricity diverted each day into the storage heater. This gives a figure of about 4.5kWh/day solar diverted into the storage heater across the month and therefore in total the storage heater delivered about 9kWh of heat/day into our main living room over the month of August.

As an interim heating method before the storage heater was installed we solely heated our main living area with the Dyson blow heater. I expected that this single 2kw heater would not be able to generate enough heat to keep the room warm but I must say that I was pleasantly surprised – it certainly worked hard but sitting in the room was not uncomfortable. I informally logged the energy use of the Dyson and on cold evenings this heater was injecting about 10 kWh of heat into our living room. Once the storage heater was installed we used the Dyson as a supplementary heater and we had no problems in keeping the room at about 19 degrees. Once we installed the FIR panels we turned off the storage heater and did not use the Dyson.

Far Infrared Panels (FIR)

The Far Infrared Panels were installed at the end of August 2015 and were not used after the end of September - we had a very rapid change from winter to summer in 2015. I installed a datalogger (with a 1 minute sampling period) on the panels for that month. When the FIR panels were installed we turned off the storage heater. Over the month the average FIR energy use in our main living area (area 50m^2) was about 4 kWh/evening. We generally turned on the panels around 5.30pm and turned them off around 11pm. At the beginning of the evening we warmed the room up, and also provided comfort heat for our family sitting in different parts of the room, by turning on both of our two (1200W) FIR panels for about one/two hours. After that one panel, being cycled on and off by the thermostat, generally kept the room and the occupants very nicely warm for the evening even though the outside temperatures were falling close to zero on some nights. Figure 8.13 provides a picture of the FIR energy use profile for the evening of the coldest night in September (1 Sept 2015 when the temperature was -3.1^0 at Canberra Airport (it would almost certainly have been a few degrees warmer outside our home)). The FIR panels were the only heat input into the room.

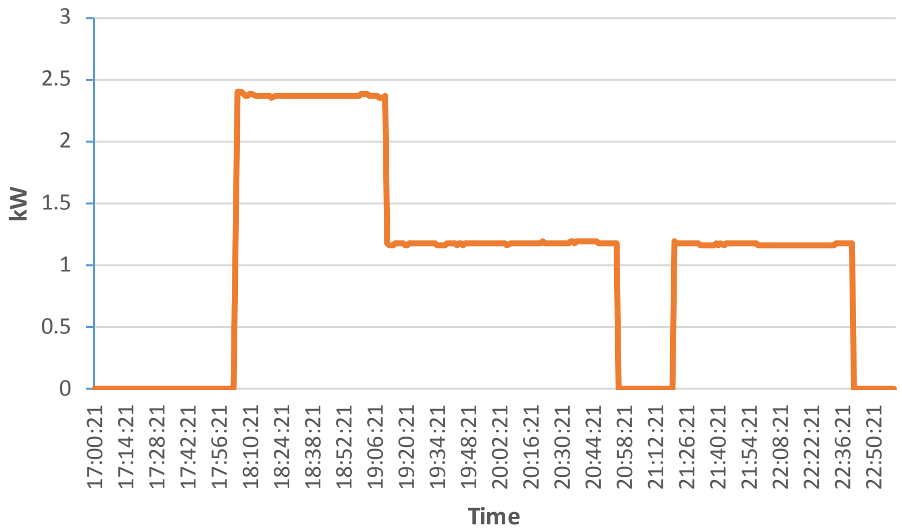

Figure 8.13: Power drawn by the FIR panels in our living room on the evening of 1 Sept 2015

You can see from Figure 8.13 that around 6pm on the night in question we turned on both panels to heat up the room. Just after 7pm we turned one panel off and for the rest of the evening the room was kept warm using just one panel (injection of 1.2kW). The notch in the graph around 9pm indicates a period of about 25 minutes where the thermostat turned off the panel (the room thermostat was set at 19^0). The FIR panels injected 6.7kWh into the living room on that evening. Figure 8.14 shows the daily FIR energy use for our living room for the month of September 2015.

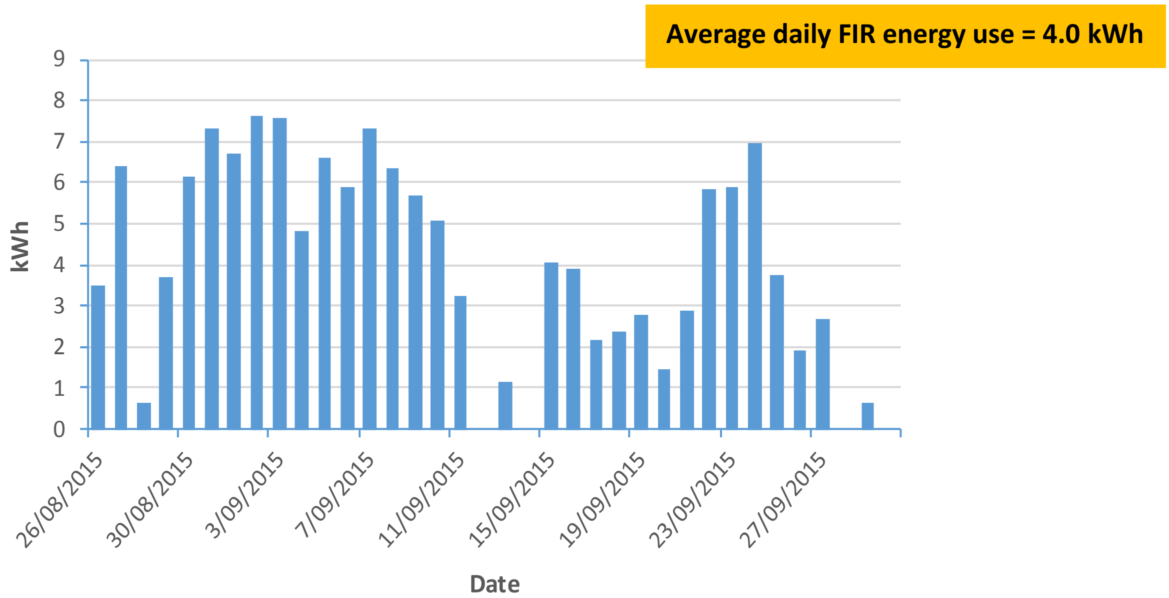

Figure 8.14: Daily FIR energy use for our main living room September 2015

During September we were, at the same time, heating our main bedroom (area 20m^2) with a heat pump with the thermostat also set at 19⁰. Subjectively the main living area, heated by the FIR panels, felt much more comfortable than the heat pump heated bedroom. Surface temperature readings taken with an infrared thermometer indicated that the walls, furniture, etc were about 2 degrees warmer in the FIR heated room.

When we switched over heaters from the storage heater (+blow heater) arrangement to the FIR panels it was readily apparent that the FIR panels give vastly superior thermal comfort. However, I do not feel that we have given the FIR panels a good test out yet. September in Canberra is generally much warmer than the preceding few months in the depths of our winter so we will have to wait until heating season 2016 to get a good appreciation of the overall level of thermal comfort they will be able to provide.

Insulation

As indicated earlier, we installed double glazing in our house in November 2014 which means that we have only had one heating season when this has been in place. Given that we installed the double glazing at more or less the same time as we were making the suite of changes with our fuels and heating devices, it was not possible to make even an informal quantitative assessment of the energy effectiveness of the enhanced insulation. In the absence of measured data, we have to resort to generic references to try and estimate the energy savings.

Our house is not particularly well insulated. Earlier I indicated that when we moved in it had a low EER of 3. It has 200 mm batts in the roof cavity, it has no insulation in the walls and it has multiple penetrations through the ceilings to accommodate the downlights, ducted gas heating and evaporative cooling systems. Given this I would estimate that around 30% of the heat injected into our house is lost through the windows.[73] If it is assumed that the double glazing, at best, reduced

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[73] *Energy out the window?* Natural Resources Defense Council. http://www.nrdc.org/living/energy/energy-out-window.asp

the heat loss through the windows by 30%[74] this would mean that overall we may have reduced the heat loss of the house by around 10% by installing the double glazing.

Double glazing will have benefits in reducing energy used for cooling the inside of a dwelling. However, we have not used mechanical cooling in our house over the past three years other than occasionally turning on some low power fans for short periods. Therefore, while the double glazing makes our house more comfortable it has effectively not saved any energy used for cooling.

The costs/benefits of installing our double glazing are discussed in the next chapter.

8.7 Summary of Energy Use + Carbon Footprint

Energy Use

Figure 8.15 is the 'before and after' figure when compared to Figure 1.2. It shows the energy split in our household for 2015. This Figure only captures the energy we have bought from outside – it does not include self-consumption of our own solar PV electricity. This of course is only a transitory picture since from now on our gas contribution will be zero. I must admit that I was somewhat surprised to see that our house and car energy contributions are almost equal – intuitively I expected the amount of energy used by our house (which includes our main family car (the EV)) to be much larger than the amount of energy used by our small petrol commuter car that only travels about 8,000km a year. This sends a clear message about the need to press forward on the adoption of electric vehicles!

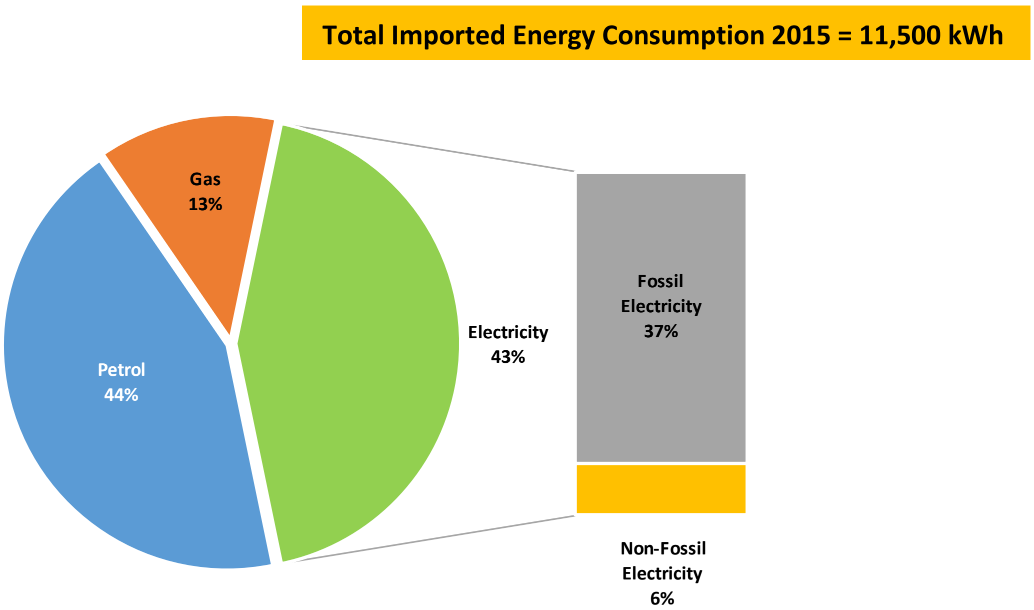

Figure 8.15: Our household (imported) energy split by fuel type 2015

Figure 8.16 shows the trends in energy use over the period of the Transition. It can be seen that there has been a marked reduction in the amount of energy used at the point of use (an approximate 60% reduction) – this does not factor in the primary fossil fuel energy inputs into electricity generation. The Figure shows an increased level of grid electricity use over the Transition which is to be expected since we have totally replaced all our gas appliances with electrical devices

[74] *How to select energy efficient glazing.* Victoria State Government Sustainability Victoria. http://www.sustainability.vic.gov.au/services-and-advice/households/energy-efficiency/toolbox/how-to/select-energy-efficient-glazing

and have replaced about 70% of our petrol use with electricity. I hope that the judicious use of Energy Diversion Devices and battery systems will enable us to very soon reduce our consumption of grid electricity, particularly at peak times.

While noting there has been a significant rise in the use of grid electricity over the period of the Transition, it is important to point out this has been more than compensated for by the increase in solar PV electricity production.

The star of the show as far as the reduction in grid energy consumption is concerned has to be hot water. To all intents and purposes we are now effectively energy independent with respect to hot water. The picture is not so clear with respect to space heating: our trials with the FIR panels in late winter/early spring were certainly extremely encouraging and I am hopeful that we can go through the coming 2016 heating season only having to use FIR heating. At the moment I am looking on the storage heater as a standby device and will only bring it into service if we need to.

Carbon Footprint

Figure 8.17 shows the trends in carbon footprints for the individual energy sources over the period of the Transition. It is important to recognise that the significant reduction in energy consumption at the point of use over the Transition (about 60% less) is not reflected in a similar reduction in the size of the carbon footprint (our total household carbon footprint in 2015 was about 20% less than in 2013). As noted many times before, this is because much of our electricity consumption is still primarily sourced from coal – the size of our carbon footprint is indicative of the amount of primary energy we are consuming. When the ACT electricity grid is fully decarbonised – the ACT Government target date is 2025 – our only carbon source will be our petrol car (assuming we have not replaced it with an EV by then – see discussion in Section 4.4).

In line with the comments on hot water and energy in the previous sub-section, clearly hot water is also the star of our domestic decarbonisation effort. The Immersun has been very successful in diverting solar energy into hot water: although hot water only involves a relatively small part of the household energy load it is now about 95% fossil fuel free.

The carbon footprint of our space heating has increased slightly over the period of the Transition. However, 2015 was a year in heating turmoil as we transitioned across to new electrical space heating devices and we will not have a good handle on the likely carbon outcomes of our changes until the end of the 2016 heating season.

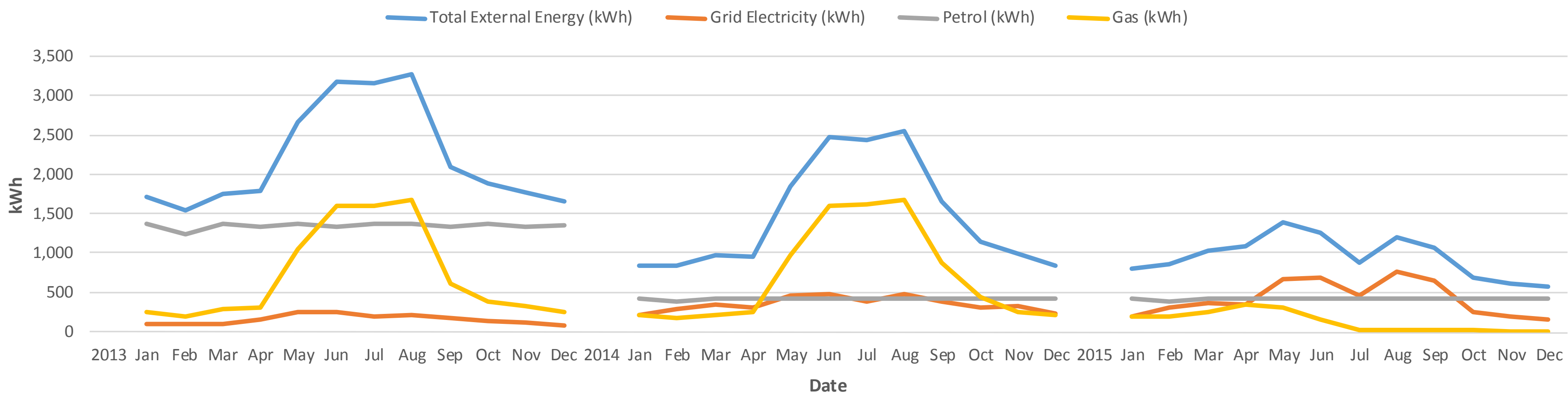

Figure 8.16: Trends in energy use over the period of the Transition

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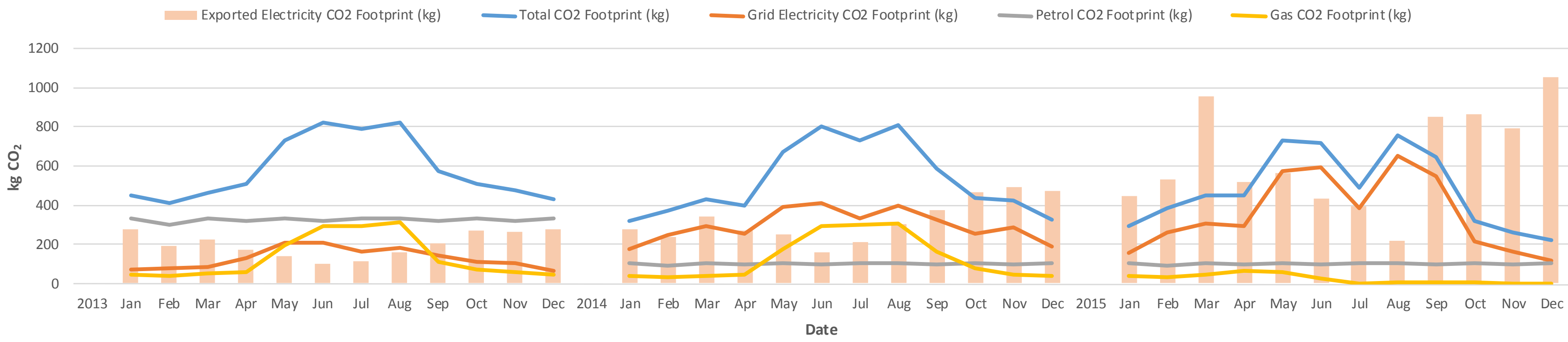

Figure 8.17: Trends in carbon footprints over the period of the Transition

Progress Toward the Target - Net Carbon Footprint

I stated in Section 1.3 that our Stage 1 goal was for our household to have a net zero carbon footprint. This brings to mind that eternal question "Are we there yet?"

