elementenergy

Further Analysis of Data from the Household Electricity Usage Study:

Correlation of Consumption with Low Carbon Technologies

Final report for

Department of Energy and Climate Change

and

Department for the Environment Food and Rural Affairs

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1 Executive summary

Objective

Between 2010 and 2011, the Department of Energy and Climate Change (DECC), the Department for the Environment Food and Rural Affairs (Defra) and the Energy Saving Trust conducted the Household Electricity Usage Study (HEUS) to examine the electricity usage patterns of 250 owner-occupier households in England. This study produced comprehensive household electricity usage profiles resolved to the level of individual appliances.

While the HEUS didn’t specifically explore low carbon technologies (LCTs) among the household appliances, both low carbon demand technologies (such as heat pumps and electric vehicles) and low carbon embedded generation technologies (such as small-scale solar photovoltaics and wind turbines) can be expected to have significant impacts on household electricity usage profiles as these technologies are more widely adopted in the UK.

Our objective in this project is to draw on our existing models of LCTs and DECC projections of their future adoption rates in the UK to explore their expected impact on the household electricity usage profiles gathered in the HEUS. We also examine how LCTs will impact on seasonal variations in domestic electricity demand (i.e. winter versus summer) along with their influence on household peak electricity demands and the extent to which demand side response (DSR) strategies could limit these impacts, on a household and national scale[1].

Findings and Recommendations

- UK domestic electricity demand from the grid is likely to rise substantially, to as much as 48% over current levels, by 2030 driven by a combination of population growth and demand from heat pumps and electric vehicles, which are offset to some extent by embedded small-scale wind and solar generation. Annual electricity demand from

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[1] We have assumed that the 250 English owner-occupied households monitored in the HEUS give a reasonable representation of current UK household electricity consumption profiles consistent with findings in other recent HEUS studies:
Element Energy (2013), “Further Analysis of Data from the Household Electricity Usage Study: Consumer Archetypes”.
Element Energy (2013), “Further Analysis of Data from the Household Electricity Usage Study: Increasing Insight and UK Applicability”.

domestic consumers rises in all scenarios, reaching as much as 162TWh/year by 2030 in the High Uptake Scenario (see Figure 1)[2].

