

MSc Architecture: Advanced Environmental and Energy Studies

Craig Embleton, 0750553, Group 1 (Melissa Taylor), B1 (Principles of light: artificial light; Daylight factor. Photovoltaics and Biomass Principals) Essay

COULD DOMESTIC PHOTOVOLTAICS PROVIDE THE
ELECTRICITY NEEDED TO MEET HOUSEHOLD DEMAND AND
POWER A FAMILY CAR IN THE UK?

Word Count 2190

admin@greenfrontier.org

<http://www.greenfrontier.org>

For the attention of Melissa Taylor

March 8th 2009

Table of Contents

<u>TABLE OF CONTENTS.....</u>	<u>2</u>
<u>INTRODUCTION.....</u>	<u>3</u>
<u>CRITICAL ANALYSIS.....</u>	<u>4</u>
<u>CONCLUSION.....</u>	<u>22</u>
<u>BIBLIOGRAPHY.....</u>	<u>24</u>
<u>APPENDICES.....</u>	<u>28</u>

Introduction

This essay relates to the lecture 'Introduction to photovoltaics' of Module B1.

Domestic electricity use accounted for about 9.57% of CO₂ emissions in the UK in 2007 (DUKES, 2008). Personal transportation is a major emitter of CO₂ in the UK, contributing 12.4% of the nation's total emissions in 2006 (DfT¹, 2008). Most cars are currently powered by petrol or diesel (DfT, 2008) obtained from processing oil from finite fossil sources. The problems of peak oil and climate change will eventually make these fossil fuels economically and environmentally untenable. Growing crops such as palm oil for fuel has been touted as a solution, but this can cause serious environmental and social problems, especially when imported from developing nations where they drive up food prices and destroy rainforests with no net reduction in greenhouse gas emissions. (Nowak, R 2008).

There is however a technology that has had a long history of powering cars: electricity (Walsh, B 2009). Most electricity is currently produced in the UK by burning fossil fuels but alternative production sources, both grid-connected and off-grid, are available such as wind turbines and photovoltaics.

The purpose of this essay is to examine whether it is feasible to supply all the electricity a household needs and power a car in the UK from domestic photovoltaics. The essay will look at the UK mean household and car use, alongside a case study of the author's.

¹ Department for Transport

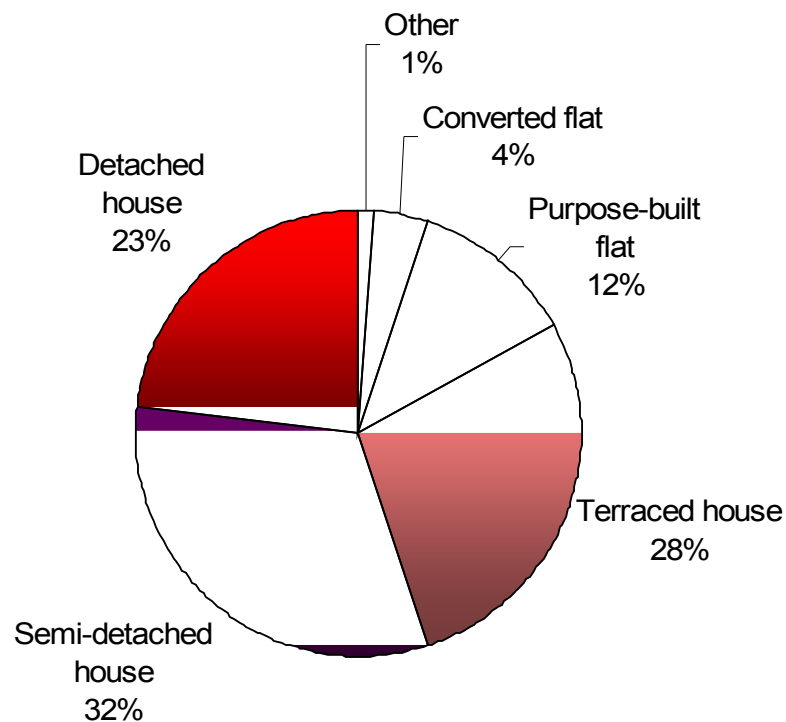
Critical Analysis

UK mean data.

Mean housing stock

As of 2002 there were twenty-five million dwellings in Britain (ESRC², 2004). Eighty-three percent of English dwellings consist of houses, as opposed to flats.

Figure 1 – Type of accommodation, England, 2006/07



Source: Department for Communities and Local Government (2008).

Writing in Renewable Energy, Godfrey Boyle suggests that many UK houses could support a 4 kWp³ photovoltaic array and that over half the houses in the UK are orientated in a direction sufficiently close to south to allow them to utilise the arrays efficiently (2004).

² Economic and Social Research Council

³ Kilowatt peak

Mean UK car journeys

The mean UK car journey, as a three-year mean for the years 2005 to 2007 was 8,883⁴ miles, and the number of cars per household in 2007 was 1.14⁵ (National Travel Survey, 2007). Hence the mean mileage per household was 10,127⁶ miles.

Mean UK electricity consumption

According to DUKES⁷ the mean household electricity consumption in 2006 was 4,457 kWhrs⁸ (2008)

Case study. 32 Wentworth Close

32 Wentworth Close, in the Suffolk town of Hadleigh, is a brick built suburban detached house built in 1975. The house has basic, retrofitted, energy efficiency features, such as double-glazing, cavity-wall insulation and loft insulation. The house has a gas-condensing boiler for water and central heating and an electric cooker. The household consists of two adults in full-time employment and no children. One adult walks to work. The other commutes in the family car.

⁴ See [Appendix 1](#) - Mean annual mileage for UK car journeys 2005 - 2007

⁵ See [Appendix 2](#) - Mean number of cars per household 2007

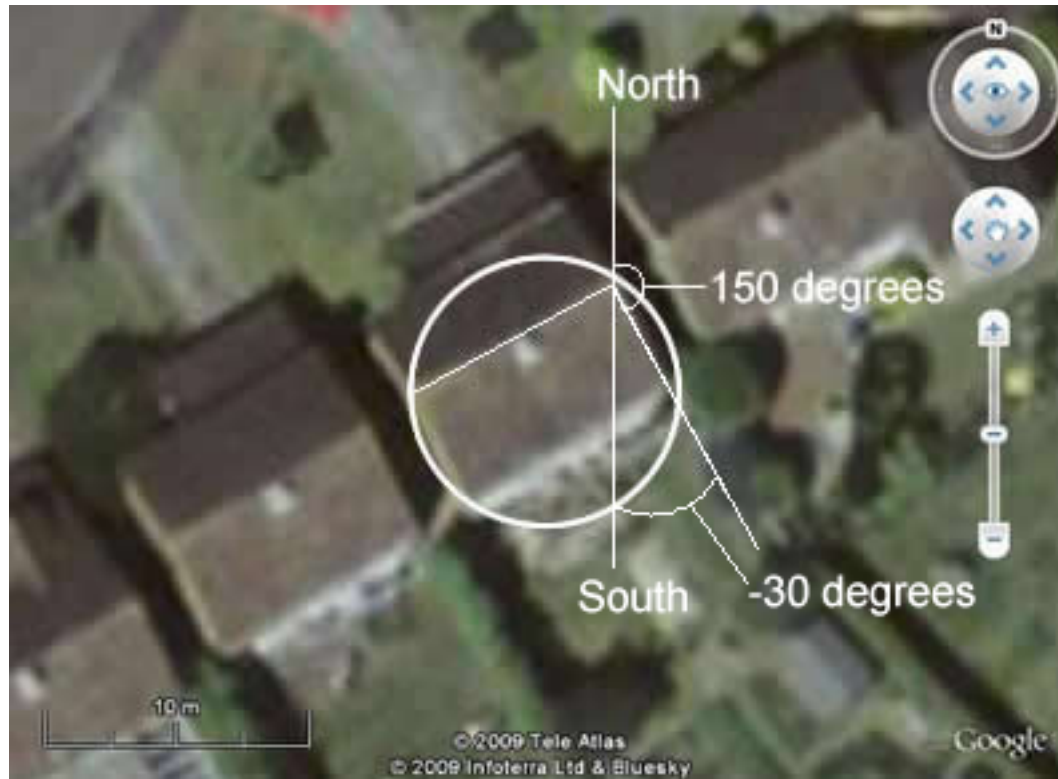
⁶ 8,883 * 1.14

⁷ Digest of United Kingdom Energy Statistics 2008

⁸ Calculated - 117,817 GWh domestic sector sales / 26,434,000 metered domestic customers.