The net carbon footprint for the household = (the carbon footprint of the fossil based grid electricity that is displaced by our solar PV electricity) – (the carbon footprint of all the fossil fuels we consume). It can be seen in Figure 8.16 that in 2013 the total household carbon footprint far exceeded the carbon footprint of the grid electricity displaced by our solar PV electricity. Over the period of the Transition the carbon footprint of the grid electricity displaced by our exports progressively increased and the net footprint moved into positive territory for the first time in late 2014. The addition of the 4 kW solar PV system in 2015 counterbalanced the energy use changes brought about the phasing out of gas in that year.

Data in Figure 8.3 showed the trends in our household carbon footprint – this is summarised graphically in Figure 8.18. It can be seen that we achieved our carbon neutral goal in 2015.

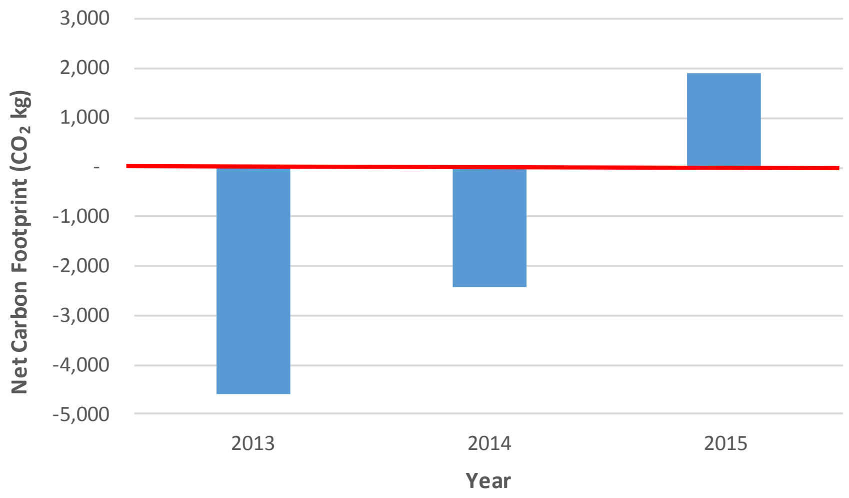

Figure 8.18: Net carbon footprint by year

While we reached our carbon neutral goal over the whole year of 2015, we were in fact net carbon negative for four months over the winter. This is illustrated in Figure 8.19. Clearly winter is a challenging time for the household carbon footprint in Canberra since solar PV production is significantly down (see Figure 8.4) while energy demand is up. If solar PV systems are beefed up to handle the increased winter demand it means that there will be an even greater surplus of solar PV electricity in summer. This of itself may not be a bad thing if the surplus can be used to satisfy air conditioning demands during the warmer months somewhere else in the system.

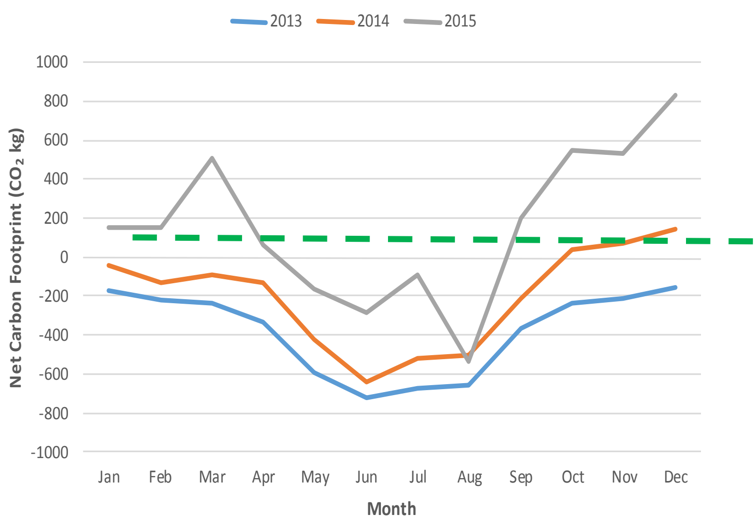

Figure 8.19: Net carbon footprint by month - 2015

It probably goes without saying that in other parts of Australia the shape of Figure 8.19 would look very different. In hot areas where cooling is the main energy user, the period of high energy demand coincides with the period of high solar PV electricity production – this demand/production match would presumably make a 100%FFF goal much more achievable.

Progress Toward the Target - % Fossil Fuel Free (%FFF)

Figure 8.20 shows the energy flows in our house broken down by fossil and non-fossil based energy. This Figure shows the average daily energy flows for a conceptual year based on the energy systems installed in our house at the end of 2015. However, seasonal changes are quite marked. During winter solar generation drops significantly while electricity demand, most particularly from space heating, rises dramatically. It is expected that the energy flows within our household will broadly look like those shown in Figure 8.20 for the year of 2016, unless of course I move into the home battery market with a vengeance very soon!

Over time, as the grid progressively decarbonises, the non-fossil component of the electricity feed from the grid will grow. Similarly, the adoption of smarter charging for the EV and the installation of home batteries should increase the proportion of energy consumption that is self-consumed solar PV electricity. The biggest step forward will of course be achieved if/when we replace our petrol car with an electric car. If/when we reach our 100%FFF target Figure 8.20 will be all yellow!

Figure 8.21 shows the trends in our household %FFF over 2014 and 2015. In 2013 the only part of our energy use that was FFF was the component of grid electricity that was sourced from renewables (this meant we were about 1%FFF - see Figure 1.2). As we added the new solar PV systems our ability to self-consume our solar PV (FFF electricity) increased – this is shown in Figure 8.6. In the last two months of 2015 about 60% of our electricity consumption was FFF (this is not readily apparent from Figure 8.21 which shows smoothed trendlines). Clearly this rate of self-consumption will decline over winter and hopefully return to similar levels next summer unless, of course, I install a battery system or a smart EV charger – these could be game changers. I estimate that over a year, with our current installed equipment, we are now about 25%FFF (see Appendix A6).

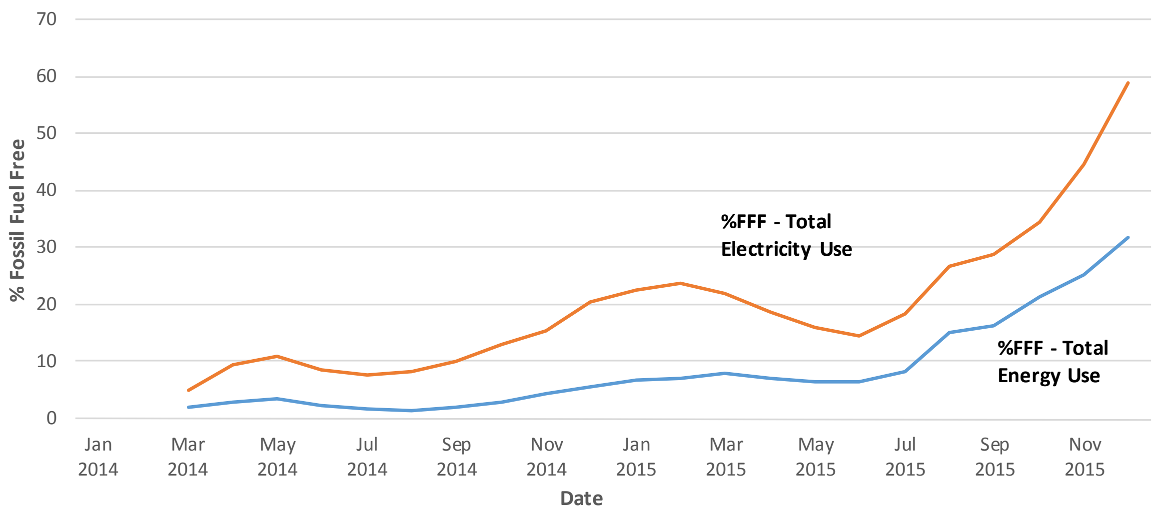

Figure 8.21: Smoothed trendlines of the changes in the %FFF over the period of the Transition

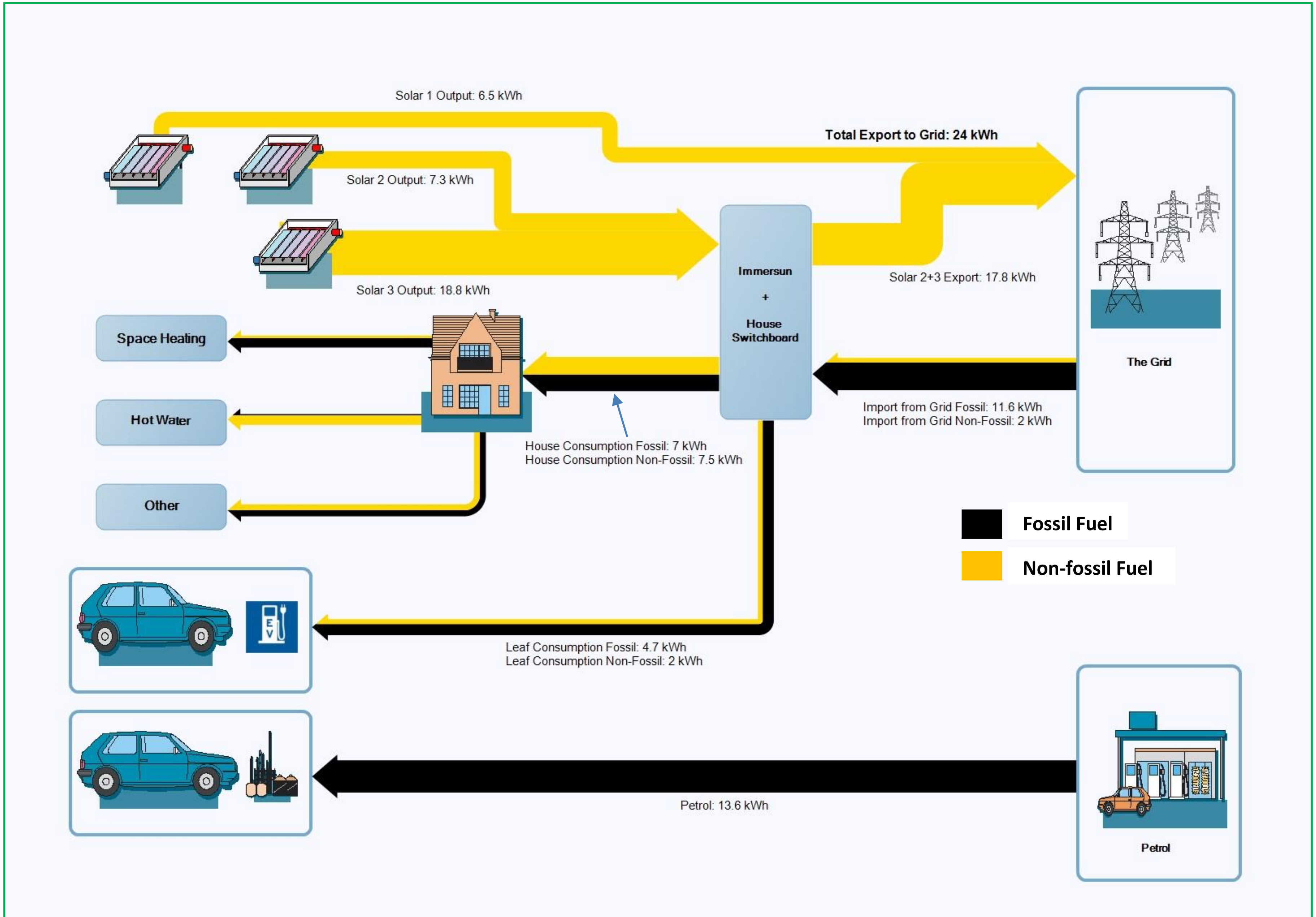

Figure 8.20: Indicative daily household energy flows, with gas disconnected, broken down into fossil and non-fossil components

Chapter 9

The Costs

9.1 Introduction

As I've noted earlier in the book, the Transition is not about cost saving and for the most part the steps we have taken were deliberately not constrained by costs. Nevertheless, as I also indicated earlier I am highly conscious that a broad energy transition across society to zero carbon footprint households will not happen until the economics are compelling.

Having said that, I am also aware that assessing costs is not objective and commonly a party will carry out cost computations in a way that gives an answer that aligns with their philosophical/political disposition. This is exemplified of course by much of the climate change debate in recent years - different parties have examined precisely the same action options yet come up with bizarrely different interpretations of the costs.

When looking at the costs of individuals' actions, such as those taken in the Transition, I like to separate out the upfront costs from the subsequent fuel costs and/or savings. When I started out on the transition project I think I had a reasonable handle on the upfront costs but wasn't too sure how the fuel costs would work out. I had no preconceived ideas and half expected that some of the measures I was taking could lead to increased fuel costs, at least in the short term. I was very comfortable with this – if weaning my family off fossil fuels was going to cost me money, so be it. As things have turned out, as far as I can tell every step in the Transition in fact has led to at least some reduction in fuel costs; every step of course has involved an upfront cost and an overall cost assessment has to weigh the value of the capital costs against the savings in ongoing costs.

Recognising that the 'normal' person will probably not shift fuels unless the price is right, I have initially tried to compare the cost of our original fuel set up with the one we changed to; clearly the question for most people will be 'What will it cost me to change?' In response, I have provided an indication of how much money I spent on buying and installing the individual transition elements and have also shown the reduction in ongoing costs (as a percentage of our previous running costs).

For people like me who have already decided they will move away from fossil fuels the question is not so much 'What will it cost me to change?' but is more likely to be 'What are the costs of taking option A rather than option B'? I have therefore included some indicative costings of the options where I can.

In order to provide a guide on weighing the capital costs of the Transition against the ongoing fuel costs I have used a simplified approach to cost/benefit analysis - payback times. The approach I have used is without reference to discount rates, inflation, and fluctuating energy prices and clearly is crude. I am not a great fan of payback time computations as I think they can be misleading but I have included these as they are commonly used when looking at changes in domestic energy use. I discuss this further in Section 9.10.

As a general comment, in almost all cases the installation cost of the appliances I have discussed in the earlier chapters has been about the same as the cost of the appliances themselves (ie the installed cost has been around twice the shop price). In this Chapter I have simply used a total price for appliances and have not differentiated between installation and purchase costs.

Most of the Sections in this Chapter are dedicated to costing the individual elements of the Transition. I pull the individual cost elements together in the last section of the chapter to give an overview of the total cost picture.

9.2 Overall Fuel Costs

Our household fuel bills give a good indication of the changes in overall day to day energy costs that have resulted from the Transition. Figure 9.1 compares our household costs of electricity, gas and petrol for the years 2013 (the base year), 2014 and 2015 using data extracted from our utility bills for electricity and gas. Data on changes in expenditure on petrol are estimates.

Year	Electricity ($)	Gas ($)	Petrol ($)	Total Fuel Bill ($)	Credit from Solar ($)	Net Fuel Bill ($)
2013	475	991	2,558	4,024	1,241	2,783
2014	766	1,112	780	2,658	902	1,756
2015	1,085	488	676	2,249	1,495	754

Figure 9.1: Our fuel bills for the period of the Transition

The periods covered by our electricity and gas bills do not align with the beginning and end of the calendar year – the numbers shown in the Figure sum up the four bills we received each year for electricity and gas. These bills also include service/supply charges. The costs in the Figure therefore show some discrepancies with other annual energy data in other parts of the book. I did not record our expenditure on petrol over the three-year period and the cost figures shown have been derived from estimates of annual distance travelled, average fuel consumption and average fuel price. The costs for petrol can only be considered as indicative – see Appendix A.4.