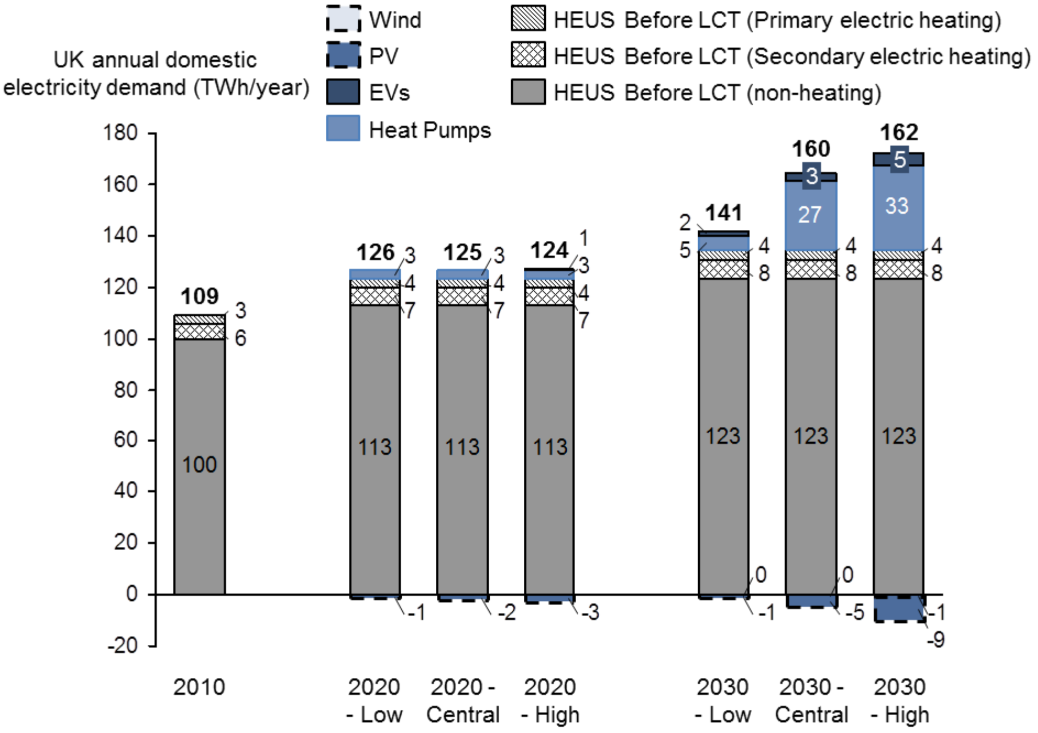

Figure 1: Forecast UK annual domestic electricity demand for three DECC LCT uptake scenarios. Substantial increases in demand are forecast for 2030 under all LCT uptake scenarios.

- The seasonal dependence of electricity consumption is set to markedly increase in the Central and High Uptake Scenarios. Average daily domestic electricity demand in December is expected to be 685GWh/day, more than double the demand forecast for the summer months (see Figure 2). The ratio of average daily domestic demand in winter versus summer months is expected to rise from 1.76 in 2010 to 2.15 in 2030 in the High Uptake Scenario.

Recommendation: Planning for generation and network capacity needs to take into account the increasing seasonal dependency of

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[2] This includes the impact of population growth on base demand, but for simplicity we have not included any effects due to increases in energy efficiency as these have been examined elsewhere:
Element Energy (2013), "Further Analysis of Data from the Household Electricity Usage Study: Increasing Insight and UK Applicability", where a UK-wide technical potential saving of 15TWh/year from energy efficiency was identified.

domestic electricity demand and the resulting system redundancies this requires in the electricity networks. This highlights the importance of comprehensive industry planning and analysis work in this area, such as that initiated by DECC and Ofgem's Smart Grid Forum. Since these impacts will vary considerably for different regional demographic compositions[3], behavioural trends, building types, LCT uptake characteristics[4,5] and levels of technology clustering, future work will need to focus on how the investment required for network reinforcement over the coming decades (estimated by the Smart Grid Forum to be between £20-£60 billion cumulatively to 2050[6]) will vary for different network regions and assets in the UK.

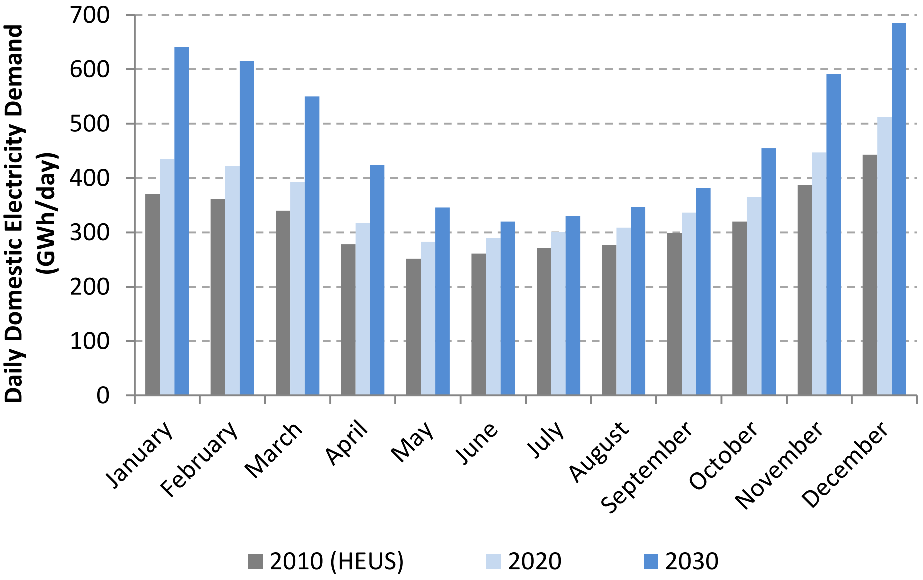

Figure 2: Forecast average daily electricity demand from domestic consumers, under the DECC High Uptake Scenario (i.e. high uptake of electric vehicles, heat pumps, solar PV and small-scale wind) compared to the 2010 HEUS monthly averages. By 2030, demand on an average day in December increases to more than double that of demand on average days in the summer months.

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[3] Element Energy (2013), "Further Analysis of Data from the Household Electricity Usage Study: Increasing Insight and UK Applicability".