Case study location and dimensions.

Figure 2 – Orientation of 32 Wentworth Close, as seen from the air.



Source: Google Earth, 2009

Table 1 – Case study location and dimensions.

Latitude	52 degrees 2 minutes 21 seconds (52.039167)
Longitude	0 degrees 58 minutes 14 seconds (0.970556)
Altitude	51 metres to ground level
Inclination of roof	35 degrees
Azimuth	-30 degrees from South
Height to ridge	5.2 metres
Length	8.5 metres
Width	7.50 metres
Dimensions of south facing part of roof	$8.5 * 4.6 \text{ metres} = 39.1 \text{ m}^2$

Case study annual electricity consumption

Table 2 – Case study electricity consumption

Quarter	Quarterly consumption	Estimated monthly mean consumption for three-

		month periods. (Quarterly consumption divided by 3)
	Kilowatt Hours	Kilowatt Hours
Nov 2007 – Jan 2008	536	179
Feb 2008 – April 2008	431	144
May 2008 – July 2008	368	123
August 2008 – Oct 2008	483	161
Annual total	1818	

Source: Quarterly electricity bills provided by the electricity supplier (Good Energy)

Case study annual mileage

Table 3 – Case study annual mileage driven and three year annual mean.

Time period	Total mileage	Monthly mean	Commuting mileage ⁹	Monthly mean Commuting mileage	Percentage commuting mileage
Nov 2005 – Oct 2006	8877	740	5141	428	58%
Nov 2006 – Oct 2007	6824	579	5141	428	75%
Nov 2007 – Oct 2008	7966	664	5141	428	65%
3 year annual mean	7889	657	5141	428	65%

Source: Ministry of Transport test certificates

Case study solar radiation received

The RET¹⁰screen software was used to calculate the monthly solar radiation received at Norwich¹¹ weather station. RETscreen uses solar radiation data supplied by NASA¹² and Hadleigh falls within the same global rectangle as Norwich at approximately latitude 52 and longitude 1 – See [appendix 3](#). This data is monthly

⁹ Based on 220 journeys a year (261 working days – 27 annual leave – mean 6 flexi-leave – 8 bank holidays and no sick) Estimated using distances provided by Google maps.

¹⁰ Renewable-energy and Energy-efficient Technologies

¹¹ Norwich weather station lies at latitude 52.6 minutes North and longitude 1.3 minutes East. It has an altitude of 18 metres.

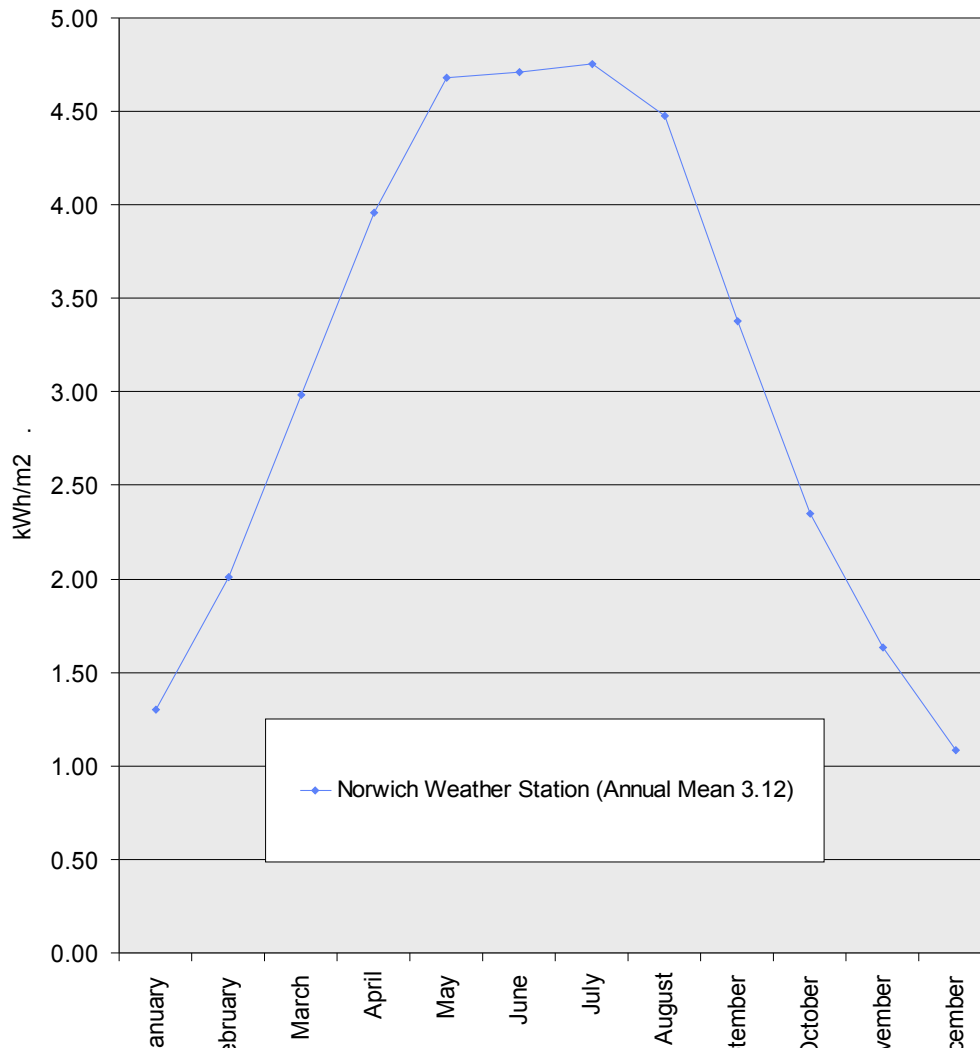
¹² National Aeronautics and Space Administration

averaged from 22 years of data and applies to a flat surface – i.e. inclination of 0 (NASA, 2009). The RETScreen algorithms radiation received at different azimuths and inclinations.

A solar panel mounted on a 35-degree slope and orientated with an azimuth of -30 degrees, as would be the case with the case study house southerly facing roof, receives between 1.09 kWh/m²/day in December to 4.75 kWh/m²/day in July¹³. The monthly solar radiation received is represented in graphical format in figure 3.

¹³ See [Appendix 4](#) - Solar radiation received at Norwich by a solar panel tilted at 35 degrees throughout the year.

Figure 3 – Monthly solar radiation received at Norwich weather station by a solar panel mounted on a 35 degrees and orientated to –30 degrees from due South.