The ABS Household Energy Survey 2012 found that the average energy expenditure for households in the ACT was $50/wk for energy used in the dwelling and $60/wk for energy used in cars. This works out to be about $2,600/year for energy use in the dwelling and $3,120 for energy use for the car(s).

It can be seen from Figure 9.1 that over the period of the Transition our ongoing net household fuel bill (ie electricity + gas + petrol – PV income) has gone from about $2,700/year to about $750/year (and this should drop further in 2016 since we will not be paying gas supply charges). This reduction in regular fuel bills must of course be looked at in conjunction with the amount of money we have spent on installing all the elements of the Transition (solar PV systems, etc).

When getting into the territory of fuel bills, rather than just the direct costs for fuel usage, it is very important to factor service/supply charges into energy cost calculations. I have not done this formally in this document because I want to place the focus on the cost of the different fuels but in the end, when fuel costs have been minimised, the service/supply charges can be very significant compared to the cost of the fuel. This is beautifully illustrated by our last gas bill which was for the period August to October 2015. As mentioned in Chapter 7, the total bill was $82 - $6 for the amount of gas used (we only operated a gas cooktop during this period) and $76 for the service charge + GST!! Our last step in moving off gas, the installation of an induction cooktop, almost certainly only made a marginal saving in fuel costs but it saved us around $250/year in service/supply charges.

The impact of service/supply charges may well be an important factor in the ABS's observation in its Household Energy Survey that households using only electricity have lower total fuel bills than those using both electricity and gas.[75]

The service/supply charge is not only an issue for gas. For many customers about 50% of their electricity bills are now made up of charges for the 'poles and wires' rather than for the electricity per se. [76]

9.3 Solar PV System

Upfront Cost ($)	Savings/Year ($)	Payback Time (Years)
System One (2kW 2014): 3,500 System Two (4.5kW 2015): 12,000	1,600 [income from electricity export + reduced electricity cost for self-consumption]	10

Figure 9.2: Summary of solar PV system costs and savings

Figure 9.2 summarises the costs and savings of buying, installing and operating the solar PV systems.

As indicated earlier we have installed two additional solar PV systems since we moved into our house in 2012. It can be seen that there is a significant difference between the capital cost of the two systems in terms of $/kW installed. The first system was installed by a large national company with no office in Canberra. It was an interesting process where all the preparatory work was carried out remotely and all the physical work was carried out by a locally based sub-contractor. This worked fine until problems arose at the ACT Government approval stage and communications with the solar company became very difficult. It took some time until the system was up and running.

Given this less than satisfactory experience, when I wanted to install my next PV system I decided to choose a company based in Canberra. This next system was essentially filling in the remaining space on the north and west facing roof areas of our house and hence was a much more complex installation with split sets of panels using microinverters. I very much valued being able to have easy contact with the company throughout the installation process and have continued to use the services of this company as I have progressively implemented the steps of the Transition.[77]

Note: There was a 2kW system already installed on the house when we moved in 2012. I have not included the capital costs of this system in this chapter because I do not have any information on the upfront costs – de facto they were subsumed in the price of the house when we bought it. Also very importantly, this system is on the old ACT Gross Feed-In Tariff and there is no self-consumption of this solar PV electricity stream; all the electricity generated by this system is exported and sold to the electricity retailer.

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[75] *Household energy consumption survey 2012.* Australian Bureau of Statistics. http://www.abs.gov.au/ausstats/abs@.nsf/Lookup/4670.0main+features132012
[76] *Electricity prices and network costs.* Energy Networks Association. April 2014. http://www.ena.asn.au/sites/default/files/electricity-prices-and-network-costs_2.pdf
[77] Solarhub. Canberra. Australia. http://www.solarhub.net.au/

Ongoing Savings

Both of our new solar PV systems qualify for the current ACT net feed-in tariff of 7.5c/kWh. We get paid 45.7c/kWh for electricity generated by our gross feed-in tariff system. The total income from the three systems is shown in Figure 9.1 and is the basis for the savings which are needed to pay off the capital invested. The income from the gross system makes up about two-thirds of our solar income.

It is common to read statements to the effect that self-consumed electricity is 'free'. Clearly this is not the case. Firstly, as just noted the capital cost of the solar PV systems has to be accounted for somehow - after the equipment has been fully depreciated, say after ten years, you could look at the electricity as being free. However, by consuming your 'home-grown' solar you are foregoing income if your electricity retailer pays you money for exporting your surplus solar electricity. While you don't get a bill for consuming electricity you have generated yourself, by using a kWh of your solar output you are foregoing an income – in my case 7.5 cents. Throughout this chapter I have therefore allocated a cost of 7.5 cents/kWh to self-consumed solar PV electricity.

Figure 9.3 essentially puts a money value on our solar PV electricity production and use. The numbers in this Figure do not directly align with those shown in Figure 9.1 because the quantities of electricity exported are extracted from my daily meter readings and show the actual amount of electricity used in each of the years, while the money data in Figure 9.1 relates to charges imposed for electricity consumed during the billing periods. The figures also do not include the service charge imposed by the electricity providers. The savings have been based on each kilowatt hour of self-consumption replacing a kilowatt hour of grid consumption at the off-peak tariff (ie a saving of 11.55 - 7.5 = 4.05c/kWh) – this understates the savings that I have made because some (unknown amount) of the self-consumption has replaced electricity at the shoulder rate (ie electricity used during the day for laundry, running electrical appliances, etc).

Year	Solar PV Exported (kWh)	Solar PV FIT Income ($)	Solar PV Self Consumption (kWh)	Self-consumption savings ($)	Effective Solar Income ($)
2013	2,772	1,241	0	0	**1,241**
2014	4,906	902	419	17	**919**
2015	10,980	1,495	2,112	86	**1,581**

Figure 9.3: Our effective solar income for the period of the Transition

If the solar systems are viewed as a whole, applying a simple payback computation gives a payback time of 15,500/1,558 = about **10 years**.

If each of the three systems are looked at individually:

- The gross system payback time was probably less than 5 years (I don't have specific information).
- The second system payback time will be around 20 years.
- The third system payback time will be around 25 years.

9.4 Electric Car

Upfront Cost ($)	Annual Fuel Costs ($)	Savings/Year (compared to petrol) ($)	% Reduction in Fuel Costs	Payback Time (Years)
40,000	420	1,500 [reduced fuel and maintenance costs]	75	10

Figure 9.4: Summary of EV costs/savings

Figure 9.4 summarises the costs and savings of buying and operating our EV – the Nissan Leaf.

In broad terms EVs cost more to buy than conventional petrol engined cars but cost significantly less to run. I discuss these costs in my book on my electric vehicle.[78] To illustrate this trade-off I have extracted Figure 5.4 from that book and it is shown below as Figure 9.5.

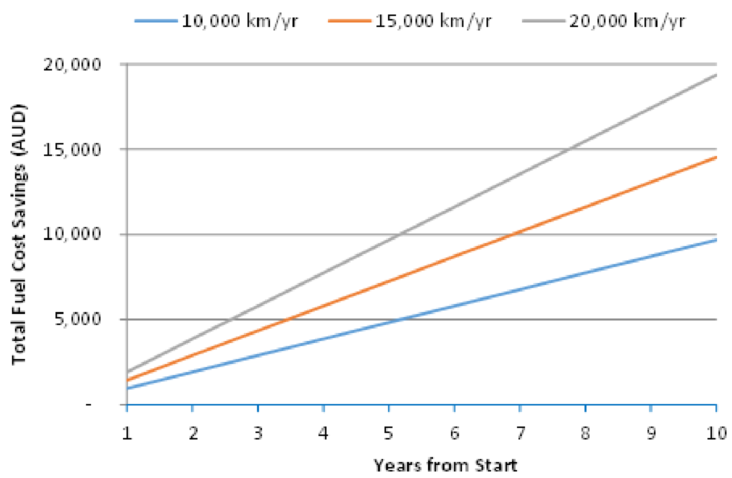

Figure 9.5: Indicative cumulative fuel cost savings for three different distance travelled scenarios (EV v petrol)

I am travelling about 15,000km/year in my EV. I estimate that I spent about $15,000 more for my EV than I would have done if I had bought an equivalent petrol car. The Figure therefore shows that for my circumstances, where I need to recover $15,000 in fuel savings to balance the extra purchase cost of the car, the payback time is about **10 years**.

The fuel costs to run an EV are typically about 75% less than to run an equivalent petrol engined car.

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[78] *Living with a plug-in electric car in Canberra*. Dave Southgate. Aug 2014. http://electricvehicleaustralia.com/electric-vehicles/

9.5 Hot Water System

Upfront Cost ($)	Annual Fuel Costs ($)	Savings/Year (compared to gas) ($)	% Reduction in Fuel Costs	Payback Time (Years)
1,800	150	200 [reduced fuel costs]	60	9

Figure 9.6: Summary of hot water costs/savings

Figure 9.6 summarises the costs and savings of buying, installing and operating the electric resistive hot water system.

The reader will note that the upfront costs I have nominated in Sections 9.5, 9.6 & 9.7, for hot water, the Immersun unit and the storage heater, are the same. The capital cost of each of these pieces of equipment was broadly around $1,000. As the three pieces of equipment were installed at the same time it was not possible to identify the installation costs separately and I have therefore simply equally apportioned the total capital and installation costs across the three areas.

Details of the computations associated with this Section are contained in Appendix A.2.

It was shown in Chapter 8 that the electric resistive heater we installed consumes about 4kWh/day on average in providing our household hot water. By installing the Immersun unit (see Section 3.2) we were able to produce about 95% of our hot water from our self-generated solar PV electricity for five months in the latter half of 2015. The remaining 5% was generated using shoulder tariff electricity. [As mentioned earlier, the Immersun was out of service for about a month in Sept/Oct and during this time most of the hot water was heated via peak period electricity].

As discussed in Section 9.3, in determining the cost of the hot water I attribute a price of 7.5c/kWh to our self-generated solar PV electricity as this is the money that we would have been paid if we had exported rather than self-used the electricity. On this basis the cost of hot water once the electric resistive system (including the Immersun) was installed in late June was approximately 32c/day (see Appendix A.2).

The cost of the gas hot water up to that time was about 90c/day. Therefore, by transitioning to the resistive electric hot water system we saved about 58c/day which is about **$200/year**. This annual saving translates into a payback time of about **9 years**.

Costing individual elements of the Transition becomes difficult in this area. Clearly the savings in hot water are dependent on the Immersun unit and therefore ideally some of the Immersun costs should be allocated to the hot water costs to get a true picture. However, the Immersun unit also diverts solar for space heating. If the Immersun were only diverting solar for hot water and all the Immersun capital costs were ascribed to hot water the above payback time would double to about 18 years.

Other Cost Comparisons

For me the key costing question was not so much how does the new situation compare with the old. Rather, having decided to get out of gas, for me the question was how did the cost of my decision to go with the resistive water heater compare to the cost of the other water heating options I discussed in Chapter 5 - heat pumps or solar collectors?

What are the costs per day of heating hot water with a heat pump? The capital cost of the resistive hot water heater system (including the Immersun arrangement) would be broadly similar to the capital cost of a heat pump hot water system. If it is assumed that the heat pump uses 2kWh/day to heat the household hot water, and that all this electricity was provided by solar at 7.5c/kWh, the cost for heat pump hot water would be 15c/day compared with 32c/day for the resistive hot water. This would translate to a saving of about $65/year. However, the annual servicing charge for the heat pump would likely exceed this saving.

If we had installed a solar collector hot water system, the capital cost would again have been similar to that for the resistive heating system (with Immersun). A solar collector hot water system typically provides around 70% of the hot water energy required by a household with the remaining energy being provided by a gas or electricity booster. [79] In our case we would presumably have diverted some of our surplus solar PV electricity to boost the solar collector. If we had installed less PV panels so that we could install a hot water collector (we have no spare space on our north and west facing roof areas), our solar PV capital costs would have been reduced but we would have foregone an income stream from the sale of solar PV electricity.

9.6 Energy Diversion Device

Upfront Cost ($)	Savings/Year ($)	% Reduction in Fuel Costs	Payback Time (Years)
1,800	95 [reduced fuel costs for both hot water and space heating]	See information for hot water and space heating	20

Figure 9.7: Summary of the Immersun costs/savings

Figure 9.7 summarises the costs and savings of buying, installing and operating the Immersun unit.

The figures for the ongoing savings generated by the Immersun are subsumed in the payback times for hot water and the storage heater discussed in Sections 9.5 and 9.7. Given this, the value added by the Immersun may best be gauged by examining what the costs would have been if I had not installed the Immersun.

[79] *Hot water running costs.* Victoria State Government Sustainability Victoria. http://www.sustainability.vic.gov.au/services-and-advice/households/energy-efficiency/at-home/hot-water-systems/hot-water-running-costs

With respect to hot water: if I had not installed the Immersun I would have generated our household hot water by using the off-peak tariff at night (11.6c/kWh). If I had done this, the additional cost of electricity would have been 4.5*(11.6-7.5) = 18.5c/day which is about $70/year.

Similar logic can be applied to space heating. If I had not charged my storage heater with solar PV during the day I would have input the heat at night using the off-peak tariff. This would have increased the cost of heating by a similar level to that of hot water – about 20c/day. However, as the heater is only likely to be used for four months of the year the annual saving would be of the order of $24/year. Therefore, in total installing the Immersun will save around **$95/year**. This gives a payback time of about **20 years**.

While for our circumstances the payback period may seem to be unreasonably long I think it is very easy to envisage circumstances which would give a very different result. For example, if I were a New South Wales resident with a resistive hot water heater system already installed in my home (about 65% of the homes in NSW[80]) and I was about to totally lose my solar feed-in tariff at the end of 2016 I would look seriously at this option. Installing an EDD at a cost of around $1,500 would save a household about 60c/day if it consumes 5kWh/day which equates to about $220/year and a payback time of **about 8 years**. If the household consumes 10kWh/day, the Australian household average energy use for hot water, and has a suitably sized PV system, the payback time would be around 4 years.

9.7 Space Heating

Upfront Costs ($)	Annual Fuel Costs ($)	Savings/Year (compared to gas) ($)	% Reduction in Fuel Costs	Payback Time (Years)
Storage Heater 1,800 FIR Heating Panels 5,000	Storage Heater 30 FIR Heaters 275 Supplementary Heaters 40	135 [reduced fuel costs] [unquantified enhancements in thermal comfort]	30	>20

Figure 9.8: Summary of space heating costs/savings

Figure 9.8 summarises the costs and savings of buying, installing and operating the two new space heating systems.

This costing needs to be broken down into two parts – the costs for the storage heater and the costs for the FIR panels.

The storage heater was installed in late June. While this was more or less half way through the Canberra core winter heating season I was able to gather one month's good data for the storage heater's energy use throughout August – I believe this would be representative of the energy costs across a Canberra winter.

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[80] *Environmental Issues: Energy Use and Conservation, Mar 2014.* Australian Bureau of Statistics. http://www.abs.gov.au/ausstats/abs@.nsf/mf/4602.0.55.001

The infrared heating panels were not installed until late August, right at the end of the core heating season. In a similar manner to the storage heater I was able to gather one month's good data for the FIR energy use throughout September. However, while the evenings in Canberra during September can still be cold (say between 10 and 0 degrees C) they are not as long as the mid-winter evenings and the house also warms up during the day at this time of the year so the heating load requirements can be relatively light compared to June/July. Therefore, I am not confident that my current FIR energy data is representative of energy use across the whole winter and hence my FIR costings for ongoing energy use should be treated with some caution.

Determining the cost savings for space heating was not straightforward and I have therefore put details of the computations in Appendix A.3. These computations indicate that for the new space heating regime installed in 2015:

Storage Heater – the electricity costs for the storage heater are likely to be about $30/year.

FIR Panels – the electricity costs for the FIR panels are likely to be about $275/year.

Supplementary Heating (fan heaters) – the electricity costs for the fan heaters are likely to be about $40/year.

Aggregating the above information gives a total annual running cost of about $345/year for the new space heating regime. The annual costs of space heating using gas was $490/year (including $40 for supplementary heating using electric fan heaters). Therefore, the savings in the space heating running costs made by going from gas to electricity were equal to $(490–345) = **$145/year** which is about a 30% reduction in annual space heating fuel costs. This translates to a payback time of around **50 years**.

Other Cost Comparisons

As with the hot water, this analysis begs the question what would the costs have looked like if we had gone with the other heating alternative we looked at – heat pumps?

If we had installed heat pumps in our two main living areas the capital cost would have been similar to that of installing the FIR panels. If we assume that the heat pumps would use half the energy of the FIR panels[81] this would equate to a saving of about $150/year. However, I assume that much of this gain would be taken up by the annual service required by heat pumps. It must also be said that the level of thermal comfort provided by the FIR panels is far superior to that provided by heat pumps and I'm not sure how much monetary value I would ascribe to that (but certainly more than $150/year).