[4] Element Energy (2011) "Plug-in Vehicles Economics and Infrastructure: Quantifying Consumer Behaviour", for the Energy Technologies Institute.

[5] Element Energy (2009), "Strategies for the uptake of electric vehicles and associated infrastructure implications", for the Committee on Climate Change.

[6] DECC/Ofgem Smart Grid Forum (2012), "Assessing the Impact of Low Carbon Technologies on Great Britain's Power Distribution Networks".

- The implications for peak-time demand from LCT uptake are also significant with an approximately 40% and 60% increase in demand during the morning and evening peaks, respectively, by 2030 for the DECC High Uptake Scenario relative to the average domestic profile from the HEUS (see Figure 3). The majority of this additional demand originates from the operation of heat pumps.

Recommendation: The increased "peakiness" of domestic diurnal demand highlights the importance of DSR strategies as LCT uptake increases. Further work is required to understand how the variations in peak shifting potentials for different consumer archetypes[7,8] map to the likelihood of LCT uptake, which will have important implications for the total amount of peak-time demand that can be shifted. Further work is also required to understand how daily peaks in domestic demand from the grid, and the ability to level them, will vary for different regions and network assets in the UK. More region and asset specific information on how peaks in domestic demand will interact with commercial and industrial loads is also needed.

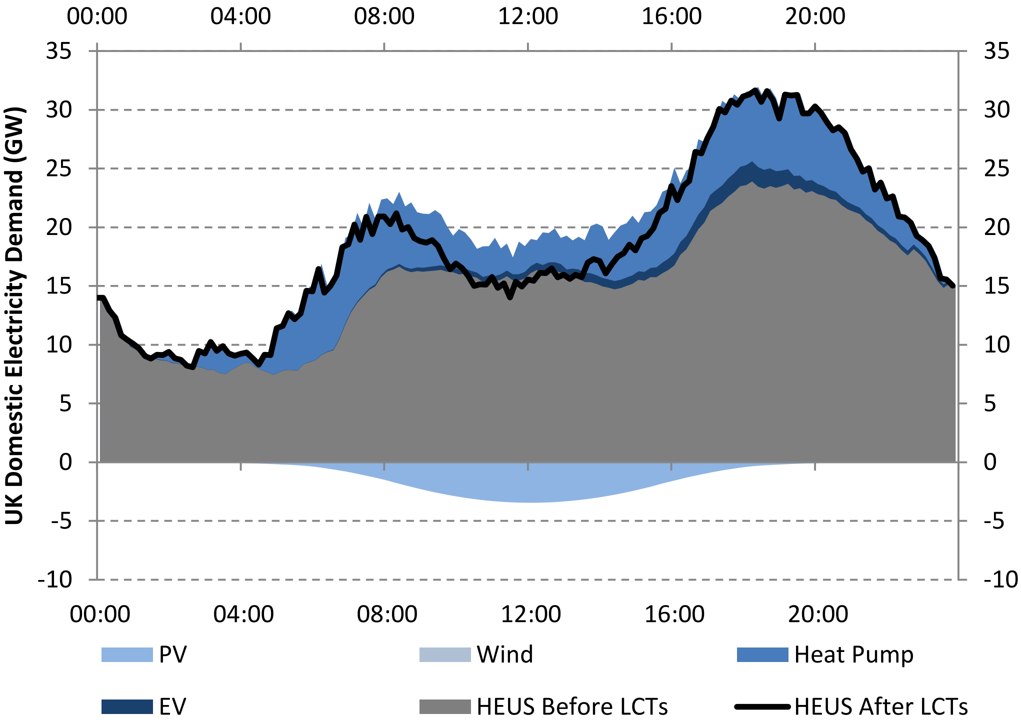

Figure 3: UK annual average electricity demand and generation profiles, in 2030 for the DECC High Uptake Scenario with no DSR.

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[7] Element Energy (2013), "Further Analysis of Data from the Household Electricity Usage Study: Consumer Archetypes".

[8] Element Energy (2013), "Further Analysis of Data from the Household Electricity Usage Study: Increasing Insight and UK Applicability".