Source: RETscreen International using data supplied by NASA

All-electric cars

All-electric cars (as opposed to non-plug-in hybrids such as the Toyota Prius) currently available in the UK have top speeds ranging from 28 to 60 mph and ranges from 30 to 75 miles in urban driving conditions (UK Electric Cars, 2009). However, there are several electric cars due to enter the UK market between 2009 and 2010 with vastly improved efficiencies.

Table 4 – Comparison of three electric cars available 2009 and 2010.

	Mini E 	Tesla Roadster 	Pininfarina B0 (B Zero) 
Top Speed in mph	95	125 (electronically limited)	80 (electronically limited)
Available	2010	2009	2009
Range in miles	156	227	153
Battery	lithium-ion	lithium-ion	lithium-polymer
Storage Kilowatt hours	35	53	30
Kilowatt hours per mile	0.22	0.23	0.20
Miles per kilowatt hour	4.46	4.28	5.1
Number of seats	2	2	4

Sources: MiniUSA, 2009, Berdichevsky, G et al, 2007, Tesla Motors, 2009, Pininfarina, 2009 and UK Electric Cars, 2009.

The Pininfarina B0 is the most efficient car of the three, consuming just 0.2 kilowatts of electricity per mile. This car is as a four door, four seat model making it more suitable for a family car than the two-seater MiniE or Tesla Roadster.

Efficiency of photovoltaic modules

There are many photovoltaic modules of various efficiencies suitable for mounting on house roofs on the market. The manufacturers provide datasheets that can be used to evaluate makes and models, and feed information into RETScreen. All manufacturers in the UK rate their modules' performance in watts or kilowatts of photovoltaic cells and modules using standard internationally agreed conditions to obtain a value of watt peak (Wp) or kilowatt peak (kWp) – See [appendix 5](#).

Table 5 –Ratings for some commercially available photovoltaic modules

Manufacturer and Model	Rating (Wp)	Module Conversion Efficiency (%)	Temperature Coefficient ¹⁴ (% / °C)	Module Area (m ²)	Peak Power per m ² (W/ m ²)	Area required to produce one kWp (m ²)
Sharp NT-175E1 MSPV ¹⁵ module	175	13.5	-0.49	1.301	134.5	7.434
Sanyo HIP-230HDE1 HIT ¹⁶ PV module	230	16.6	-0.3	1.386	165.9	6.027
SunPower 230	230	18.5	-0.38	1.244	184.9	5.409

Sources: SunPower (2008), Sanyo (2008), Sharp Electronics (2007)

The most efficient photovoltaic module of the three is the SunPower 230, which requires an area of 5.41 m² to produce a kilowatt peak of electricity.

Most grid-connected houses, like the case study house, have the opportunity to export and import electricity to and from the national grid via electricity suppliers like Good Energy (Solar Century, 2007). Godfrey Boyle describes the use of the grid in

¹⁴ The efficiency of most photovoltaic cell types decrease with increasing temperature.

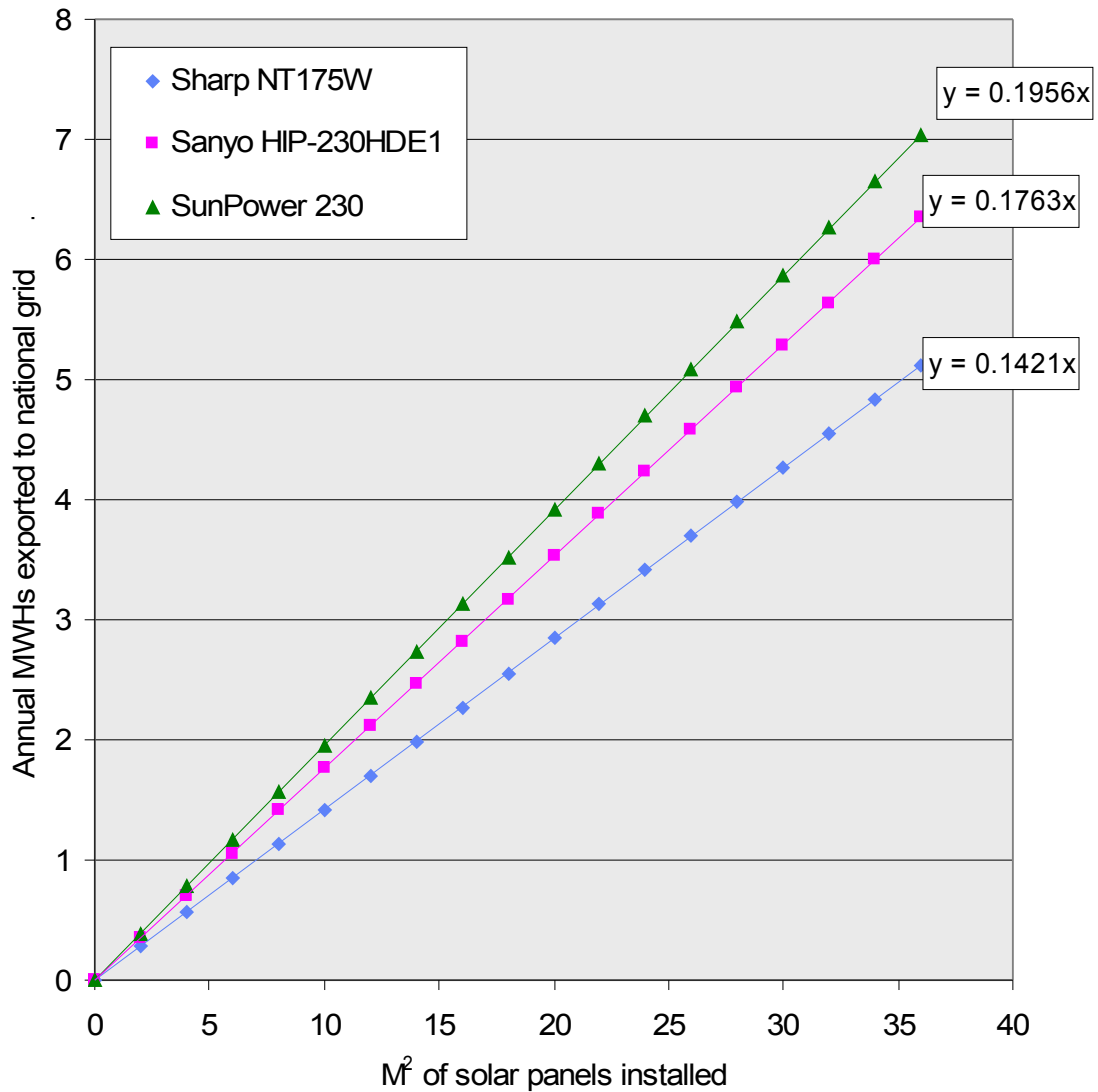
¹⁵ Monocrystalline silicon Photovoltaic

¹⁶ Heterojunction with Intrinsic Thin layer

this way as a giant battery, effectively storing excess electricity for use at later times (2004).

By analysing the values in table 5 with RETscreen it is possible to plot how many Megawatt hours of electricity can be exported to the national grid against the size of photovoltaic panel installations for the three different types of solar panels. To convert from the direct current produced by the solar panels to the alternating current required by the national grid and household appliances it is necessary to use an inverter. The inverter chosen was a SMA AG Sunny Mini Central. This has a conversion efficiency of 95.2% (Solar Technology, 2008).

Figure 5 – Annual Megawatt hours of electricity exported to the national grid for different sized installations of three brands of photovoltaic panels.



Source data: SunPower (2008), Sanyo (2008), Sharp Electronics (2007), examined using RETScreen International. (2009).