9.8 Double Glazing

Figure 9.9 on the next page summarises the costs and savings of installing the double glazing.

When we were heating our house primarily with gas, our annual total heating bill for gas was around $490 (including $40 for supplementary heating using electric fan heaters) (see Appendix A.5 for the derivation of this number).

[81] *Why are radiant heaters more energy-efficient than central heating?* Herschel Infrared Ltd. https://www.herschel-infrared.com/heater-fundamentals/energy-savings/

Upfront Cost ($)	Savings/Year ($)	% Reduction in Fuel Costs	Payback Time (Years)
12,000	50 [reduced fuel costs] [unquantified improvements in comfort + house value]	10	>20

Figure 9.9: Summary of double glazing costs/savings

As indicated earlier, it was not possible for us to do even an informal assessment of the thermal effectiveness of our double glazing due to the overlap in timing between the installation of the double glazing and the new heating system. Given that, in Section 8.6 I use generic data to estimate that installing double glazing may have reduced our total heating bill by around 10%. Clearly there is a high level of uncertainty in that number so in order to get a different perspective on the costs/benefits let's take the most extreme case and assume, for the sake of argument, that the double glazing totally eradicated the need for space heating in our house. This extreme case would give us an annual saving of about **$500/year**, which would translate into a payback time of about **25 years**. In practice the payback time will far exceed this number of years.

9.9 Cost Overview

It is important to note at the outset that the assessments of the costs/benefits of the Transition actions described in this document only apply to our family situation – they cannot be simply transferred to the general case. What may be cost effective for our household may not be appropriate for another family. The cost impacts depend on a range of variables such as the house design, construction and location, desired internal temperatures, preference for radiant rather than convected heat, etc.

The most important point to make about the costs is that the Transition was not intended to be a cost saving exercise. It was totally focussed on reducing our household carbon footprint and ultimately eliminating the use of fossil fuels – my view throughout the whole exercise has always been 'I want to go down this path – let's see what it costs'.

Figure 9.10 on the next page summarises the results of the cost computations contained in the previous Sections for each of the Transition elements.

The balance between upfront and ongoing costs for the individual transition steps is interesting. In some cases, the drop in fuel costs was quite dramatic (eg the cost of fuelling an EV is about 25% of that of fuelling a petrol car), in other cases while the reductions in fuel costs were less spectacular, the associated benefits were quite stark (for example the very significant gains in thermal comfort from installing the FIR heating panels).

Date	Transition Step	Upfront Cost ($)	Fuel Cost Reductions	Payback Time (years)	Additionality[1]
Jan 2014	Buy Electric Car	40,000	75%	≈10	No
Feb 2014	Install 2kW solar PV system	3,500	N/A	≈10	Yes
Nov 2014	Install double glazing	12,000	≈10%	>20	No
Feb 2015	Install 4.5kW solar PV system	12,000	N/A	≈10	Yes
Jun 2015	Replace gas hot water with electric	1,800	60%	≈10	Yes
Jun 2015	Install energy diversion device (Immersun)	1,800	N/A	≈20	Yes
Jun2015	Install storage heater	1,800	20%[2]	>20	Yes
Aug 2015	Install infrared heating panels	5,000			Yes
Nov 2015	Install Induction cooktop	2,000	Note 3	Note 3	Yes

Figure 9.10: Summary of the cost/savings for the individual elements of the Transition

Notes

1 *'Additionality' indicates whether the step would have been taken in the absence of the Transition. 'No' indicates that the step would have been taken anyway (eg the table indicates that I was due to replace my car in early 2014 irrespective of the Transition).*

2 *The data for space heating has been combined since it was not possible to separately allocate the savings between the two heater types. There will be some overlap (maybe quite significant) with the energy savings resulting from the installation of the double glazing.*

3 *Any direct energy and/or cost savings will be extremely small but installing the induction cooktop enabled us to disconnect the gas supply. This will save around $250/year in supply charges. This money has not been factored into any of the figures in the Table but it is a significant amount in the context of our energy bills (eg our total annual fuel costs for space heating with our new heating arrangements will be around $350)*

There seems to be a broad rule of thumb that, for the domestic situation, a payback time of up to ten years for an investment is quite respectable but if the period extends much beyond that then the project is questionable. You can see from Figure 9.10 that quite a few of my transition actions would likely be called 'irrational' by my economist friends. However, I indicated earlier that I am not too comfortable with using payback times as a way to assess costs and benefits. This is because it reduces complex multifaceted, often highly subjective, decisions purely down to money being saved or lost. In reality, when looking at the domestic situation most home improvement decisions are not based on saving money – for example, when people put in a new bathroom or kitchen they do not work out payback times (because there generally isn't any financial 'payback') but spend the money because they believe it will make the house more liveable, improve the property value, stamp their personal character on the house, etc. This point is nicely made in an article I read which reflects on the uptake trajectory for home battery systems.[82]

In broad terms the data shown in Figures 9.2, 9.3, 9.4, 9.6, 9.8 & 9.9 indicates that we will have a return of around $3,500/year, either in solar PV income or from savings in fuel bills, for a total outlay of just under $80,000 (ie a total payback time of about 25 years). While this is the overall picture, I indicate in Figure 9.10 that I would have purchased a new car and installed double glazing irrespective of the Transition. Therefore, the true transition expenditure is more like $28,000 with an annual return from solar PV income + fuel savings of around $2,000 (about a 15 year payback time).

[82] *By 2020 batteries still don't add up, but neither does an SUV.* Business Spectator. Nov 2015. http://www.businessspectator.com.au/article/2015/11/16/solar-energy/2020-batteries-still-dont-add-neither-does-suv?utm_source=exact&utm_medium=email&utm_content=1680976&utm_campaign=cs_daily&modapt=

Chapter 10

Overview & Next Steps

10.1 Tying Things Together

At the end of three years we have achieved our first objective – becoming a carbon neutral household - but we are quite a way from being a fossil fuel free family.

It's been a fascinating journey. For me the star of the show has to be Far Infrared (FIR) heating – it was something I just accidently fell across but I think it is very special and deserves a lot of attention.

Clearly, if households are to move toward being fossil fuel free there needs to be much more emphasis on the phasing out of petrol as a fuel. Cars are the largest energy user in most households and are the greatest contributors to the household carbon footprint. Electric vehicles are wonderful and do save the owner money in the long run but they require a sizeable upfront investment.

I'm very interested in energy diversion devices. Before we start pouring our solar PV output into home batteries we need to work out ways to maximise self-consumption. Storing solar PV in the form of heat, particularly hot water, is something of a no-brainer. When EVs become widespread we will to need to be able to put as much of our solar PV output as possible directly into car batteries rather than transferring it between home batteries and car batteries. This would minimise the size needed for home battery systems and would also save a lot of energy.

Transitioning a house to a low carbon footprint household is unlikely to save you money at the present time but, in common with acquiring an EV, the nature of money ingoings/outgoings is likely to change: significant reductions in fuel costs can result but only after making upfront investments. Houses which only use electricity tend to have smaller energy bills than those using more than one fuel – the doubling up of service/supply charges can have a significant impact on household energy costs.

After looking at the Transition expenditures in Figure 9.10, the reader may well ask is the Transition 'money well spent'? The answer of course depends on what is important to you. If you are looking to make or save money you would almost certainly get a better return by investing your money in the stock market or leaving it in the bank. However, I look on our energy transition as being a sort of house make-over akin to putting in a new kitchen. So far, our energy transition has cost about the same amount of money as installing a new kitchen. As far as I am concerned, living in a house which is well on the way to being fossil fuel free gives me much greater satisfaction than living in a house with a super flash kitchen.

While it has been useful to document our journey so far, this is not the end. At the end of 2015 about 30% of the energy we were using came from our solar PV system. However, over 2015 we used about 14kWh/day of grid, primarily fossil based, electricity and on average our petrol car guzzled about the same amount of energy each day. Is it feasible for us to reduce this fossil fuel consumption to zero?

10.2 Where to from Here?

I've pointed out earlier in the book that the Transition is simply a three-year window on a long process – the end game is a household which uses no fossil fuels for its day to day living. Clearly we are not there yet, but we have put in place the foundations to make this happen. We have now cut off the gas from our house which has been a major step forward but we have two remaining fossil fuels we have to deal with:

Petrol

Despite having replaced our main car with an EV, petrol still makes up about 50% of our household energy use. I have been closely following EV development for some time and I am very confident that within about 2-3 years we will be seeing the start of a step change in the uptake of EVs. The mass production of batteries for electric cars is now beginning in earnest (eg the Tesla gigafactory[83]). A number of major car manufacturers are now sending signals that they are well down the path of producing lower cost EVs that will have a range of about 300km (about double the range of current 'normal' EVs) – 300km range is widely considered the point at which EVs will gain mainstream acceptance. As mentioned earlier, General Motors has just announced that the release of such a vehicle is due in the United States in late 2016.

Having said that, I imagine in the near to medium term most single car families will opt for some form of plug-in hybrid electric car (electricity fuelling city driving; petrol fuelling longer trips) while the full electric car is likely to have more appeal for two car families (at least until new generation EVs with greatly extended range become cheaply available).

Fossil Fuel Based Electricity

Across Australia our grid electricity is currently derived from a number of sources, principally: coal (both black and brown), gas, hydro, wind and solar. Tasmania essentially uses carbon free electricity: hydro, wind and solar. South Australia is well advanced on decarbonising its electricity – in 2014/15 about 40% of its electricity was derived from renewables.[84] As noted earlier, the ACT Government is rapidly decarbonising its sources of electricity through a series of reverse auctions for renewables – Figure 10.1 shows the smoothed trajectory to 100%FFF electricity in the ACT in 2025. In essence this means that for our family, even if we do absolutely nothing, should be able to meet another key milestone in our energy transition within the next decade – we will have carbon free electricity.

Having said that, I'm not keen to simply be a passive passenger on the ride to a carbon free economy. Rather than wait for the ACT government to provide us with a carbon free grid there are quite a few things I think we can do – these principally revolve around energy storage; smart charging for EVs and equipping our house with more efficient appliances.

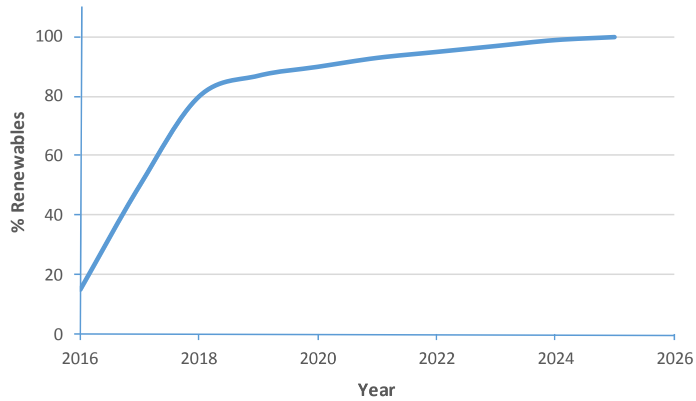

Figure 10.1: Projected rate of decarbonisation of the electricity supply in the ACT

[83] *Tesla Gigafactory.* Tesla Motors. https://www.teslamotors.com/en_AU/gigafactory

[84] *South Australian Electricity Report.* AEMO Aug 2015. http://www.aemo.com.au/Electricity/Planning/South-Australian-Advisory-Functions/~/media/Files/Electricity/Planning/Reports/SAER/2015/2015_SAER.ashx

10.3 Energy Storage

These days it is difficult to avoid media articles about home battery storage systems. Quite clearly these are going to have a massive influence on the carbon footprint of households – not only will they reduce the domestic demand from the grid, they should influence the way the grid is used and should enhance the advent of large scale renewables. There are quite a lot of home battery systems on the Australian market today but although I am a self-confessed early adopter I have not yet been tempted to buy. It's partly the price but much more importantly I'm not sure that we are necessarily on the right path; before I jump I want to see the direction these systems take.

In essence, I want to use my beautiful home grown solar PV electricity in the best way possible. In the first instance I want, as far as possible, to use my home generated electricity for direct use. For example, in the Transition I have looked to store the electricity in the form of heat both for hot water and space heating – this is not only significantly cheaper than storing the electricity in an electrochemical battery, it is also much more energy efficient. Of particular interest to me is the charging of my EV.

If I charge a home battery system with my solar PV electricity and then transfer this energy to my EV battery I will be going through a few AC/DC inversions and charge/discharge cycles. This potentially loses a fair amount of electricity not to mention the fact that I will need a much higher capacity home battery system if I want to use this to charge my EV. As I discussed in Section 4.3, I would hope that some form of smart charger will emerge, based on the EDD concept, that will allow optimised EV charging. In turn I trust that this will ultimately lead to the introduction of systems which enable the battery in my EV to be the household's main battery storage, in addition to being our main transport fuel storage. [85,86]

Having said all that, I'm sure that I won't be able to resist getting some form of home battery system in the not too distant future. Incentives for home battery storage recently announced by the ACT Government under its Next Generation Renewable Energy Scheme may provide the stimulus that I need.[87] At the moment I am attracted to highly modular systems which let the user incrementally add storage capacity – this type of flexible system will hopefully allow me to experiment with different equipment configurations so I can try and get the right balance between energy diversion and battery energy storage.

10.4 More Efficient Appliances

This is an area I'm a bit wary off. We have a number of inefficient electrical devices in our house – eg an old fridge and a plasma TV. I can certainly see that I could improve our household energy efficiency but to what effect? At the moment it appears that in total these inefficient appliances may be using 3-4kWh/day of electricity on average. This figure would maybe drop to 2-3kWh/day if we replaced all our old appliances. These low energy use figures do not appear to justify us making major appliance changes in a hurry - we will simply progressively refresh appliances with more energy efficient versions as and when they need replacement.

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[85] *"Vehicle to Home" Electricity Supply System.* Nissan Motor Company. http://www.nissan-global.com/EN/TECHNOLOGY/OVERVIEW/vehicle_to_home.html

[86] [86] *Nissan Teams with ENEL to Transform Electric Cars into Mobile Energy Source.* InsideEVs. Dec 2015. http://insideevs.com/nissan-teams-enel-transform-electric-cars-mobile-energy-source/

[87] *Next Generation Renewables.* ACT Government. Dec 2015. http://www.environment.act.gov.au/energy/next-generation-renewables

10.5 Our Transition Target Trajectory

We can now use the thoughts in the previous three Sections to draw up a timeline to our final project goal – a fossil fuel free (FFF) household.

The key driver shaping the timeline will inevitably be the rate of decarbonisation of the ACT electricity supply as shown in Figure 10.1. I will informally monitor the rate of decarbonisation and if for any reason this program is curtailed, or is seriously delayed, I will evaluate what gains we can make by adding additional solar PV capacity to our house.

Against this background, I have developed three potential routes to our final FFF goal:

Scenario 1	*Aggressive action*	*Target: Fossil Fuel Free by 2018*
Scenario 2	*Accelerated action*	*Target: Fossil Fuel Free by 2020*
Scenario 3	*Go with the Flow*	*Target: Fossil Fuel Free by 2025*

Scenario 1 – 100% FFF by 2018

This is the 'go for it' option.

The obvious proactive response would be to install a home battery system. The market is now being bombarded with a range of home battery systems. If we opted today to install say a 20 kWh system (a big system by normal standards), we would have six months in the year (Oct-Mar) when we would essentially not need to draw any electricity from the grid. In 2015 we consumed about 30% of our annual external electricity in this six-month period. Computations of how much external electricity we would be forced to import over the winter six months are difficult to carry out with any confidence, but from my perusal of the data I would not anticipate a major contribution to our FFF drive from a battery of this size. On many days during winter 2015 we used well over 20kWh of imported electricity while at the same time only producing a small surplus of electricity from our solar PV system that could have been diverted into a battery. Having said that, by 2018 our grid electricity should be 80%FFF and therefore over the year we would not be far from our 100%FFF target.

In the first instance I would like to install some form of EDD designed for EV charging. After a period of working with this, and assessing its capability, we could then purchase a more optimally sized battery system.

As mentioned in Section 4.4, the next generation of EVs (range >300km; price<$30,000) are due for release at the end of this year in the United States. The purchase of one of these could possibly put us in a position where we sell the petrol car, become a two EV family and hence, to all intents and purposes, reach our target of 100%FFF.

Inevitably this is a high cost option. Even if the yet to be fulfilled promises of EDDs for EVs and the next generation of EVs do eventuate, it is unlikely that these are going to come cheap in the early phase of the product cycle.