- We have modelled several DSR scenarios for heat pumps and electric vehicles to determine the extent to which the morning and evening peak increases could be mitigated. We find that simple time-of-use tariffs (such as the current Economy 10 tariff), if widely deployed with uniform time bandings, could potentially create network load problems related to loss of diversity in UK electricity consumption. Figure 4 shows that heat pumps and electric vehicle charging that are automated to avoid high-tariff periods will create significant peaks at the beginning of static low-tariff time-periods as these devices all activate at the same time.

Recommendation: When designing peak-shifting strategies, care must be taken to ensure behavioural diversity is maintained. For example, in the case of time-of-use tariffs, staggered start-times for different consumers, both locally and nationally, could be used to ensure that new peaks at the beginning of low-tariff periods are not created if these schemes are widely adopted. The formation of new peaks could also be mitigated by the use of a suite of DSR technologies and incentives (also including direct remote control of LCT devices, well-monitored dynamic time-of-use tariffs, etc.).

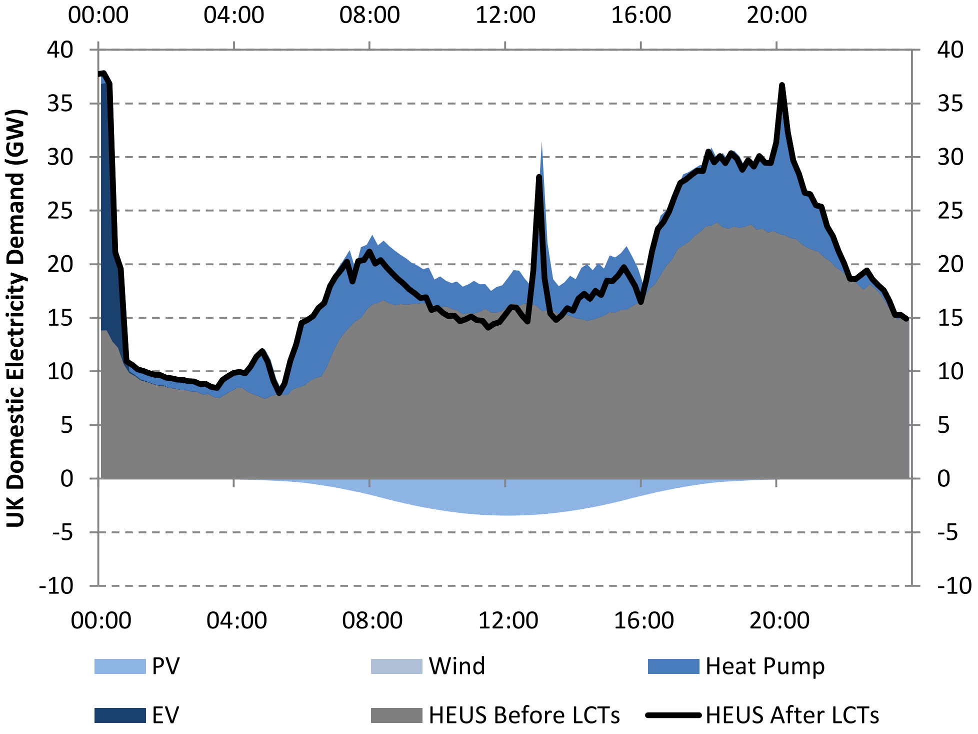

Figure 4: UK annual average electricity demand and generation profile, in 2030 for the DECC High Uptake Scenario, with heat pumps and EVs operating on the Economy 10 tariff. Substantial new peaks are formed at the beginning of low-tariff periods.

- We modelled the effect of diversified DSR approaches to determine the optimised technical potential for DSR (see Figure 5). In this case, an average reduction of 2.5GW can be achieved in the evening peak period. The heat pump component of this shift (approximately 50-80%, depending on season) is based on access to a 180L thermal storage tank – a consideration which must be balanced with its physical footprint in a typical household.

> **Recommendation:** Further research is required to assess the physical capacity, consumer attitudes, and likelihood of uptake for hot water thermal storage tanks in UK domestic heat pump installations since this is a critical element for significant domestic DSR when LCTs are more widely adopted in the UK.