Area of SunPower 230 solar panels required to provide household electricity and power a Pininfarina B0.

From the equation for a straight-line graph that intercepts at zero: $y = mx$, the area of SunPower 230 modules required to generate the electricity to meet household needs and power a Pininfarina B0 can be calculated. The areas are summarised for the UK mean and the case study in table 6.

The following assumptions were made:

1. The azimuth of the UK mean house and the inclination of the roof were taken to be the same as the case study house when performing calculations.
2. All journeys made in the electric car can be powered by electricity supplied by the domestic photovoltaics. I.e. the journeys are not further than the storage capacity of the battery would allow.

Table 6 – M² of SunPower solar modules to meet mean and case study electricity requirements

	Case study	UK mean
Annual household electricity consumption	1.818 MWHs	4.457 MWHs
Annual electricity that would be consumed by Pininfarina B0	7,889 * 0.2 (0.1961) = 1,547 kilowatt hours = 1.547 MWHs	10,127 * 0.2 (0.1961) = 1,986 kilowatt hours = 1.986 MWHs
Total electricity requirement	3.365 MWHs	6.643 MWHs
M ² of SunPower solar panels required for household electricity consumption (calculated using $y = mx$)	$y = 0.1956x$ $x = y/0.1956$ $x = 1.818/0.1956 =$ 9.294 m².	$y = 0.1956x$ $x = y/0.1956$ $x = 4.457/0.1956 =$ 22.79 m².
M ² of SunPower solar panels required to provide electricity to power a Pininfarina B0.	$y = mx$ $y = 0.1956x$ $x = y/0.1956$ $x = 1.547/0.1956 =$ 7.909 m²	$y = mx$ $y = 0.1956x$ $x = y/0.1956$ $x = 1.986/0.1956 =$ 10.153 m²
M ² of SunPower solar panels to supply total annual requirements.	17.203 m²	32.943 m²

The case study house would require just over half the installation of SunPower solar modules to meet the annual electricity requirements of the household and to power a Pininfarina B0, compared to the UK mean.

Electricity balance

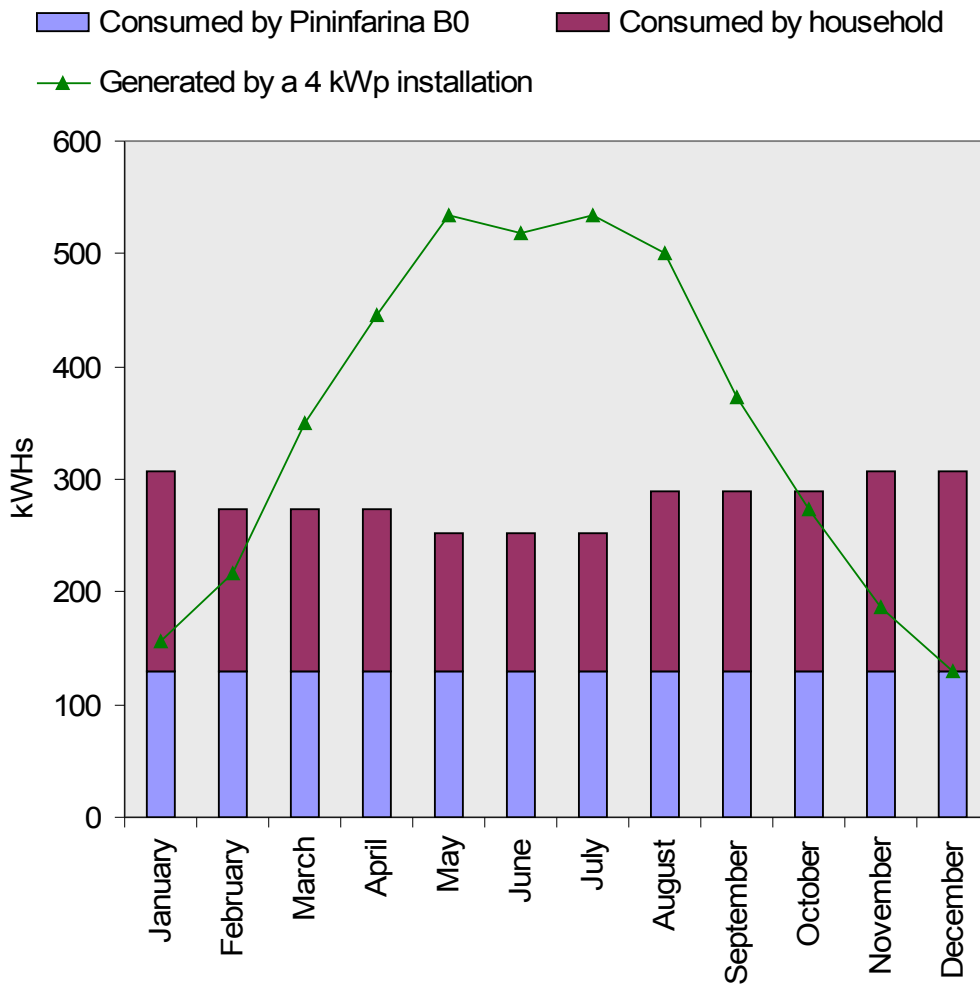
The electricity generated and consumed by the case study household and the mean UK household are not evenly distributed across the whole year. More electricity is generated in the summer and more is consumed in the winter. As stated earlier grid-connected houses have the opportunity to sell and buy back electricity as it is generated and used. But would it be possible to generate all the electricity generated to power at least the car even through the winter?

To answer this question several RETScreen scenarios were investigated.

(NB: It was assumed that the quarterly distribution of electricity consumption for the UK mean household was the same as for the case study house – see [appendix 7](#).)

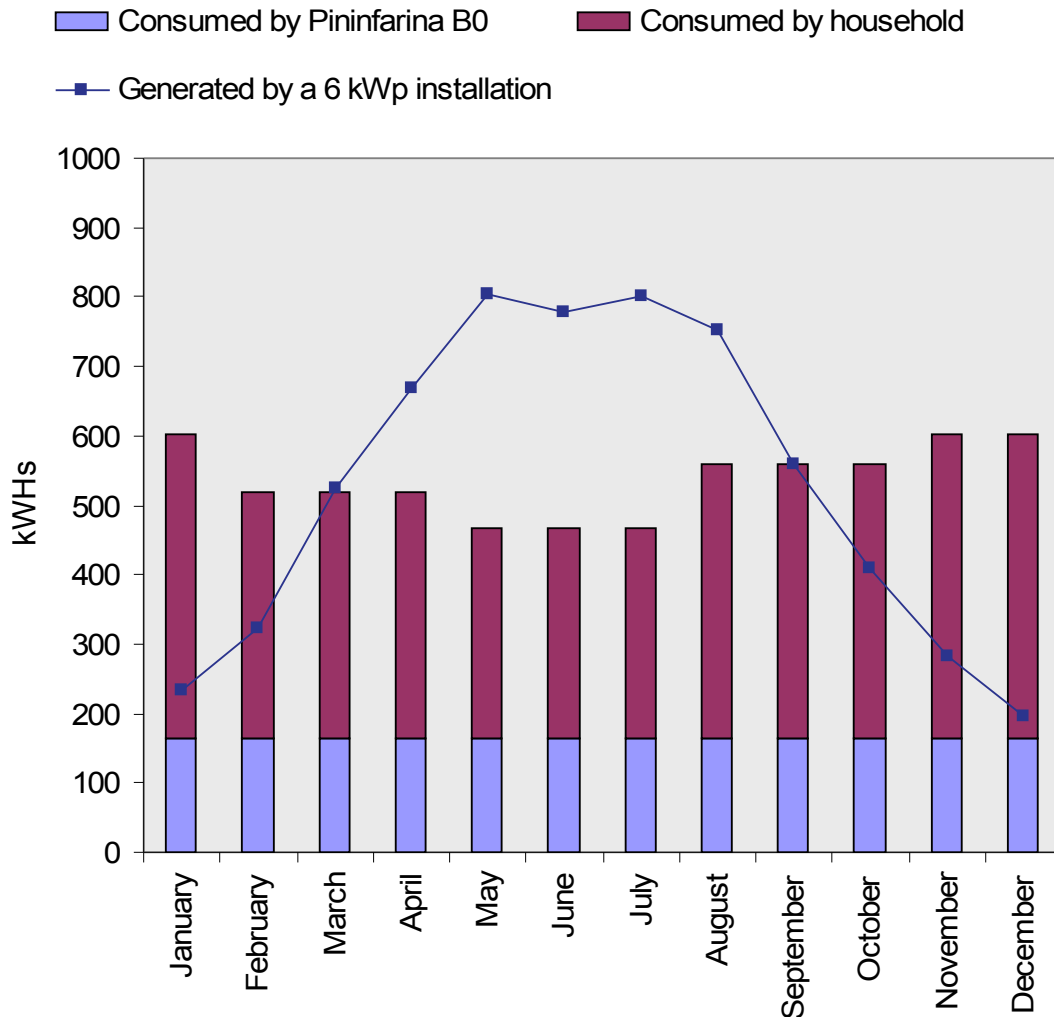
In order to provide the electricity required to power the car on a month-by-month basis the case study required a 4 kWp installation – covering 22 m² of roof space and the mean UK house required a 6 kWp installation – covering 32 m² of roof space. Figures 6 and 7 show the electricity generated and consumed for the case study household and the UK mean household respectively.