Scenario 2 – 100%FFF by 2020

This is the mid-range 'not sitting on the hands' option.

By 2020 grid electricity in the ACT will be 90%FFF and therefore the amount of fossil fuel to be avoided will be relatively small. I estimate if we install a medium sized battery system (say 10-15 kWh), we could be effectively 100%FFF as far as electricity is concerned at this time. As in

Scenario 1, the use of an EDD to charge the EV would be very beneficial – it would be hoped by this time not only will suitable EDDs be widely available, but practical systems that enable a household to use their EV batteries for powering the home will also be on the market.

Also by 2020 the second generation EVs should be well established. I envisage these will be game changers and trust that if we get one of these we may be able to be effectively 100%FFF for our household transport.

Scenario 3 – 100%FFF by 2015

This is essentially the 'do nothing' or 'business as usual' option.

We could simply sit tight and let the ACT Government's electricity decarbonisation program achieve carbon free electricity for our household. However, if we simply did this we would still have one petrol car with a not insignificant carbon footprint – we will not be FFF until we carry out all our motoring in EVs fuelled with electricity based on renewable energy.

I envisage that we will have acquired a second EV by 2025. As an alternative we may have opted to buy a plug-in hybrid EV as our second car. This would allow us to do say 90% of our car travel FFF (which would be in the urban area), but give us the flexibility to switch to petrol if/when we want to do more extended trips.

I envisage this will be a no, or low, cost option. We will probably need to change our second car by 2025 and I expect by then EVs will be mainstream cars.

Discussion

Figure 10.2 shows the timelines for the three scenarios discussed above.

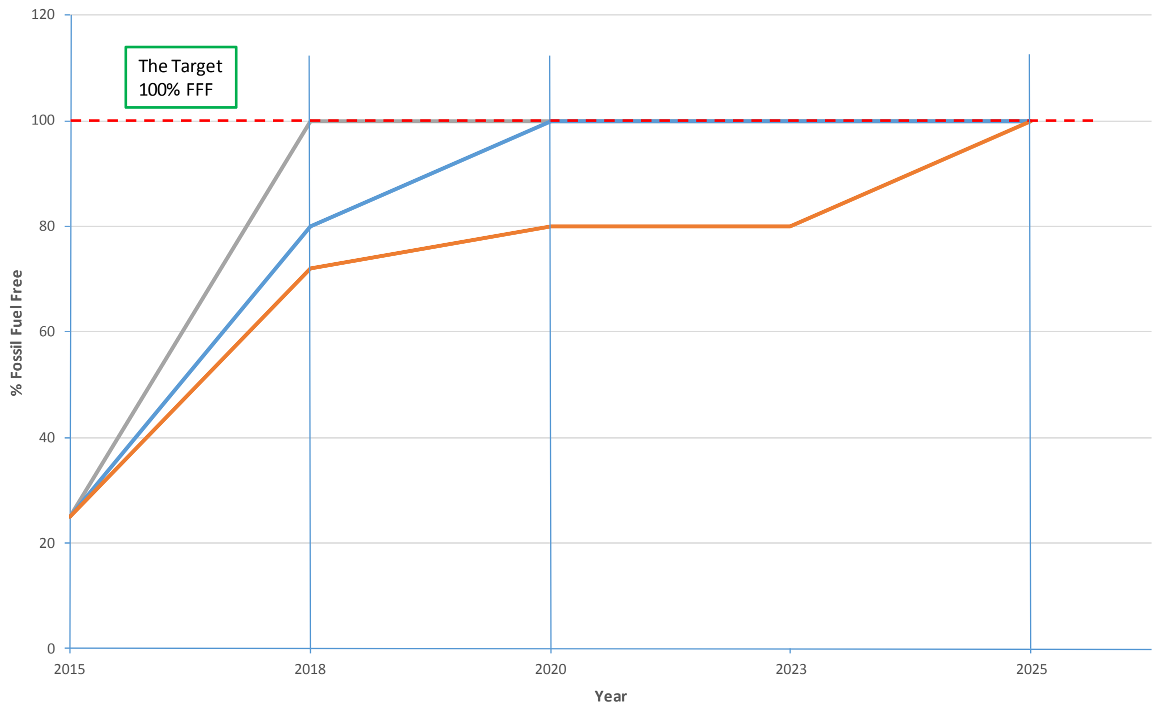

Figure 10.2: Indicative timelines for the three FFF scenarios

It is apparent from the Figure that the main driver toward a 100%FFF for our household, and presumably all other households in the ACT, is the dramatic effect of the ACT Government's electricity decarbonisation program. Even the 'do nothing' option gives a change from 25%FFF in 2015 to about 60%FFF in 2018. The differences in the timing to reach 100%FFF essentially relate to the timing of the installation of home battery systems, and the purchase of EVs and their associated smart chargers.

At this point in time we are not set on selecting any one of the scenarios. Aiming to be 100%FFF around 2020 appears to be the most attractive option. My main interest at the moment is acquiring an EDD that can integrate with charging my EV. Installing a home battery system is a lower priority but I think I may put in a basic battery system in the relatively near future simply to test out the technology – it goes without saying that in doing this I will be looking for some form of modular system that can be progressively added to in response to lessons learnt about the system performance.

One may ask why not just buy Green Power and be 100%FFF with respect to electricity from today. That's a great question and one I have asked myself more than once. Without entering into a long debate, if I had done that I would have missed out on a lot of learning. I'm fascinated by seeing what level of fossil fuel freedom can be achieved at the household level by physically playing around with different equipment configurations. If everyone just bought Green Power, lots of interesting domestic level energy management devices would not have seen the light of day.

10.6 Improved Monitoring

I'm one of those people who can never get enough data. Access to good data enables the user to both optimise control of a system when it is running and to analyse and report on its operation after the event.

One of the best things about moving away from gas is that electricity is much easier to monitor and control than gas. However, at the moment I'm not particularly happy with our ability to monitor, and gather data about, our electricity use at a disaggregated level. For example, monitoring of hard wired appliances generally requires the use of CT clamps which can only be hooked up and removed by a licensed electrician (which is both inconvenient and expensive). You will note that there are many data gaps and estimates of energy use throughout this book – I would have loved to have worked with more complete datasets.

I certainly hope that smarter, and more accessible, monitoring systems will become widely available on the Australian market in the near future.

10.7 Not intending to go off grid

I am always somewhat surprised at the constant media references to an end game where everyone goes off the grid. There is no doubt that going off grid makes a lot of sense for remote locations – this benefits both the user and the electricity provider.[88] However, for the urban dweller I'm not sure it's the ideal outcome. Going off grid is certainly not my vision.

I believe that grids are vital to a smart electricity transmission/distribution system. Sharing electricity will lead to efficiencies where one man's (or woman's) excess meets the next person's demand. For example, living in Canberra in a house with poor solar orientation means that in order

[88] *Disconnecting from the grid via batteries – a sobering tale.* Climate Spectator. http://www.businessspectator.com.au/article/2015/10/26/smart-energy/disconnecting-grid-batteries-%E2%80%93-sobering-tale?t=0567f6317b13fd6ac4950ee0fb76fb9cf3e8b3ad

to meet our winter heating demand for electricity we have a large surplus in summer – ideally this can be used by a household somewhere in Australia (or ideally locally) that has low heating demand in winter but high cooling demand in summer. Not only does the grid enable a more efficient system it also provides our family with some extra income – I would possibly think differently if our FIT was zero.

I am aware of interesting work that is going on to set up local area electricity networks.[89] Another interesting project is this area is the electricity trading model for small generators which is being trialled by a company called Reposit Power.[90] Both of these examples demonstrate the advantages of being hooked into some form of network.

10.8 The End Point

In the context of this book I guess the end point for Australia is having all households being fossil fuel free. We have fully explored the 'fossil fuel free' potential for our family and I am very confident that we can become fossil fuel free within the next five years. This leaves the obvious question: what is likely to happen if only a small proportion of Australian households actively try to wean themselves off fossil fuels?

Users with no interest in their carbon footprint, or even those with an intense interest in climate change but no resources to invest in personal action, will presumably be simply driven by energy costs. Given this, the answer ultimately lies in what steps governments in Australia take to drive the transition away from fossil fuels, particularly the rate of decarbonisation of electricity supply.

Will there be a widespread turning off of gas? Probably not in the near term. Gas provides a reasonably priced way to receive convenient hot water and space heating. However, many people may 'turn off the gas' simply as a reaction to the numerous articles discussing the likelihood of sharp increases in gas prices in coming years because of parity pricing.[91] If the forecast price increases actually eventuate there may well be a widespread changing over to electricity for household space heating and hot water.

In addition to the above, there is no doubt that gas is now, along with coal, becoming a fuel with a negative image. This is mainly associated with keywords such as coal seam gas, fracking, access to prime agricultural land, etc. I don't imagine this is endearing the fuel to too many consumers.

What about Electric Cars? In a similar way to moving away from gas, there will probably not be any major move away from petrol for fuelling cars until the economics are compelling. However, in my experience, in contrast to changing from gas to electricity, the cost advantages of moving to EVs are already here. In my view the main inhibitors to greater EV adoption are factors such as the very meagre choice of EV models currently on the market in Australia and the almost total lack of government interest in encouraging EV uptake. Having said that, irrespective of government action it is not difficult to see a large proportion of the population preferring EVs over petrol engined cars in say 5-10 years' time when the next generation of electric vehicles are widely available.

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[89] *A call to value local energy in Australia's future grid.* Reneweconomy. Dec 2015. http://reneweconomy.com.au/2015/a-call-to-value-local-energy-in-australias-future-grid-65757
[90] *Store. Shift. Trade. Make money from your solar energy.* RepositPower. http://www.repositpower.com/
[91] *Why gas isn't the answer to falling commodity prices or employment.* The Conversation. Dec 2014. https://theconversation.com/why-gas-isnt-the-answer-to-falling-commodity-prices-or-employment-34601

Will households continue to install Solar PV? Australia has a very high take up of rooftop solar on houses.[92] Nevertheless, there is clearly a high potential for very much more uptake. The public response to date illustrates that households will install solar PV if the right policy settings are in place.

Overall I am optimistic. I have little doubt that within the next few decades all Australian households will have effectively weaned themselves off fossil fuels. I trust this book has been useful in demonstrating that a fossil fuel free household is achievable. The actual timing of the widespread transition away from fossil fuels in Australia will be contingent on policy settings adopted by the various levels of government – this is the real unknown!

[92] *Australia the world leader in rooftop solar – daylight second.* Energy Supply Association of Australia. Sep 2015. http://www.esaa.com.au/media/australia_the_world_leader_in_rooftop_solar_daylight_second_1_1_1_1

APPENDIX

Introduction

This Appendix contains notes and details of the computations that underlie many of the computed numbers shown in the body of the report. Appendix A.7 contains a copy of the dataset I have used to compute the numbers behind most of the Figures in this document.

Appendix A.1

Computational Factors

Throughout the report I have used a number of factors to facilitate assessment of the changes we have made in the Transition. In particular, I have presented all energy data in the form of kWh to enable an easy understanding of the relative energy contributions made by the different fuel types. Similarly, I have converted energy use in its different forms into CO_2 output using fuel specific emission factors. In carrying out these conversions I have used factors specified in the Australian Government's *National Greenhouse Accounts*.[93] These factors are updated and published each year – I have chosen to use the 2014 factors across all three years as these represent the middle year of the transition period and the annual changes in the factors are very small compared to the uncertainty of many of the derived figures reported in this book.

When computing energy use and carbon footprints for motor vehicles I have used data presented in the Australian Government's *Green Vehicle Guide.*[94]

Electricity

Emission factor for grid electricity NSW/ACT: 0.86 kg CO_2/kWh

Gas

Energy content factor: 39.3 x 10^{-3} GJ/m^3

Emission factor: 51.2 kg CO_2/GJ

Petrol

Energy content factor: 34.2 GJ/kL

Emission factor: 66.7 kg CO_2/GJ

Energy

1GJ = 278 kWh

[93] *National Greenhouse Accounts Factors.* Australian Government Department of the Environment. Dec 2014. http://www.environment.gov.au/system/files/resources/b24f8db4-e55a-4deb-a0b3-32cf763a5dab/files/national-greenhouse-accounts-factors-dec-2014.pdf
[94] GreenVehicleGuide. Australian Government. http://www.greenvehicleguide.gov.au/

Appendix A.2 – Hot Water

Hot Water Energy Use

Gas

It was not possible to work out the precise energy input into hot water when we were using gas as there was no way of separately monitoring the gas use of individual appliances. However, it can be estimated with some fair degree of confidence by examining total gas use for the house in the summer months when no gas was being used for heating and effectively all gas was being used to provide hot water. While gas was also being used for a gas cooktop during summer the amount of energy used for that purpose was negligible – our last gas bill for Aug-Oct 2015 quarter, when the cooktop was the only remaining gas appliance we were using, showed a charge of $6 for gas use (about 0.4kWh/day).

During all of 2013 and 2014 for the first six months of 2015 our hot water was produced by gas. We estimated gas use for hot water for 2013 and 2014 by taking the average total gas use for the first three months of the year and assuming that this would equal the average gas use for hot water for the year. [This probably slightly understates our gas usage for hot water since our monitoring of our electricity based hot water in 2015 indicates a slightly higher energy input in winter than in summer (see Section 8.5)]

For 2015, I assumed that all gas use for the year until we changed over to electricity in late June was related to heating water (ie we used no gas for spacing heating in 2015 and gas use for the cooktop was treated as being negligible).

Electricity

Once we had changed over to electrical hot water in June 2015, I had access to much firmer data for hot water energy use since the Immersun interface gives a daily reading on, amongst other things, energy use.

During August the Immersun unit was diverting solar PV into both hot water and space heating; however, its monitoring program did not separately identify these two energy streams. Informal daily observations indicated that we were using of the order of 4-5kWh/day to heat our water – this was nearly always totally sourced from solar PV.

When the Immersun unit came back into service at the beginning of October the heating was no longer turned on and this provided a solid dataset of hot water energy diversion for almost all of the last three months of the year.

Hot Water Carbon Footprint

Gas

The gas carbon footprint was computed using the factors for gas in Appendix A.1.

Electricity

All self-consumption of solar PV electricity has been taken to be zero carbon. The carbon footprint of all grid electricity was computed using the factor for NSW/ACT grid electricity shown in Appendix A.1.

The split between self-consumption and grid electricity is discussed in Section 8.5.

Hot Water Energy Costs

Gas

Our Mar-May 2015 gas bill (83-day period) shows that our average daily gas use over that period was 30.5MJ/day and the gas consumption cost was $67.85 (ie costs ignoring supply charge). This translates to (67.85/83) = **81.3c/day.**

Electricity

For the purposes of the cost estimations it was assumed that generating hot water used 4kWh/day – the average daily energy usage over the second half of 2015. It was also assumed that 95% of our hot water was derived from self-consumed solar PV electricity (@7.5 c/kWh) and the remainder was from the grid using shoulder period grid electricity (@ 15.8 c/kWh). (see Section 8.5)

Applying these assumptions, the cost of hot water per day under our new energy regime using electricity was:

4*(.95x7.5 +.05x15.8) = **31.7c/day**.

Appendix A.3 – Space Heating

Space Heating Energy Use

Gas

The energy/CO_2 data for space heating was computed by difference. In essence the amount of gas used for space heating in 2013 and 2014 was taken to be the total gas usage during the notional six month Canberra heating season mid-April to mid-October (15 April to 15 October) minus the computed hot water gas usage for the same period (see Appendix A.2). [Gas cooktop gas usage was taken as being negligible].

We used no gas for space heating in 2015.

Electricity

For 2013 and 2014 it was assumed 1 kWh/day of electricity was used for supplementary heating through the six-month heating period. This estimation is based on informal surveying of the energy used by our supplementary heaters.

Electric heating for 2015 was more complex to compute since, as explained in the body of the text, we went through a number of heating phases during the winter as we transitioned from gas to electric heating. Given the difficulties of accurately tracking the individual heating devices in the house the total electrical space heating load was computed in the same way as gas space heating for the previous two years – by difference.

The total daily electric load for space heating was taken to be (daily figures):

= (grid electricity imported) + (internal consumption of PV solar electricity) – (electricity used for hot water) – (electricity used in the EV) – 5.5 kWh (‘other electricity’ which covers electricity used to power lights, oven, TV, fridge, etc over the winter period).

Space Heating Carbon Footprint

Gas

The gas carbon footprint was computed using the factors for gas in Appendix A.1.

Electricity

All self-consumption of solar PV electricity was taken to be zero carbon. The carbon footprint of all grid electricity was computed using the factor for NSW/ACT grid electricity shown in Appendix A.1.