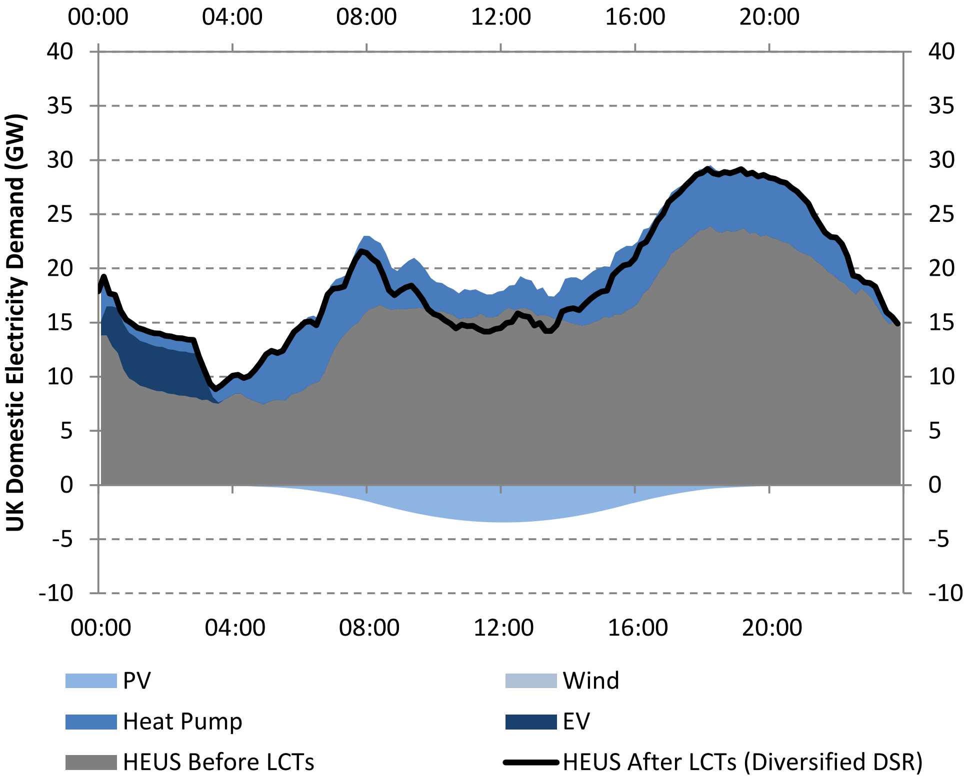

Figure 5: UK annual average electricity demand and generation profile, in 2030 with diversified DSR measures for the DECC High Uptake Scenario.

2 Introduction

Between 2010 and 2011, the Department of Energy and Climate Change (DECC), the Department for the Environment Food and Rural Affairs (Defra) and the Energy Saving Trust (EST) conducted the Household Electricity Usage Study (HEUS) which examined the electricity usage behaviour of 250 owner-occupier households in England. A large dataset was produced by this study on the appliance and electricity usage characteristics of each monitored household, as well as various details about the demographics of the household occupants and the characteristics of the buildings in which they live.

While the incidence of low carbon technologies (LCTs) in the HEUS households was low, DECC projections[9] forecast significant uptake of LCTs in UK households over the coming decades, with significant implications for the electricity consumed, and generated, by households in the UK.

In this report, we investigate how the electricity consumption profiles for typical English households, as recorded by the HEUS, will be impacted by the uptake of LCTs including electric vehicles (EVs) and heat pumps, as well as domestic solar photovoltaic (PV) and micro-wind generation systems.

More specifically, this report examines:

a) Typical profiles of electricity demand/generation from heat pumps, electric vehicles, domestic solar PV and small-scale wind turbine systems.
b) The interactions between these new LCT demand and generation profiles with the existing electricity consumption profile of the average English household (from the HEUS) are explored to determine where new peaks in consumption (or electricity export) might emerge. The forecast uptake rates for each LCT[9] are used to examine when these peaks are expected to emerge in the average UK domestic profile[10].
c) The potential for demand side response (DSR) measures to limit the impact of new demand peaks on a household and national scale.

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[9] DECC/Ofgem Smart Grid Forum (2012), "Assessing the Impact of Low Carbon Technologies on Great Britain's Power Distribution Networks".

[10] In this report we assume that the HEUS household profiles are approximately representative of the UK average based on the findings of earlier work:
Element Energy (2013), "Further Analysis of Data from the Household Electricity Usage Study: Increasing Insight and UK Applicability".