Figure 6 – Electricity generated and consumed by 32 Wentworth Close in kilowatt hours per month. See [appendix 6](#) for data.



Source: Calculated using case study house electricity consumption ratios (see [appendix 7](#)) and RETscreen algorithms

Figure 7 – Electricity generated and consumed by national mean in kilowatt hours per month. See [appendix 7](#) for data.

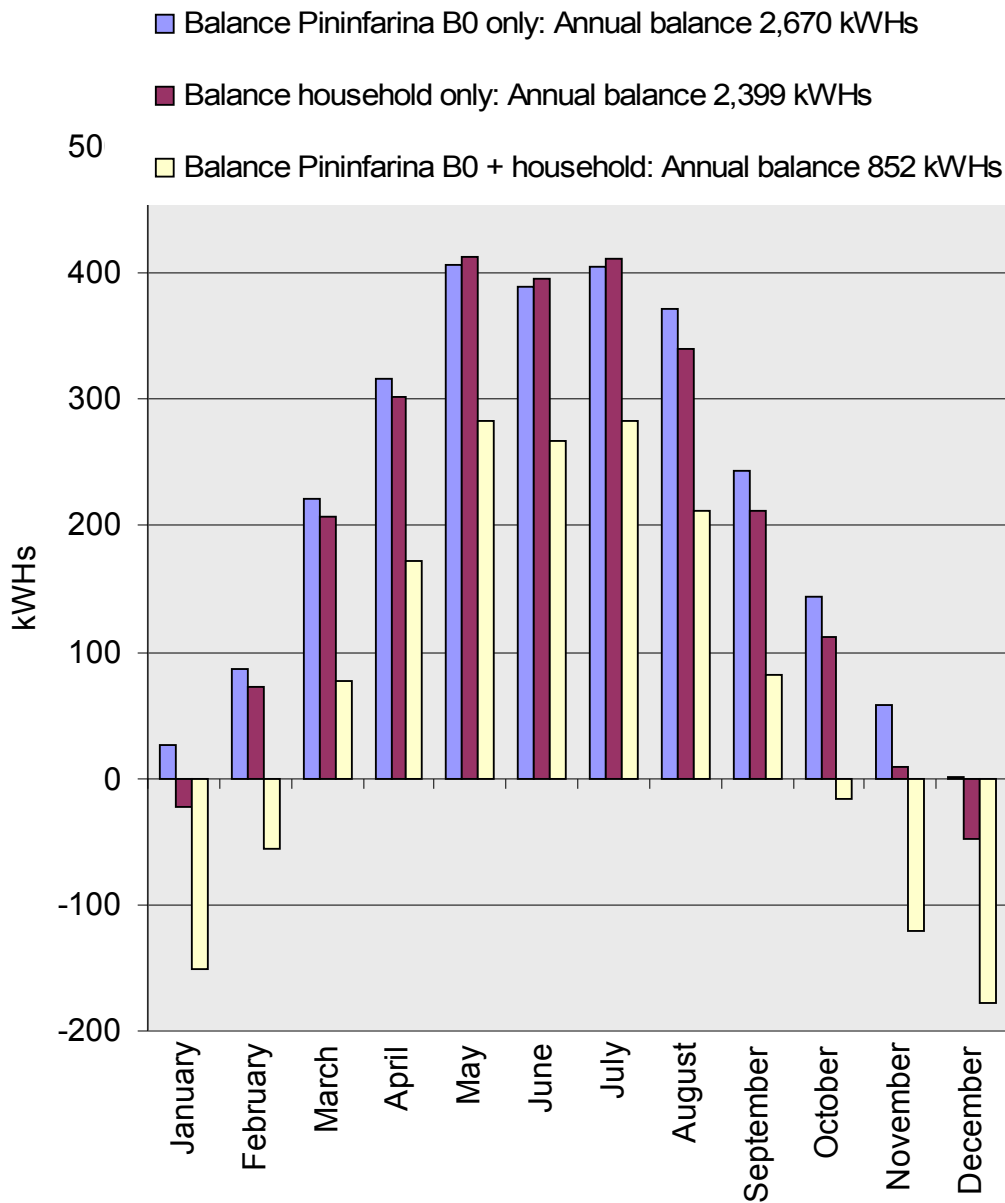


Source: Calculated using RETscreen algorithms

Figures 6 and 7 show that the solar panels would be capable of generating enough electricity on a month-by-month basis to supply the electricity required to power the car. But what about the other electricity requirements?