The split between self-consumption and grid electricity is discussed in Section 8.6.

Space Heating Energy Costs

Gas

Our total gas bill for 2013 was $991 and for 2014 was $1,112 (these include supply charges). The supply charge for these years was about $250 and therefore the fuel charge was about $750 each year. The computed gas bill for hot water was 81.3c/day (see Appendix A.2), that is approximately $296/year. This means that the fuel charge for gas heating was about **$450** in 2013 and 2014 ($750 - $300).

Electricity

If you take the annual electric heating energy use shown in Figure 8.11 and assume, as a worst case, all the grid electricity was used during early evenings at the peak tariff of 23.4c/kWh this provides a total cost of 1,853*0.234 ≈ **$435/year**.

To cross check this it is useful to cost the individual heating components:

Storage Heater

As indicated in the main body of the text I only have one month of good data for the energy use of the storage heater and therefore I had to make assumptions about the heating costs for a year. In the transition year of 2015 we were putting about 4.5kWh/day into the storage heater at night using the off-peak tariff; this was adding to the approximately 4.5kWh/day of solar PV that was being diverted into the heaters during the day via the Immersun (see the discussion around Figure 8.12).

The trial of the FIR panels that we carried out in September suggested from this point on we will not need to inject any off-peak heat into the storage heater and we will in the future be able to just rely on diverted solar PV electricity to charge the storage heater over the coming winters (if indeed we need to use the storage heater at all). If we assume that we will need to use the storage heater for the three core winter months of June, July and August (the FIR panels should be more than capable of heating the house by themselves in the other three months) the total cost of running the storage heater will be 90 days at 4.5kWh/day at 7.5c/kWh (solar PV electricity) ≈ **$30/year**.

FIR Panels

As indicated earlier, we only have limited experience with these panels but our tests to date suggest that a reasonable heating scenario for the FIR panels would be:

- 10kWh/day for three months (June/July/August) + 5kWh/day for the remaining three months (180 days in total).
- for the 10kWh day assume 6kWh @ 23.3c/kWh + 4kWh @ 15.8c/kWh = **$2.03/day**.

- for the 5kWh day assume 3kWh @ 23.3c/kWh + 2kWh @ 15.8c/kWh = **$1.02/day**.
- Total cost = 90*(2.03+1.02) = **$275/year**.

[Our household is on the ActewAGL time of use tariff: peak tariff = 23.3 c/kWh; shoulder tariff = 15.8 c/kWh]

FIR Panels Running Costs: ≈$275/year

Supplementary Heating

It has been assumed in Section 8.6 that we use on average 1 kWh/day of supplementary heating across the six-month heating season. If you assume the worst case of all this energy being used at the peak tariff of 23.4c/kWh this equates to 180*0.234 = **$40/year**

Summing up the individual heating components gives an estimate for the total heating bill for a year under the electric scenario of 30+275+40 = **$345/year.** This figure is not particularly supported by the worst case total above of **$435/year** but the figure of $345 appears to be more robust (even though the comparison indicates that the figures need to be treated as indicative)**.**

Appendix A.4 – Motor Vehicles

Car Energy Use

Our Petrol Cars

In 2013 we owned two petrol cars – a Nissan Pulsar and a Hyundai i30. The distance travelled by each car in this year was estimated from the vehicle odometers and distances recorded at vehicle maintenance services – I did not keep accurate vehicle distance records. I believe the distances travelled in 2013 were typical of average years and hence for the purposes of energy/CO_2 calculations I have adopted the following annual distance estimations:

Hyundai i30 = 8,000 km/year

Nissan Pulsar = 15,000 km/year

The Australian Government's GreenVehicle Guide indicates the following fuel consumption rates[95]:

Hyundai i30 = 6.5L/100km.

Nissan Pulsar = 7.9 L/100km

Applying the above information gives annual fuel consumption of

Hyundai i30 = 520 L/year petrol (80*6.5)

Nissan Pulsar = 1,185 L/year petrol (150*7.9)

[95] GreenVehicleGuide. Australian Government. http://www.greenvehicleguide.gov.au/

Applying the energy content factor for petrol in Appendix A.1 the annual energy consumptions for the cars are:

Hyundai i30 = **4,948 kWh/year** (34.2*.52= 17.8GJ/yr)

Nissan Pulsar = **11,259 kWh/year** (34.2*1.185= 40.5GJ/yr)

The numbers shown in the body of the text have been extracted from the core dataset which is shown at Appendix A7. There are small rounding differences between the numbers shown above and those shown in the body of the report.

EV

This is discussed in Section 8.4.

Car Carbon Footprint

Petrol Car

Applying the CO_2 emission factor for petrol in Appendix A.1 the annual carbon footprint for the cars are:

Hyundai i30 = **1,187 kg CO_2/year** (66.7*17.8)

Nissan Pulsar = **2,701 kg CO_2/year** (66.7*40.5)

As with the energy data, the numbers shown in the body of the text have been extracted from the core dataset which is shown at Appendix A7. There are small rounding differences between the numbers shown above and those shown in the body of the report.

EV

This is discussed in Section 8.4.

Car Energy Costs

Petrol

Fuel costs fluctuate wildly. The fuel prices shown in Figure A4.1 have been taken from sample internet prices for one period in each of the three years.[96] These are purely indicative.

Year	Petrol Price ($/litre)	Petrol Volume (litres)	Total Petrol Cost ($)
2013	1.50	1,705	2,558
2014	1.50	520	780
2015	1.30	520	676

Figure A4.1: Indicative petrol prices

[96] *Weekly fuel report.* NRMA. http://www.mynrma.com.au/about/latest-weekly-fuel-report.htm

EV

I discuss the cost of fuelling my EV in Section 5.3 of my EV book.[97] For the first seven months of 2014 the daily average fuel cost for the EV was $1.16. If this figure is applied across a year it is equivalent to about **$420/year**.

Appendix A.5 – Double Glazing

The house heating bill in 2013 and 2014, when we were primarily heating with gas (+ some supplementary heating with electric fan heaters), was about $450 for gas + $40 for supplementary electricity ≈ **$500/year.** This is explained in Appendix A.3.

Appendix A.6 – Other Computations

%FFF for 2015

In the text I state that we are now in a position of about 25%FFF.

It can be seen from Figure 8.21 that at the end of 2015 we were just over 30%FFF with respect to our total energy consumption while our electricity use was about 60%FFF. The impact of our continued petrol use is quite marked. Clearly over a period of a year the %FFF will be much less than these summer values given the changes in the energy use and energy consumption patterns that take place between warm and cold months.

Examining the last six months of 2015 will probably give the best indication of an annual %FFF with our current household energy regime – 2015 was a year of transition and by the end of June we had more or less changed over our energy systems.

Figure A6.1 shows the monthly total energy usage (electricity + petrol) and the % of the total energy use that was met by internal energy (ie self-consumed solar PV electricity) to compute the amount of FFF electricity that was consumed each month. In total, over the six months about 25% of our energy use was provided by FFF electricity.

Month	Total Energy Consumed (kWh)	Internal Consumption as % of Total Energy Consumed	FFF Electricity Consumed (kWh)
Jul	1,029	10.1	103
Aug	1,598	25.3	404
Sep	1,224	13.2	161
Oct	937	25.1	235
Nov	964	37.4	360
Dec	849	32.6	276
Total	**6,600**		**1,539**

Figure A6.1: %FFF computation for Jul-Dec 2015

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[97] *Living with a plug-in electric car in Canberra.* Dave Southgate. Aug 2014. http://electricvehicleaustralia.com/electric-vehicles/

It can be seen that two months – July and September give a somewhat lower internal consumption rate than the other months. In July we were on holiday for three weeks and hence almost all our solar PV production was exported while in September our EDD (the Immersun) was out of action and we produced our hot water almost totally using grid electricity.

Charging the EV with solar PV electricity

In the text I indicate that I was able to inject solar PV electricity into the EV on an opportunistic basis over the last three months of 2015. I did this simply by being aware of the time of day; the power import/export situation of our PV system (using the Immersun interface); and looking out of the window to informally assess the state of sun/cloud.

I was not able to directly monitor how much solar PV electricity I was able to inject into the car this way so I have carried out a crude assessment using available data on the energy flows in the house.

I was not carrying out the opportunistic EV charging in the first three months of 2015 so I used the data for internal electricity use for Jan-Mar to estimate our 'background' solar use (ie the daytime use of computer, washing machine, vacuum cleaner, etc) in the warmer months – this was about 2.5kWh/day.

I used the data produced by the Immersun monitoring system (see Section 3.2) to ascertain how much solar PV electricity had been diverted to the hot water system each day. My core dataset captures daily internal electricity use (ie solar PV electricity use) and I simply worked out a daily figure for the amount of solar PV diverted to the EV by subtracting the hot water and background solar PV use from the total internal use to arrive at a figure for the EV use of solar PV electricity.
I show monthly data in Figure A6.2 below.

Month	Internal Consumption (kWh)	Hot Water (kWh)	Background Electricity (kWh)	Solar Use in EV (kWh)	Total EV Electricity (kWh)	EV % Solar Electricity
Oct	195	79	50	66	141	47
Nov	364	115	75	174	237	73
Dec	288	94	78	117	142	82
Total	**847**	**288**	**203**	**357**	**520**	**69**

Figure A6.2: Split in Internal solar PV electricity – Oct/Nov 2015

The Figure shows that over the three-month period the EV used 520kWh of electricity in total, of which 357kWh was derived from solar – that is about 70% of the electricity used by the EV was sourced from our solar PV panels.

Appendix A.7 – Datasets underlying the Figures

I believe very strongly that books such as this, which provide a large number of Figures/Tables interpreting data, should provide readers with at least some level of access to the underlying data. On the one hand this enables third parties to further analyse the data to view the topic from perspectives not covered by the author, but more importantly it allows the interested reader to see how the author has interpreted the data and enables the identification of errors. Basic transparency.

The challenge for the author in providing this transparency is of course how to do this without weighing the document down with masses of data. Inevitably this involves compromises. In this case I have split my core dataset into two halves and have condensed the data down from daily values to weekly values. Table A7.1, which contains 12 pages, shows the energy entries in my dataset. Table A7.2, which contains 7 pages, shows the CO_2 outcomes of our energy consumption. All the values in Table A7.2 have been derived by applying the conversion factors in Appendix 1 to the energy values in Table A7.1.

I am aware that it is not too easy to read the lengthy tables – these can easily be copied and pasted into Microsoft Excel to allow easier viewing/interrogation.

Notes on the Tables

The data in Table A7.1 relating to electricity usage, generation and self-consumption was gathered by the daily reading of:

- our electricity meters;
- the energy output as shown by the inverters on our solar systems; and
- the data produced by our Immersun data monitoring unit.

As indicated throughout the text a number of approximations have been made in building up the dataset:

1. The energy consumed by our cars was computed as a total amount for a year (see Appendix A.4). This was allocated equally across the days of the year – see Column 3 in Table A7.1.
2. Similarly for hot water – in the absence of solid data much of the data was allocated assuming equal energy use across all days. When reliable daily energy use data for hot water was available this was used (specifically the last three months of 2015).
3. The data for space heating and 'Other' usage was derived by difference (see Appendix A.3). Quite a number of the entries in these columns (particularly in the warmer months) appear to be anomalous and should be treated with caution.
4. The values in the 'EV Electricity Use' column have been calculated on the basis of the EV charging process being 80% efficient – this is explained in my previously mentioned book on my EV experiences.

Figure A7.1: Energy consumption/generation data

Week	Grid Electricity Use (kWh)	Gas Use (kWh)	Petrol Use (kWh)	Total External Energy Use (kWh)	Solar PV Electricity Generated (kWh)	Electricity Exported (kWh)	Energy Used for Hot Water (kWh)	Energy Used for Space Heating (kWh)	Other Energy Use (kWh)	Self consumption (kWh)	Total Energy Use (kWh)	EV Electricity Use (kWh)	Self consumption as % of total energy use
1/01/2013 - 7/01/2013	19	51	311	381	80	80	56	5	13	-	381	-	-
8/01/2013 - 14/01/2013	18	51	311	380	71	71	56	2	8	-	380	-	-
15/01/2013 - 21/01/2013	21	54	311	386	73	73	56	3	17	-	386	-	-
22/01/2013 - 28/01/2013	16	61	311	388	67	67	56	9	14	-	388	-	-
29/01/2013 - 4/02/2013	20	59	311	390	66	66	56	9	15	-	390	-	-
5/02/2013 - 11/02/2013	20	52	311	383	63	63	56	2	13	-	383	-	-
12/02/2013 - 18/02/2013	21	33	311	365	66	66	56	1	-6	-	365	-	-
19/02/2013 - 25/02/2013	26	57	311	393	49	49	56	4	23	-	393	-	-
26/02/2013 - 4/03/2013	23	64	311	398	41	41	56	9	23	-	398	-	-
5/03/2013 - 11/03/2013	20	54	311	385	68	68	56	2	18	-	385	-	-
12/03/2013 - 18/03/2013	20	54	311	385	63	63	56	2	12	-	385	-	-
19/03/2013 - 25/03/2013	24	67	311	401	54	54	56	12	26	-	401	-	-
26/03/2013 - 1/04/2013	27	67	311	404	52	52	56	12	25	-	404	-	-

Week	Grid Electricity Use (kWh)	Gas Use (kWh)	Petrol Use (kWh)	Total External Energy Use (kWh)	Solar PV Electricity Generated (kWh)	Electricity Exported (kWh)	Energy Used for Hot Water (kWh)	Energy Used for Space Heating (kWh)	Other Energy Use (kWh)	Self consumption (kWh)	Total Energy Use (kWh)	EV Electricity Use (kWh)	Self consumption as % of total energy use
2/04/2013 - 8/04/2013	30	68	311	409	47	47	56	11	30	-	409	-	-
9/04/2013 - 15/04/2013	32	69	311	412	49	49	56	12	29	-	412	-	-
16/04/2013 - 22/04/2013	44	76	311	430	43	43	56	27	35	-	430	-	-
23/04/2013 - 29/04/2013	34	67	311	411	48	48	56	23	23	-	411	-	-
30/04/2013 - 6/05/2013	54	87	311	451	44	44	56	35	44	-	451	-	-
7/05/2013 - 13/05/2013	54	89	311	454	38	38	56	35	48	-	454	-	-
14/05/2013 - 20/05/2013	55	379	311	745	33	33	56	297	47	-	745	-	-
21/05/2013 - 27/05/2013	56	360	311	727	32	32	56	311	51	-	727	-	-
28/05/2013 - 3/06/2013	58	289	311	658	28	28	56	225	48	-	658	-	-
4/06/2013 - 10/06/2013	54	408	311	773	28	28	56	314	46	-	773	-	-
11/06/2013 - 17/06/2013	63	322	311	696	26	26	56	380	- 4	-	696	-	-
18/06/2013 - 24/06/2013	58	460	311	829	29	29	56	435	54	-	829	-	-
25/06/2013 - 1/07/2013	53	329	311	693	25	25	56	252	43	-	693	-	-
2/07/2013 - 8/07/2013	33	280	311	624	30	30	56	288	33	-	624	-	-

Week	Grid Electricity Use (kWh)	Gas Use (kWh)	Petrol Use (kWh)	Total External Energy Use (kWh)	Solar PV Electricity Generated (kWh)	Electricity Exported (kWh)	Energy Used for Hot Water (kWh)	Energy Used for Space Heating (kWh)	Other Energy Use (kWh)	Self consumption (kWh)	Total Energy Use (kWh)	EV Electricity Use (kWh)	Self consumption as % of total energy use
9/07/2013 - 15/07/2013	22	213	311	546	27	27	56	82	8	-	546	-	-
16/07/2013 - 22/07/2013	60	509	311	880	21	21	56	434	53	-	880	-	-
23/07/2013 - 29/07/2013	52	444	311	807	36	36	56	462	47	-	807	-	-
30/07/2013 - 5/08/2013	46	411	311	768	38	38	56	347	40	-	768	-	-
6/08/2013 - 12/08/2013	46	453	311	810	31	31	56	379	39	-	810	-	-
13/08/2013 - 19/08/2013	51	404	311	766	51	51	56	355	42	-	766	-	-
20/08/2013 - 26/08/2013	48	364	311	723	43	43	56	360	44	-	723	-	-
27/08/2013 - 2/09/2013	45	162	311	518	49	49	56	145	37	-	518	-	-
3/09/2013 - 9/09/2013	40	87	311	437	52	52	56	42	34	-	437	-	-
10/09/2013 - 16/09/2013	41	144	311	496	50	50	56	70	33	-	496	-	-
17/09/2013 - 23/09/2013	35	198	311	544	52	52	56	177	32	-	544	-	-
24/09/2013 - 30/09/2013	34	140	311	485	66	66	56	89	25	-	485	-	-
1/10/2013 - 7/10/2013	28	112	311	451	60	60	56	70	25	-	451	-	-
8/10/2013 - 14/10/2013	24	71	311	406	74	74	56	20	10	-	406	-	-