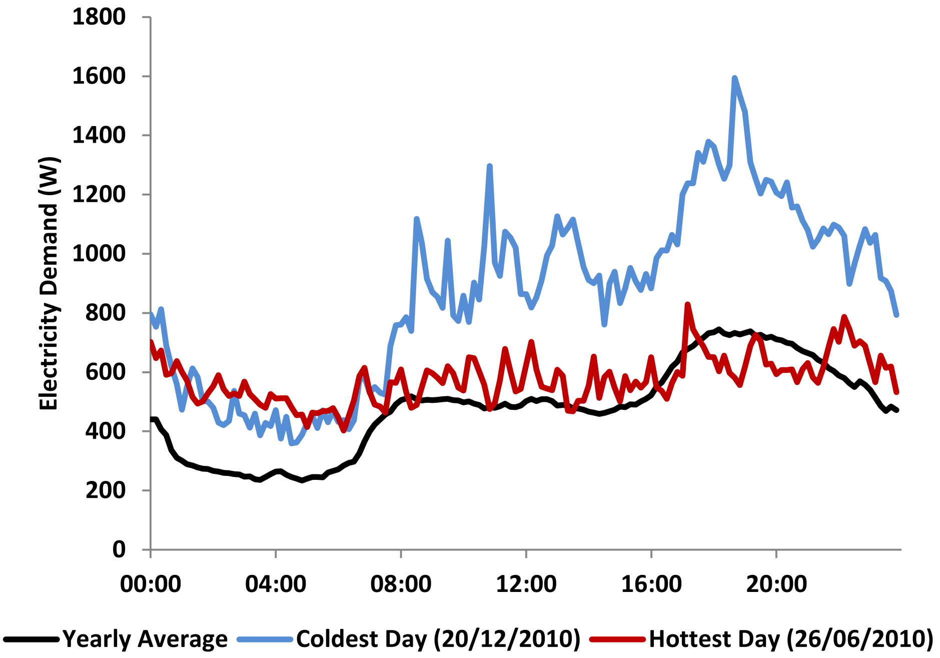

Figure 6: Electricity demand profile of the average HEUS household as a function of time of day, as a yearly average and for the hottest and coldest days of the year[11].

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[11] Above average demand levels on the coldest and hottest days of the year are primarily related to additional demand from heating and cold appliances, respectively.

3 Methodology and assumptions

3.1 Annual and monthly household electricity consumption

The first step was to calculate the average annual and monthly electricity demand profiles for the 250 HEUS households, with 10-minute resolution. Because not all HEUS households were monitored over a full year, the mean monthly consumption profiles are taken from households where measurements were available for the month in question. The strong seasonal dependence of domestic electricity consumption in the HEUS households is shown below in Figure 7. All monthly average profiles exhibit a strong peak during the early evening, between 6-7pm.

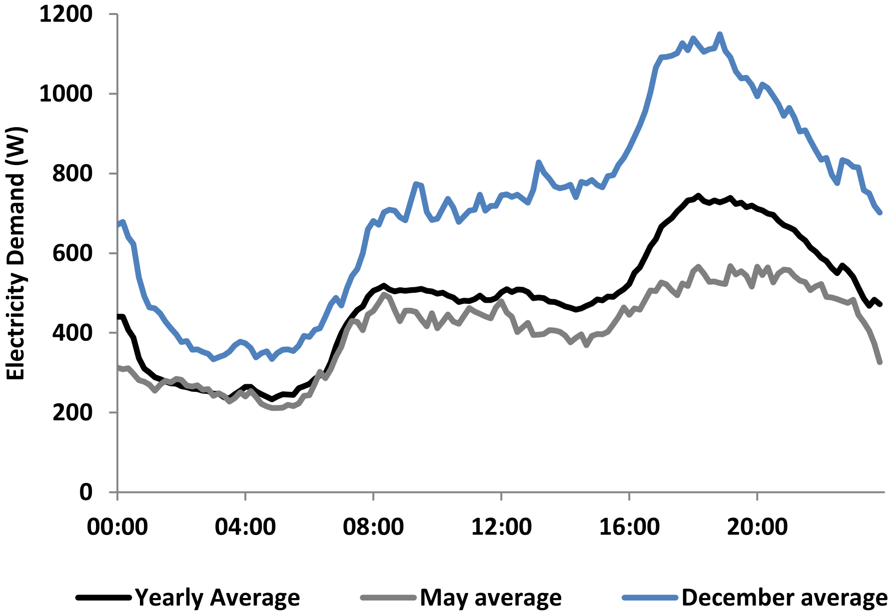

Figure 7: The average diurnal electricity demand profile for the HEUS households over a whole year and for the months with lowest (May) and highest (December) total electricity demand.