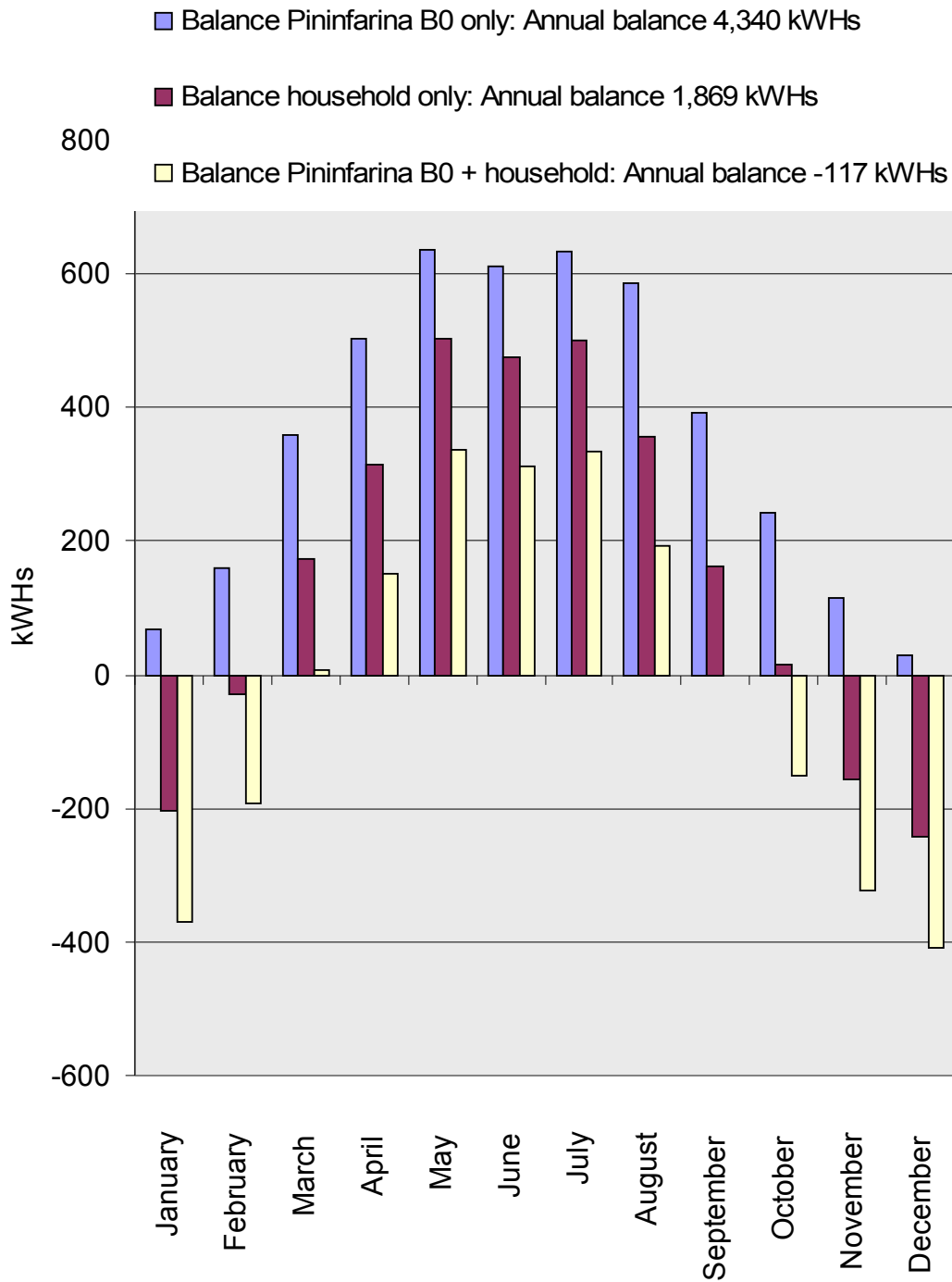
Figures 8 and 9 show the electricity balance for the case study household and the UK mean household respectively.

Figure 8 – Electricity generated by a 22 m2 4 kWp SunPower 230 installation minus the electricity consumed by a Pininfarina B0, the electricity consumed by the household and the total electricity consumed on a month-by-month basis for the case study household. See [appendix 6](#) for data.



Source: Calculated using RETscreen algorithms

Figure 9 – Electricity generated by a 32 m2 6 kWp SunPower 230 installation minus the electricity consumed by a Pininfarina B0, the electricity consumed by the household and the total electricity consumed on a month-by-month basis for the mean UK household. See [appendix 7](#) for data.



Source: Calculated using RETscreen algorithms

Figure 8 shows that with a 4 kWp installation the case study house would be a net exporter to the grid from March to September. Considering household electricity consumption only, the house would only need to import electricity during December and January. The house would generate 852 kWhs of electricity more than it and the car consumed annually.

Figure 6 shows that with a 6 kWp installation the mean UK house would be a net exporter to the grid from March to September too. Considering household electricity consumption only, the house would only need to import electricity from November to February. Overall the house would generate 117 kWhs of electricity less than it and the car consumed annually.

Other studies

The author found little recent data on the use of photovoltaics to power cars. Dr Susan Roaf's pioneering solar home in Oxford, built in 1994, has an integrated 4 kWp grid-linked array. Fifty-four percent of the annual 2.7 MWh of electricity generated supplies the house's annual electricity needs and enough to power a small electric car (Kewet EI Set). The surplus is exported to the national grid (ESRU¹⁷, 2002). Dr Roaf's house is an environmentally designed house, atypical of the mean housing stock. The Kewet EI Set is an early generation lead-acid battery-powered vehicle suitable for short journeys.

Tesla motors are working with photovoltaic manufacturer Solar City to promote the use of solar power to charge the Tesla Roadster (Eberhard, M and Musk, E. 2006). Empirical data is absent on the size of the installations needed.

¹⁷ Energy Systems Research Unit

Conclusion

Summary of case the made

A 4 kWp photovoltaic module installation on the south-facing roof of the case study house could generate more than enough electricity to supply the net annual household electricity and power an electric car. The roof had sufficient space to accommodate a far larger array.

The mean UK household consumed more than twice the electricity than the case study house and it would also consume over a quarter more electricity to power an electric car. A 6 kWp installation covering 32 m² would provide 97% of the total electricity needs – assuming the azimuth and roof inclination were the same as the case study house.

Existing Orthodoxy

Gas is a more efficient way of heating a UK house than electricity due to losses in transmission and the fact that most electricity is generated using gas or coal fired power stations. This would not be true if the electricity was generated using photovoltaic cells and used to power electric storage heaters.

If large numbers of houses in the UK began exporting photovoltaics-produced electricity to the national grid in periods of peak generation, the grid may not be able to act as a 'battery' and supply electricity in the winter. Perhaps houses need their own storage systems.

Limitations of the essay

Much of the data used in the calculations in this essay were provided from datasheets supplied by commercial organisations. The accuracy of this data, particularly around the efficiency of the electric cars will need to be verified in real world independent trials.

The cost of electricity generated using photovoltaics compared to other sources was not investigated. Nor was the payback time of the embodied energy contained within photovoltaic modules.

The essay did not consider how the degradation of efficiency of photovoltaics over time would affect the sizing of the installation. It did not consider the transmission losses rectifying the electricity from the AC of the national grid to the DC required by the electric car.

Not all houses in the UK are arranged in a North-south orientation, nor do their roofs have the same inclination angle. This essay assumed that they did.

The journeys made by the electric car in this essay are assumed to be within the range allowed by the battery in the electric car. Longer journeys would not be possible without recharging points that could quickly recharge the batteries.

Further research

This essay was written considering existing technologies. There is ongoing research into the efficiencies of solar panels and the efficiencies of electric cars, particularly in the battery technology. In the future UK households should be able to generate electricity more efficiently and drive further distances in electric cars than at present.

There is no actual mean UK house. Research needs to be undertaken to ascertain the orientations, inclinations and the sizes of all the roofs in the United Kingdom.

The electricity consumed and annual mileage driven by these households will also need to be obtained.

Similar data to that obtained for the case study house will need to be gathered for a large sample of houses in the UK, (detached, semi-detached, terraced, town, suburban, rural) and correlations plotted within the data. For example, rural households may drive further than city households, due to lack of access to amenities and public transport, but they may also have considerably larger roofs capable of hosting larger arrays of photovoltaics.

Bibliography

Berdichevsky, G Kelty, K, Straubel, JB and Toomre, E. (2007). *The Tesla Roadster*

Battery System. Available:

http://www.teslamotors.com/display_data/TeslaRoadsterBatterySystem.pdf. Last accessed 8 February 2009.

Boyle, G. (2004). *Solar Photovoltaics*. In: Boyle, G Renewable Energy. 2nd ed.

Oxford: Oxford University Press. 66-104.