Week	Grid Electricity Use (kWh)	Gas Use (kWh)	Petrol Use (kWh)	Total External Energy Use (kWh)	Solar PV Electricity Generated (kWh)	Electricity Exported (kWh)	Energy Used for Hot Water (kWh)	Energy Used for Space Heating (kWh)	Other Energy Use (kWh)	Self consumption (kWh)	Total Energy Use (kWh)	EV Electricity Use (kWh)	Self consumption as % of total energy use
15/10/2013 - 21/10/2013	31	77	311	418	73	73	56	25	31	-	418	-	-
22/10/2013 - 28/10/2013	30	79	311	420	70	70	56	21	28	-	420	-	-
29/10/2013 - 4/11/2013	31	79	311	421	79	79	56	22	31	-	421	-	-
5/11/2013 - 11/11/2013	29	76	311	415	60	60	56	21	27	-	415	-	-
12/11/2013 - 18/11/2013	29	80	311	420	77	77	56	24	31	-	420	-	-
19/11/2013 - 25/11/2013	23	64	311	398	73	73	56	12	23	-	398	-	-
26/11/2013 - 2/12/2013	23	60	311	394	75	75	56	11	19	-	394	-	-
3/12/2013 - 9/12/2013	19	78	311	408	75	75	56	21	15	-	408	-	-
10/12/2013 - 16/12/2013	19	62	311	392	78	78	56	11	17	-	392	-	-
17/12/2013 - 23/12/2013	17	51	311	379	70	70	56	3	11	-	379	-	-
24/12/2013 - 30/12/2013	13	34	311	358	68	68	56	1	-7	-	358	-	-
31/12/2013 - 6/01/2014	16	40	126	182	76	76	50	1	-4	-	182	-	-
7/01/2014 - 13/01/2014	70	53	95	218	71	71	49	7	10	-	218	64	-
14/01/2014 - 20/01/2014	39	45	95	179	72	72	49	0	5	-	179	25	-

Week	Grid Electricity Use (kWh)	Gas Use (kWh)	Petrol Use (kWh)	Total External Energy Use (kWh)	Solar PV Electricity Generated (kWh)	Electricity Exported (kWh)	Energy Used for Hot Water (kWh)	Energy Used for Space Heating (kWh)	Other Energy Use (kWh)	Self consumption (kWh)	Total Energy Use (kWh)	EV Electricity Use (kWh)	Self consumption as % of total energy use
21/01/2014 - 27/01/2014	47	52	95	194	72	72	49	6	15	-	194	28	-
28/01/2014 - 3/02/2014	60	39	95	194	75	75	49	0	-8	-	194	61	-
4/02/2014 - 10/02/2014	78	43	95	216	72	72	49	2	1	-	216	65	-
11/02/2014 - 17/02/2014	66	47	95	208	51	51	49	3	8	-	208	54	-
18/02/2014 - 24/02/2014	64	40	95	199	81	79	49	7	1	-	199	45	-
25/02/2014 - 3/03/2014	83	47	95	225	97	87	49	3	27	10	235	66	29
4/03/2014 - 10/03/2014	84	43	95	222	121	109	49	0	22	12	234	68	36
11/03/2014 - 17/03/2014	75	46	95	216	110	98	49	2	21	11	227	53	35
18/03/2014 - 24/03/2014	65	47	95	207	109	100	49	1	27	11	218	49	35
25/03/2014 - 31/03/2014	86	54	95	235	59	50	49	6	31	8	243	62	23
1/04/2014 - 7/04/2014	62	49	95	206	72	65	49	2	25	7	213	39	20
8/04/2014 - 14/04/2014	83	57	95	235	77	68	49	10	35	11	246	59	30
15/04/2014 - 21/04/2014	77	68	95	240	101	92	49	25	36	8	248	47	22
22/04/2014 - 28/04/2014	43	50	95	188	74	67	49	18	16	7	195	14	26

Week	Grid Electricity Use (kWh)	Gas Use (kWh)	Petrol Use (kWh)	Total External Energy Use (kWh)	Solar PV Electricity Generated (kWh)	Electricity Exported (kWh)	Energy Used for Hot Water (kWh)	Energy Used for Space Heating (kWh)	Other Energy Use (kWh)	Self consumption (kWh)	Total Energy Use (kWh)	EV Electricity Use (kWh)	Self consumption as % of total energy use
29/04/2014 - 5/05/2014	114	217	95	426	76	69	49	138	43	7	433	66	12
6/05/2014 - 12/05/2014	90	234	95	419	77	71	49	206	35	5	424	56	9
13/05/2014 - 19/05/2014	105	206	95	406	78	72	49	168	42	8	414	62	14
20/05/2014 - 26/05/2014	92	181	95	369	69	62	49	148	45	5	374	48	11
27/05/2014 - 2/06/2014	117	245	95	457	45	40	49	176	48	6	463	66	11
3/06/2014 - 9/06/2014	102	297	95	494	59	51	49	251	43	7	501	60	10
10/06/2014 - 16/06/2014	111	350	95	556	50	44	49	296	38	7	563	74	9
17/06/2014 - 23/06/2014	109	382	95	586	53	47	49	331	47	7	593	55	8
24/06/2014 - 30/06/2014	120	466	95	681	40	34	49	416	52	4	685	72	4
1/07/2014 - 7/07/2014	77	342	95	514	60	54	49	368	45	7	521	34	11
8/07/2014 - 14/07/2014	12	127	95	235	59	55	49	28	5	4	239	13	12
15/07/2014 - 21/07/2014	119	571	95	785	57	45	49	532	54	12	797	50	11
22/07/2014 - 28/07/2014	124	442	95	661	65	58	49	398	51	8	669	80	8
29/07/2014 - 4/08/2014	108	450	95	653	83	72	49	410	56	9	662	55	9

Week	Grid Electricity Use (kWh)	Gas Use (kWh)	Petrol Use (kWh)	Total External Energy Use (kWh)	Solar PV Electricity Generated (kWh)	Electricity Exported (kWh)	Energy Used for Hot Water (kWh)	Energy Used for Space Heating (kWh)	Other Energy Use (kWh)	Self consumption (kWh)	Total Energy Use (kWh)	EV Electricity Use (kWh)	Self consumption as % of total energy use
5/08/2014 - 11/08/2014	95	385	95	575	92	87	49	321	33	7	582	59	10
12/08/2014 - 18/08/2014	112	420	95	627	78	70	49	407	66	7	634	48	8
19/08/2014 - 25/08/2014	100	304	95	499	84	75	49	274	48	8	507	51	11
26/08/2014 - 1/09/2014	116	283	95	494	95	87	49	252	34	9	503	87	12
2/09/2014 - 8/09/2014	112	296	95	503	98	89	49	255	49	9	512	64	14
9/09/2014 - 15/09/2014	103	195	95	393	99	88	49	160	47	11	404	59	21
16/09/2014 - 22/09/2014	88	223	95	406	123	113	49	187	45	9	415	50	16
23/09/2014 - 29/09/2014	63	109	95	267	120	112	49	77	32	9	276	41	24
30/09/2014 - 6/10/2014	27	64	95	186	147	138	49	28	24	9	195	4	33
7/10/2014 - 13/10/2014	76	81	95	252	134	122	49	33	36	12	264	29	31
14/10/2014 - 20/10/2014	87	180	95	363	117	106	49	136	40	11	374	61	26
21/10/2014 - 27/10/2014	67	71	95	233	123	112	49	23	30	11	244	49	31
28/10/2014 - 3/11/2014	66	77	95	238	155	143	49	26	41	11	249	38	31
4/11/2014 - 10/11/2014	79	64	95	238	161	147	49	19	17	14	252	75	39

Week	Grid Electricity Use (kWh)	Gas Use (kWh)	Petrol Use (kWh)	Total External Energy Use (kWh)	Solar PV Electricity Generated (kWh)	Electricity Exported (kWh)	Energy Used for Hot Water (kWh)	Energy Used for Space Heating (kWh)	Other Energy Use (kWh)	Self consumption (kWh)	Total Energy Use (kWh)	EV Electricity Use (kWh)	Self consumption as % of total energy use
11/11/2014 - 17/11/2014	83	55	95	233	125	113	49	8	34	12	245	59	34
18/11/2014 - 24/11/2014	75	46	95	216	154	140	49	2	27	15	231	57	45
25/11/2014 - 1/12/2014	72	50	95	217	152	139	49	2	35	13	230	54	39
2/12/2014 - 8/12/2014	69	50	95	214	120	105	49	6	25	13	227	50	39
9/12/2014 - 15/12/2014	63	53	95	211	144	128	49	6	34	15	226	44	47
16/12/2014 - 22/12/2014	50	47	95	192	166	146	49	0	43	22	214	18	72
23/12/2014 - 29/12/2014	25	39	95	159	125	116	49	6	10	9	168	27	31
30/12/2014 - 5/01/2015	10	21	95	126	155	144	29	-	2	2	128	-	10
6/01/2015 - 12/01/2015	28	36	95	159	118	92	36	-	36	22	181	7	80
13/01/2015 - 19/01/2015	35	52	95	182	155	138	52	-	39	19	201	13	67
20/01/2015 - 26/01/2015	59	45	95	199	131	115	45	-	36	16	215	35	54
27/01/2015 - 2/02/2015	70	56	95	221	105	89	56	-	41	15	236	44	45
3/02/2015 - 9/02/2015	76	44	95	215	136	120	44	-	46	16	231	50	49
10/02/2015 - 16/02/2015	79	44	95	218	103	90	44	-	29	13	231	56	39

Week	Grid Electricity Use (kWh)	Gas Use (kWh)	Petrol Use (kWh)	Total External Energy Use (kWh)	Solar PV Electricity Generated (kWh)	Electricity Exported (kWh)	Energy Used for Hot Water (kWh)	Energy Used for Space Heating (kWh)	Other Energy Use (kWh)	Self consumption (kWh)	Total Energy Use (kWh)	EV Electricity Use (kWh)	Self consumption as % of total energy use
17/02/2015 - 23/02/2015	70	43	95	208	241	225	43	-	48	17	225	47	53
24/02/2015 - 2/03/2015	72	47	95	214	260	243	47	-	37	17	231	49	52
3/03/2015 - 9/03/2015	79	49	95	223	307	283	49	-	46	23	246	58	64
10/03/2015 - 16/03/2015	79	51	95	225	292	265	51	-	50	27	252	54	69
17/03/2015 - 23/03/2015	71	46	95	212	235	219	46	-	41	16	228	48	49
24/03/2015 - 30/03/2015	96	73	95	264	250	219	73	-	31	32	296	85	68
31/03/2015 - 6/04/2015	51	49	95	195	148	139	49	-	51	10	205	25	34
7/04/2015 - 13/04/2015	100	99	95	294	191	176	99	-	49	12	306	56	28
14/04/2015 - 20/04/2015	59	80	95	234	135	123	80	-	12	14	248	29	39
21/04/2015 - 27/04/2015	87	90	95	272	142	128	90	3	87	15	287	36	39
28/04/2015 - 4/05/2015	114	65	95	274	166	155	65	-	70	11	285	61	27
5/05/2015 - 11/05/2015	139	67	95	301	171	160	67	4	82	11	312	57	24
12/05/2015 - 18/05/2015	162	67	95	324	194	173	67	8	93	12	336	76	26
19/05/2015 - 25/05/2015	160	68	95	323	151	133	68	21	96	27	350	63	50

Week	Grid Electricity Use (kWh)	Gas Use (kWh)	Petrol Use (kWh)	Total External Energy Use (kWh)	Solar PV Electricity Generated (kWh)	Electricity Exported (kWh)	Energy Used for Hot Water (kWh)	Energy Used for Space Heating (kWh)	Other Energy Use (kWh)	Self consumption (kWh)	Total Energy Use (kWh)	EV Electricity Use (kWh)	Self consumption as % of total energy use
26/05/2015 - 1/06/2015	173	67	95	335	153	130	67	29	90	22	357	72	41
2/06/2015 - 8/06/2015	175	77	95	347	182	170	77	16	116	12	359	59	24
9/06/2015 - 15/06/2015	190	60	95	345	154	142	60	36	102	12	357	55	24
16/06/2015 - 22/06/2015	202	4	95	301	105	43	32	104	57	50	351	82	100
23/06/2015 - 29/06/2015	92	-	95	187	134	97	32	76	9	50	237	45	128
30/06/2015 - 6/07/2015	14	-	95	109	140	135	32	-	10	5	114	-	31
7/07/2015 - 13/07/2015	14	-	95	109	137	132	32	-	14	5	114	-	30
14/07/2015 - 20/07/2015	73	3	95	171	146	125	32	13	2	6	177	14	27
21/07/2015 - 27/07/2015	225	3	95	323	116	38	32	122	47	73	396	94	123
28/07/2015 - 3/08/2015	203	5	95	303	160	68	32	172	43	99	402	58	171
4/08/2015 - 10/08/2015	167	3	95	265	163	75	32	155	39	91	356	47	181
11/08/2015 - 17/08/2015	167	3	95	265	152	54	32	125	53	98	363	53	190
18/08/2015 - 24/08/2015	162	4	95	261	142	51	32	149	33	100	361	51	194
25/08/2015 - 31/08/2015	178	4	95	277	149	59	32	131	45	80	357	66	154

Week	Grid Electricity Use (kWh)	Gas Use (kWh)	Petrol Use (kWh)	Total External Energy Use (kWh)	Solar PV Electricity Generated (kWh)	Electricity Exported (kWh)	Energy Used for Hot Water (kWh)	Energy Used for Space Heating (kWh)	Other Energy Use (kWh)	Self consumption (kWh)	Total Energy Use (kWh)	EV Electricity Use (kWh)	Self consumption as % of total energy use
1/09/2015 - 7/09/2015	185	4	95	284	226	176	32	97	40	55	339	70	110
8/09/2015 - 14/09/2015	147	4	95	246	280	245	32	60	42	37	283	63	92
15/09/2015 - 21/09/2015	145	5	95	245	265	236	32	57	46	30	275	46	76
22/09/2015 - 28/09/2015	142	5	95	242	275	243	32	61	32	29	271	61	84
29/09/2015 - 5/10/2015	51	4	95	150	310	279	32	34	26	37	187	6	115
6/10/2015 - 12/10/2015	60	3	95	158	282	235	31	9	18	34	192	35	115
13/10/2015 - 19/10/2015	51	6	95	152	289	227	27	8	52	66	218	40	208
20/10/2015 - 26/10/2015	54	3	95	152	258	195	29	-	52	66	218	39	212
27/10/2015 - 2/11/2015	58	2	95	156	296	214	28	-	49	76	232	63	227
3/11/2015 - 9/11/2015	53	0	95	149	251	186	27	-	53	69	218	39	221
10/11/2015 - 16/11/2015	63	1	95	159	223	144	28	-	40	71	230	70	217
17/11/2015 - 23/11/2015	29	0	95	124	360	266	24	-	56	96	220	45	300
24/11/2015 - 30/11/2015	37	-	95	131	376	276	27	-	49	110	241	70	321
1/12/2015 - 7/12/2015	52	-	95	150	344	271	24	-	42	69	219	55	220

Week	Grid Electricity Use (kWh)	Gas Use (kWh)	Petrol Use (kWh)	Total External Energy Use (kWh)	Solar PV Electricity Generated (kWh)	Electricity Exported (kWh)	Energy Used for Hot Water (kWh)	Energy Used for Space Heating (kWh)	Other Energy Use (kWh)	Self consumption (kWh)	Total Energy Use (kWh)	EV Electricity Use (kWh)	Self consumption as % of total energy use
8/12/2015 - 14/12/2015	22	-	95	116	362	296	22	-	45	66	182	21	241
15/12/2015 - 21/12/2015	37	-	95	131	307	239	21	-	48	72	203	40	242
22/12/2015 - 28/12/2015	23	-	95	116	329	258	23	-	48	71	187	23	258
29/12/2015 - 1/01/2016	8	-	41	47	173	163	4	-	11	10	57	3	49