Department for Business, Enterprise & Regulatory Reform (BERR). (2008). *Digest of United Kingdom Energy Statistics 2008*. Available:

<http://stats.berr.gov.uk/energystats/dukes08.pdf>. Last accessed 7 February 2009.

Department for Communities and Local Government. (2008). *Housing in England 2006/07*. Available:

<http://www.communities.gov.uk/documents/corporate/pdf/971061.pdf>. Last accessed 6 February 2009.

Department for Transport. (2008). *National Travel Survey: 2007*. Available:

<http://www.dft.gov.uk/162259/162469/221412/221531/223955/3227431/NTS2007.pdf>. Last accessed 11 February 2009.

Department for Transport. (2008). *Transport Statistics Great Britain (TSGB), Section 3 - Energy and Environment*. Available:

<http://www.dft.gov.uk/pgr/statistics/datatablespublications/tsgb/2008edition/section3energyenvironment.pdf>. Last accessed 6 February 2009.

Department for Transport. (2008). **Vehicle licensing statistics: 2007**. Available: <http://www.dft.gov.uk/pgr/statistics/datatablespublications/vehicles/licensing/>. Last accessed 6 February 2009.

Eberhard, M and Musk, E. (2006). **Electric Cars and Photovoltaic Solar Cells**. Available: <http://www.teslamotors.com/blog2/?p=29>. Last accessed 15 February 2009.

Economic and Social Research Council. (2004). **Social Trends 43**. Available: http://www.statistics.gov.uk/downloads/theme_social/Social_Trends34/Social_Trends34.pdf. Last accessed 6 February 2009.

Energy Systems Research Unit University of Strathclyde. (2002). **Solar House with Fully-integrated Photovoltaic Roof**. Available: http://www.esru.strath.ac.uk/EandE/Web_sites/01-02/RE_info/solar1.htm. Last accessed 15 February 2009.

Giles, J. (2008). **Mean machines go green**. Available: <http://www.newscientist.com/article/mg19926741.600-mean-machines-go-green.html?full=true#bx267416B1>. Last accessed 30 January 2009.

Mini USA. (2008). **MiniE field trial**. Available: <http://www.miniusa.com/minie-usa/>. Last accessed 9 February 2009.

NASA. (2009). **NASA Surface meteorology and Solar Energy: Locate RETScreen Data**. Available: <http://eosweb.larc.nasa.gov/cgi-bin/sse/ion-p?>

page=globe_main.ion&app=ret&email=rets@nrcan.gc.ca. Last accessed 15 February 2009.

Nowak, R. (2008). **Algae hold the key to the biofuel conundrum**, Available: <http://www.newscientist.com/article/mg19726414.400-algae-hold-the-key-to-the-biofuel-conundrum.html>. Last accessed 27 December 2008.

Pininfarina. (2008). **B0 the Electric Car**. Available: <http://www.pininfarina.it/repository/Immagini/auto%20elettrica/BO%20pininfarina.pdf>. Last accessed 16 February 2009.

Pininfarina. (2008). **Pininfarina B0 image gallery**. Available: <http://www.pininfarina.it/repository/Immagini/auto%20elettrica/pagina%20download/Tqa.jpg>. Last accessed 16 February 2009.

RETScreen International. (2009). **RETScreen Clean Energy Project Analysis Software Download page**. Available: <http://www.retscreen.net/ang/home.php>. Last accessed 1 February 2009.

Sanyo Solar. (2008). **Datasheet: HIT photovoltaic module - HIP-230HDE1**. Available: http://www.sanyo-solar.eu/uploads/media/SANYO_HIP-230_225_220HDE1_EN_screen.pdf. Last accessed 8 February 2009.

Sharp Electronics. (2007). **Datasheet: NT Series - 175W**. Available: http://www.sharp.co.uk/content/ebiz/sharp/resources/pdf/solarspecsheet_nu.pdf. Last accessed 9 February 2009.

SMA Solar Technology AG. (2008). **Datasheet: Sunny Mini Central - SMC 5000A**. Available: <http://www.sma.de/en/products/solar-inverters/sunny-mini-central/sunny-mini-central-4600a-5000a-6000a/dl/U01DNDYwMF82MDAwQV9ERU4wODI1MTE%3D/download.html>. Last accessed 8 February 2009.

Solarcentury. (2007). **Datasheet : Solar electric roof tile - C21e**. Available: <http://www.solarcentury.com/content/download/1201/8980/file/C21e-Tile-datasheet-GB.pdf>. Last accessed 8 February 2009.

Solar Century. (2007). **Exporting electricity**. Available: <http://solarcentury.com/Your-home/Exporting-electricity>. Last accessed 16 February 2009.

SunPower. (2008). **Datasheet: 230 Solar Panel**. Available: http://www.sunpowercorp.com/Products-and-Services/~//media/Downloads/for_products_services/spwr_230wh_res_en_lt_w_ra.aspx. Last accessed 11 February 2009.

Tesla Motors. (2009). **FAQs**. Available: http://www.teslamotors.com/learn_more/faqs.php?flat=1. Last accessed 8 February 2009.

UK Electric Cars. (2009). **UK electric cars available now**. Available: <http://www.ukelectriccars.co.uk/index.htm>. Last accessed 9 February 2009.

Walsh, B. (2007). *The History of the Electric Car*. Available:

http://www.time.com/time/specials/2007/article/0,28804,1669723_1669725,00.html.

Last accessed 6 February 2009.

Word Count – 2190

Appendices

Appendix 1. Mean annual mileage for UK car journeys 2005 - 2007

	Business mileage	Commuting mileage	Other private mileage	Total mileage
2005	1,090	2,840	5,080	9,010
2006	1,040	2,770	4,960	8,770
2007	1,070	2,740	5,060	8,870
Three year mean	1,067	2,783	5,033	8,883

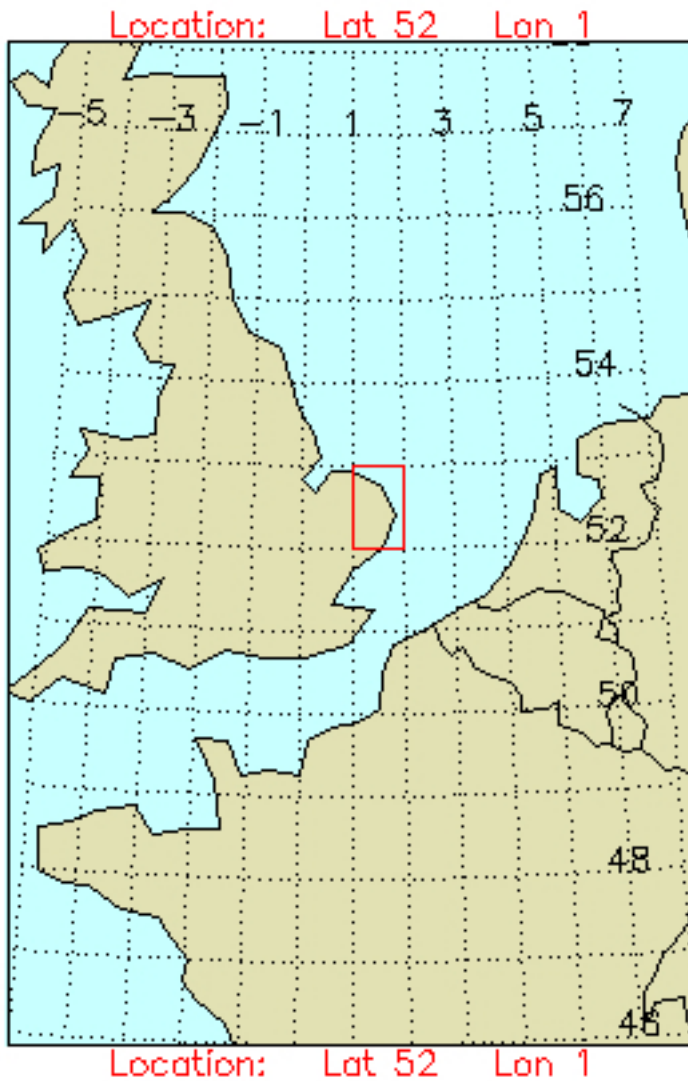
Source: National Travel Survey: 2007

Appendix 2 – Mean number of cars per household 2007

	No car	One car	Two or more cars	All house- holds	Cars per household
London Boroughs	43	41	16	100	0.77
Metropolitan built-up areas	31	42	27	100	1.01
Large urban	27	44	29	100	1.08
Medium urban	23	44	32	100	1.16
Small/medium urban	22	46	32	100	1.17
Small urban	19	42	40	100	1.31
Rural	10	38	51	100	1.54
All areas	25	43	32	100	1.14

Source: National Travel Survey: 2007

Appendix 3 – NASA surface meteorology and solar energy RETScreen data. Rectangle containing Norwich weather station and the case study house.



Source NASA, 2009

Appendix 4 - Solar radiation received at Norwich weather station by a solar panel tilted at 35 degrees and orientated to -30 degrees from due South throughout the year.

Month	Daily solar radiation received (kWh/m ² /d) at Norwich weather station.
January	1.30
February	2.01
March	2.98
April	3.96
May	4.68
June	4.71
July	4.75
August	4.48
September	3.38

October	2.35
November	1.63
December	1.09
Annual Mean	3.12

Source: RET¹⁸screen International using data supplied by NASA¹⁹

Appendix 5 – kilowatt peak (kWp).

The performance in watts or kilowatts of photovoltaic cells is measured under standard internationally agreed conditions.

- The module must be at 25°C.
- The solar radiation incident on the cell must be 1,000 watts m⁻² - typical of bright sunlight.
- The spectral power distribution, or Air Mass (AM) must be 1.5.

According to Boyle “*Air Mass is the ratio of the path length of the Sun’s rays through the atmosphere when the Sun is at a given angle θ to the zenith, to the path length when the Sun is at its zenith.*” (2004).

Air Mass 0 is the spectral power distribution on the edge of the earth’s atmosphere where the irradiance in W/m² is typically 1350 W/m².

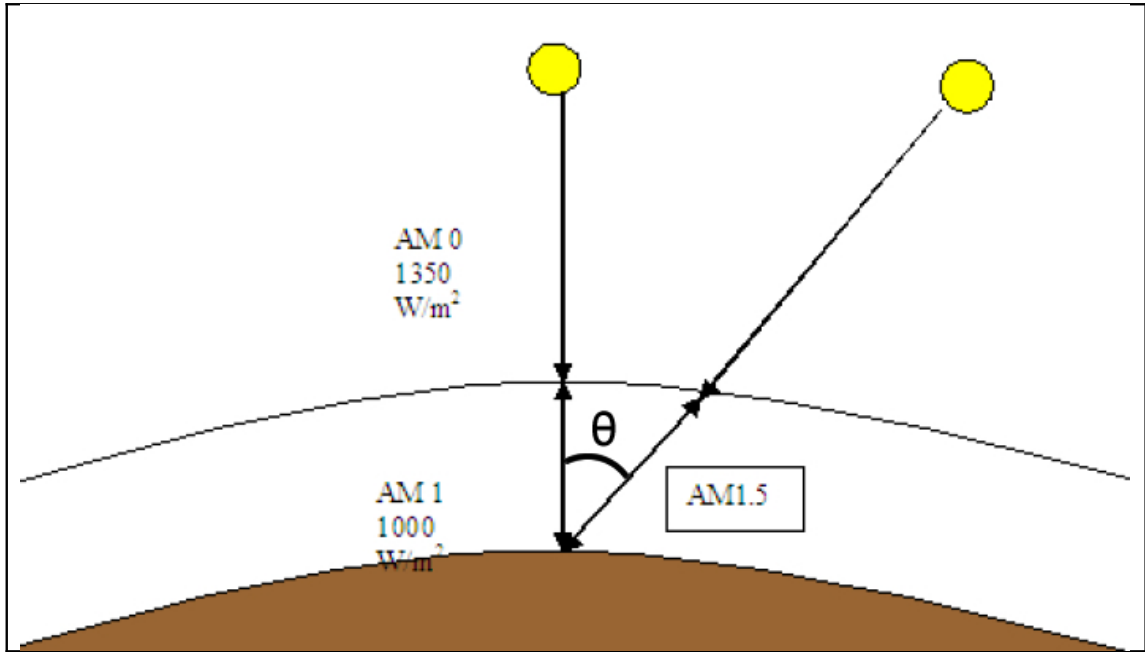
Air Mass 1 is the spectral power distribution at the earth’s surface when the Sun is directly overhead (at its zenith). The ratio is $1/1 = 1$.

Air Mass 1.5 is spectral power distribution at the earth’s surface when the Sun is 48° from its zenith. ($1/\cosine \theta$)

Figure AM0, AM1 and AM2

¹⁸ Renewable-energy and Energy-efficient Technologies

¹⁹ National Aeronautics and Space Administration



Source: Introduction to photovoltaics

Appendix 6 – Case study house - kWhs electricity generated and consumed by a 4 kWp installation.

	Consumed by household	Consumed by Pininfarina B0	Total consumed	Generated	Generated – consumed by Pininfarina B0	Generated – consumed by household	Net Balance
Jan	179	129	308	156	27	-23	-152
Feb	144	129	273	216	87	72	-57
Mar	144	129	273	350	221	206	77
April	144	129	273	445	316	301	172
May	123	129	252	535	406	412	283
June	123	129	252	518	389	395	266
July	123	129	252	534	405	411	282
Aug	161	129	290	501	372	340	211
Sept	161	129	290	372	243	211	82
Oct	161	129	290	273	144	112	-17
Nov	179	129	308	187	58	8	-121
Dec	179	129	308	130	1	-49	-178
	1818	1547	3365	4217	2670	2399	852

Appendix 7 – UK mean house - kWhs electricity generated and consumed by a 6 kWp installation.

It was assumed that the quarterly distribution of electricity consumption for the UK mean household was the same as for the case study house.

The case study house consumed 1818 kWhs of electricity annually in a ratio of: 536:431:368:483 for each quarter.

Therefore the UK mean house consumed 4457 kWhs of electricity annually in a ratio of:

1314:1056:903:1185 for each quarter. These figures were in turn divided by 3 each to give the monthly mean each quarter.

	Consumed by household	Consumed by Pininfarina B0	Total consumed	Generated	Generated – consumed by Pininfarina B0	Generated – consumed by household	Net Balance
Jan	438	165	603	234	69	-204	-369
Feb	352	165	518	324	159	-28	-194
Mar	352	165	518	525	360	173	7
April	352	165	518	668	503	316	150
May	301	165	466	803	638	502	337
June	301	165	466	777	612	476	311
July	301	165	466	800	635	499	334
Aug	395	165	560	752	587	357	192
Sept	395	165	560	558	393	163	-2
Oct	395	165	560	409	244	14	-151
Nov	438	165	603	281	116	-157	-322
Dec	438	165	603	195	30	-243	-408
	4457	1986	6443	6326	4340	1869	-117