Figure A7.2: Carbon footprint data

Week	Grid Electricity Carbon Footprint (kg CO_2)	Gas Carbon Footprint (kg CO_2)	Petrol Carbon Footprint (kg CO_2)	Carbon Footprint of Exported Electricity (kg CO_2)	Total Carbon Footprint (kg CO_2)	Net Carbon Footprint (kg CO_2)	Hot Water Carbon Footprint (kg CO_2)	EV Carbon Footprint (kg CO_2)	Space Heating Carbon Footprint (kg CO_2)
1/01/2013 - 7/01/2013	16	9	75	69	100	-32	10		1
8/01/2013 - 14/01/2013	15	9	75	61	99	-38	10		0
15/01/2013 - 21/01/2013	18	10	75	63	103	-40	10		0
22/01/2013 - 28/01/2013	14	11	75	58	100	-42	10		2
29/01/2013 - 4/02/2013	17	11	75	57	103	-46	10		2
5/02/2013 - 11/02/2013	17	10	75	54	101	-47	10		0
12/02/2013 - 18/02/2013	18	6	75	57	99	-42	10		0
19/02/2013 - 25/02/2013	22	10	75	42	107	-65	10		1
26/02/2013 - 4/03/2013	20	12	75	35	106	-71	10		2
5/03/2013 - 11/03/2013	17	10	75	58	102	-43	10		0
12/03/2013 - 18/03/2013	17	10	75	54	102	-48	10		0
19/03/2013 - 25/03/2013	21	12	75	46	107	-61	10		2
26/03/2013 - 1/04/2013	23	12	75	45	110	-65	10		2
2/04/2013 - 8/04/2013	26	12	75	40	113	-72	10		2
9/04/2013 - 15/04/2013	28	13	75	42	115	-73	10		2
16/04/2013 - 22/04/2013	38	14	75	37	126	-89	10		5
23/04/2013 - 29/04/2013	29	12	75	41	116	-75	10		4
30/04/2013 - 6/05/2013	46	16	75	38	137	-99	10		7
7/05/2013 - 13/05/2013	46	16	75	33	137	-105	10		7
14/05/2013 - 20/05/2013	47	70	75	28	192	-163	10		55
21/05/2013 - 27/05/2013	48	66	75	28	189	-162	10		57
28/05/2013 - 3/06/2013	50	53	75	24	178	-154	10		42
4/06/2013 - 10/06/2013	46	75	75	24	196	-172	10		58

Week	Grid Electricity Carbon Footprint (kg CO_2)	Gas Carbon Footprint (kg CO_2)	Petrol Carbon Footprint (kg CO_2)	Carbon Footprint of Exported Electricity (kg CO_2)	Total Carbon Footprint (kg CO_2)	Net Carbon Footprint (kg CO_2)	Hot Water Carbon Footprint (kg CO_2)	EV Carbon Footprint (kg CO_2)	Space Heating Carbon Footprint (kg CO_2)
11/06/2013 - 17/06/2013	54	59	75	22	188	-166	10		70
18/06/2013 - 24/06/2013	50	85	75	25	209	-184	10		80
25/06/2013 - 1/07/2013	46	61	75	22	181	-159	10		46
2/07/2013 - 8/07/2013	28	52	75	26	155	-129	10		53
9/07/2013 - 15/07/2013	19	39	75	23	133	-110	10		15
16/07/2013 - 22/07/2013	52	94	75	18	220	-202	10		80
23/07/2013 - 29/07/2013	45	82	75	31	201	-170	10		85
30/07/2013 - 5/08/2013	40	76	75	33	190	-157	10		64
6/08/2013 - 12/08/2013	40	83	75	27	198	-171	10		70
13/08/2013 - 19/08/2013	44	74	75	44	193	-149	10		65
20/08/2013 - 26/08/2013	41	67	75	37	183	-146	10		66
27/08/2013 - 2/09/2013	39	30	75	42	143	-101	10		27
3/09/2013 - 9/09/2013	34	16	75	45	125	-80	10		8
10/09/2013 - 16/09/2013	35	27	75	43	136	-93	10		13
17/09/2013 - 23/09/2013	30	36	75	45	141	-96	10		33
24/09/2013 - 30/09/2013	29	26	75	57	130	-73	10		16
1/10/2013 - 7/10/2013	24	21	75	52	119	-68	10		13
8/10/2013 - 14/10/2013	21	13	75	64	108	-45	10		4
15/10/2013 - 21/10/2013	27	14	75	63	115	-53	10		5
22/10/2013 - 28/10/2013	26	15	75	60	115	-55	10		4
29/10/2013 - 4/11/2013	27	15	75	68	116	-48	10		4
5/11/2013 - 11/11/2013	25	14	75	52	113	-62	10		4
12/11/2013 - 18/11/2013	25	15	75	66	114	-48	10		4

Week	Grid Electricity Carbon Footprint (kg CO_2)	Gas Carbon Footprint (kg CO_2)	Petrol Carbon Footprint (kg CO_2)	Carbon Footprint of Exported Electricity (kg CO_2)	Total Carbon Footprint (kg CO_2)	Net Carbon Footprint (kg CO_2)	Hot Water Carbon Footprint (kg CO_2)	EV Carbon Footprint (kg CO_2)	Space Heating Carbon Footprint (kg CO_2)
19/11/2013 - 25/11/2013	20	12	75	63	106	-43	10		2
26/11/2013 - 2/12/2013	20	11	75	65	105	-41	10		2
3/12/2013 - 9/12/2013	16	14	75	65	105	-41	10		4
10/12/2013 - 16/12/2013	16	11	75	67	102	-35	10		2
17/12/2013 - 23/12/2013	15	9	75	60	99	-38	10		1
24/12/2013 - 30/12/2013	11	6	75	58	92	-34	10		0
31/12/2013 - 6/01/2014	14	7	30	65	51	14	9	0	0
7/01/2014 - 13/01/2014	60	10	23	61	93	-32	9	55	1
14/01/2014 - 20/01/2014	34	8	23	62	65	-3	9	22	0
21/01/2014 - 27/01/2014	40	10	23	62	73	-11	9	24	1
28/01/2014 - 3/02/2014	52	7	23	65	82	-17	9	53	0
4/02/2014 - 10/02/2014	67	8	23	62	98	-36	9	56	0
11/02/2014 - 17/02/2014	57	9	23	44	88	-44	9	47	1
18/02/2014 - 24/02/2014	55	7	23	68	85	-17	9	39	1
25/02/2014 - 3/03/2014	71	9	23	75	103	-28	9	57	1
4/03/2014 - 10/03/2014	72	8	23	94	103	-9	9	59	0
11/03/2014 - 17/03/2014	65	8	23	84	96	-12	9	46	0
18/03/2014 - 24/03/2014	56	9	23	86	87	-1	9	42	0
25/03/2014 - 31/03/2014	74	10	23	43	107	-64	9	53	1
1/04/2014 - 7/04/2014	53	9	23	56	85	-29	9	33	0
8/04/2014 - 14/04/2014	71	11	23	58	105	-46	9	51	2
15/04/2014 - 21/04/2014	66	13	23	79	102	-22	9	40	5
22/04/2014 - 28/04/2014	37	9	23	58	69	-11	9	12	3

Week	Grid Electricity Carbon Footprint (kg CO_2)	Gas Carbon Footprint (kg CO_2)	Petrol Carbon Footprint (kg CO_2)	Carbon Footprint of Exported Electricity (kg CO_2)	Total Carbon Footprint (kg CO_2)	Net Carbon Footprint (kg CO_2)	Hot Water Carbon Footprint (kg CO_2)	EV Carbon Footprint (kg CO_2)	Space Heating Carbon Footprint (kg CO_2)
29/04/2014 - 5/05/2014	98	40	23	59	161	-101	9	57	26
6/05/2014 - 12/05/2014	77	43	23	61	143	-82	9	48	38
13/05/2014 - 19/05/2014	90	38	23	62	151	-89	9	53	31
20/05/2014 - 26/05/2014	79	33	23	53	135	-82	9	42	27
27/05/2014 - 2/06/2014	101	45	23	34	169	-134	9	56	32
3/06/2014 - 9/06/2014	88	55	23	44	165	-121	9	52	46
10/06/2014 - 16/06/2014	95	64	23	38	183	-145	9	64	54
17/06/2014 - 23/06/2014	94	70	23	40	187	-147	9	47	61
24/06/2014 - 30/06/2014	103	86	23	29	212	-183	9	62	77
1/07/2014 - 7/07/2014	66	63	23	46	152	-106	9	30	68
8/07/2014 - 14/07/2014	10	23	23	47	57	-9	9	11	5
15/07/2014 - 21/07/2014	102	105	23	39	230	-192	9	43	98
22/07/2014 - 28/07/2014	107	81	23	50	211	-161	9	68	73
29/07/2014 - 4/08/2014	93	83	23	62	199	-137	9	47	76
5/08/2014 - 11/08/2014	82	71	23	75	175	-101	9	51	59
12/08/2014 - 18/08/2014	96	77	23	60	197	-136	9	41	75
19/08/2014 - 25/08/2014	86	56	23	65	165	-100	9	44	50
26/08/2014 - 1/09/2014	100	52	23	75	175	-100	9	75	46
2/09/2014 - 8/09/2014	96	54	23	77	174	-97	9	55	47
9/09/2014 - 15/09/2014	89	36	23	76	147	-72	9	51	29
16/09/2014 - 22/09/2014	76	41	23	97	140	-42	9	43	34
23/09/2014 - 29/09/2014	54	20	23	96	97	-1	9	36	14
30/09/2014 - 6/10/2014	23	12	23	119	58	61	9	4	5

Week	Grid Electricity Carbon Footprint (kg CO_2)	Gas Carbon Footprint (kg CO_2)	Petrol Carbon Footprint (kg CO_2)	Carbon Footprint of Exported Electricity (kg CO_2)	Total Carbon Footprint (kg CO_2)	Net Carbon Footprint (kg CO_2)	Hot Water Carbon Footprint (kg CO_2)	EV Carbon Footprint (kg CO_2)	Space Heating Carbon Footprint (kg CO_2)
7/10/2014 - 13/10/2014	65	15	23	105	103	2	9	25	6
14/10/2014 - 20/10/2014	75	33	23	91	131	-40	9	52	25
21/10/2014 - 27/10/2014	58	13	23	96	94	3	9	42	4
28/10/2014 - 3/11/2014	57	14	23	123	94	29	9	32	5
4/11/2014 - 10/11/2014	68	12	23	126	103	24	9	65	4
11/11/2014 - 17/11/2014	71	10	23	97	104	-7	9	51	1
18/11/2014 - 24/11/2014	65	8	23	120	96	25	9	49	0
25/11/2014 - 1/12/2014	62	9	23	120	94	26	9	46	0
2/12/2014 - 8/12/2014	59	9	23	90	91	-1	9	43	1
9/12/2014 - 15/12/2014	54	10	23	110	87	23	9	38	1
16/12/2014 - 22/12/2014	43	9	23	126	75	51	9	16	0
23/12/2014 - 29/12/2014	22	7	23	100	52	48	9	23	1
30/12/2014 - 5/01/2015	9	4	23	124	35	89	5	0	0
6/01/2015 - 12/01/2015	24	7	23	79	54	26	7	6	0
13/01/2015 - 19/01/2015	30	10	23	119	63	56	10	11	0
20/01/2015 - 26/01/2015	51	8	23	99	82	17	8	30	0
27/01/2015 - 2/02/2015	60	10	23	77	93	-17	10	38	0
3/02/2015 - 9/02/2015	65	8	23	103	96	7	8	43	0
10/02/2015 - 16/02/2015	68	8	23	77	99	-22	8	48	0
17/02/2015 - 23/02/2015	60	8	23	194	91	103	8	40	0
24/02/2015 - 2/03/2015	62	9	23	209	93	116	9	42	0
3/03/2015 - 9/03/2015	68	9	23	243	100	144	9	50	0
10/03/2015 - 16/03/2015	68	9	23	228	100	128	9	47	0

Week	Grid Electricity Carbon Footprint (kg CO_2)	Gas Carbon Footprint (kg CO_2)	Petrol Carbon Footprint (kg CO_2)	Carbon Footprint of Exported Electricity (kg CO_2)	Total Carbon Footprint (kg CO_2)	Net Carbon Footprint (kg CO_2)	Hot Water Carbon Footprint (kg CO_2)	EV Carbon Footprint (kg CO_2)	Space Heating Carbon Footprint (kg CO_2)
17/03/2015 - 23/03/2015	61	8	23	188	92	96	8	41	0
24/03/2015 - 30/03/2015	83	13	23	188	119	69	13	73	0
31/03/2015 - 6/04/2015	44	9	23	120	76	44	9	21	0
7/04/2015 - 13/04/2015	86	18	23	151	127	24	18	49	0
14/04/2015 - 20/04/2015	51	15	23	106	88	17	15	25	0
21/04/2015 - 27/04/2015	75	17	23	110	114	-4	17	31	3
28/04/2015 - 4/05/2015	98	12	23	133	133	0	12	52	0
5/05/2015 - 11/05/2015	120	12	23	138	155	-17	12	49	3
12/05/2015 - 18/05/2015	139	12	23	149	175	-26	12	65	7
19/05/2015 - 25/05/2015	138	13	23	114	173	-59	13	54	18
26/05/2015 - 1/06/2015	149	12	23	112	184	-72	12	62	25
2/06/2015 - 8/06/2015	151	14	23	146	188	-41	14	51	14
9/06/2015 - 15/06/2015	163	11	23	122	197	-75	11	47	31
16/06/2015 - 22/06/2015	174	1	23	37	197	-160	12	70	90
23/06/2015 - 29/06/2015	79	0	23	84	102	-18	0	39	65
30/06/2015 - 6/07/2015	12	0	23	116	35	81	0	0	0
7/07/2015 - 13/07/2015	12	0	23	113	35	78	0	0	0
14/07/2015 - 20/07/2015	63	1	23	107	86	21	0	12	11
21/07/2015 - 27/07/2015	194	1	23	33	217	-184	4	81	105
28/07/2015 - 3/08/2015	175	1	23	58	198	-140	0	50	148
4/08/2015 - 10/08/2015	144	1	23	65	167	-103	0	40	134
11/08/2015 - 17/08/2015	144	1	23	46	167	-121	0	46	108
18/08/2015 - 24/08/2015	139	1	23	44	163	-119	0	44	128

Week	Grid Electricity Carbon Footprint (kg CO_2)	Gas Carbon Footprint (kg CO_2)	Petrol Carbon Footprint (kg CO_2)	Carbon Footprint of Exported Electricity (kg CO_2)	Total Carbon Footprint (kg CO_2)	Net Carbon Footprint (kg CO_2)	Hot Water Carbon Footprint (kg CO_2)	EV Carbon Footprint (kg CO_2)	Space Heating Carbon Footprint (kg CO_2)
25/08/2015 - 31/08/2015	153	1	23	51	177	-126	4	57	113
1/09/2015 - 7/09/2015	159	1	23	151	183	-31	15	60	84
8/09/2015 - 14/09/2015	126	1	23	211	150	61	27	54	51
15/09/2015 - 21/09/2015	125	1	23	203	148	54	27	40	49
22/09/2015 - 28/09/2015	122	1	23	209	146	63	27	52	52
29/09/2015 - 5/10/2015	44	1	23	240	67	173	27	5	29
6/10/2015 - 12/10/2015	52	1	23	202	75	127	23	30	8
13/10/2015 - 19/10/2015	44	1	23	195	68	127	0	35	7
20/10/2015 - 26/10/2015	46	1	23	168	70	98	0	34	0
27/10/2015 - 2/11/2015	50	0	23	184	73	111	0	54	0
3/11/2015 - 9/11/2015	46	0	23	160	68	91	0	34	0
10/11/2015 - 16/11/2015	54	0	23	124	77	47	0	60	0
17/11/2015 - 23/11/2015	25	0	23	229	48	181	0	39	0
24/11/2015 - 30/11/2015	31	0	23	237	54	184	0	60	0
1/12/2015 - 7/12/2015	47	0	23	233	70	163	0	47	0
8/12/2015 - 14/12/2015	18	0	23	255	41	214	0	18	0
15/12/2015 - 21/12/2015	31	0	23	206	54	152	0	34	0
22/12/2015 - 28/12/2015	18	0	23	222	41	181	0	20	0
29/12/2015 - 1/01/2016	5	0	10	140	15	125	0	2	0

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 energy and transport. 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.[98]

Since his retirement Dave has written three books reporting on the carbon footprint of aviation and one on his experiences with owning an electric car.[99] 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.[100]

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

[98] Public Service Medal: http://www.itsanhonour.gov.au/honours/honour_roll/search.cfm?aus_award_id=1137899&search_type=quick&showInd=true
[99] Dave Southgate's website: http://fossilfuelfreedom.com
[100] SolarShare Canberra: http://solarshare.com.au/