While energy efficiency improvements and new appliances can be expected to change typical domestic demand profiles over time, for simplicity, we have not considered these effects when looking at the impact of LCT adoption on the average HEUS household demand profiles[12].

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[12] The impact of energy efficiency measures on the HEUS households has already been examined in:
Element Energy (2013), “Further Analysis of Data from the Household Electricity Usage Study: Increasing Insight and UK Applicability”, and
Cambridge Architectural Research, Element Energy, Loughborough University (2013), “Electrical Appliances at Home: Tuning in to Energy Saving”.

Similarly, we have not considered changes to existing consumption patterns in response to adoption of new LCTs (e.g. households adopting solar PV may adjust existing consumption patterns to maximise on-site use of generated electricity). That is, we assumed no change in the underlying demand profile when examining the impact of increasing levels of LCT adoption over time. In the case of households that install heat pumps, we do deduct any existing primary electric space heating consumption from their underlying profile. Where households used secondary electric space heating to supplement their primary system, it was assumed that this behaviour would continue regardless of the primary system used, though it is recognised that improvements in thermal efficiency and heating control systems may in fact reduce secondary electric space heating usage in some of these cases.

When determining the average demand from space heating in the 250 HEUS households, only the 116 households that were monitored during the November to March space heating period were included, since households monitored outside this period would give artificially low space heating values. For all other appliance types, the full HEUS sample was used. Of the 250 HEUS households, only 9 used primary electric heating, and only 3 of these were monitored during the November to March heating period. As such, the sample size on which primary space heating load was determined was unfortunately small. However, the high uncertainty in the primary electric heating load profile is offset by the low proportion of homes with this technology (less than 4% of the HEUS sample) when building the national average domestic profile for the HEUS dataset. For comparison, 8% of households across the UK are reported to use primary electric heating[13,14].

Analysis in this report is constrained by the limited sample size (250 households) and monitoring duration (26 households were monitored for a full year, the remaining 224 were monitored for a month each on a rolling basis throughout the trial) of the HEUS dataset. Therefore, we have tried to avoid cross-sectioning the dataset into smaller groups where possible. Given the seasonal nature of many LCT domestic loads, it was necessary to break the average HEUS demand profiles out by month, however, to preserve sample sizes, we have not further broken down the HEUS group by household types. For larger sample sizes, it is possible to apply different LCT uptake rates for various household types. However, the extra resolution of this approach would not be meaningful in the context of the small HEUS sample size.

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[13] Department of Energy and Climate Change (2012), “Energy Consumption in the UK”, available from: https://www.gov.uk/government/publications/energy-consumption-in-the-uk

[14] Palmer, J, Cooper, I (2012), “UK Housing Energy Fact File 2012”, for DECC.

3.2 Low carbon technology demand and generation profiles

3.2.1 Electric vehicle charging

Electric vehicle charging profiles have been constructed from data on time-of-arrival for drivers at their home destination, from the National Travel Survey conducted in 2010[15], interpolated to 10-minutely resolution (see Figure 8). For simplicity, we assume all drivers travel the same distance every day, 365 days per year – 37.75km in 2012 and 32.8km by 2030. The annual distance driven is informed by Element Energy's work in modelling of the GB vehicle stock[16,17], and can be found in Appendix 10.3.

We distinguish between plug-in hybrid electric vehicles (PHEVs), which can travel only a small proportion of their trip on battery power, with the remainder supplied by an internal combustion engine; range extended electric vehicles (RE-EVs), where a larger fraction of the journey is travelled under electric power; and Battery Electric Vehicles (BEVs), where the vehicle's motive power is solely supplied by the battery. Further technical details of the modelled vehicles, including battery size, annual mileage and uptake of each vehicle type can be found in Appendix 10.3. The default charging rate for electric vehicles is 3kW, identified by the Smart Grid Forum (equivalent to 12.5A at 240V)[18].

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[15] Department for Transport (2011), "National Travel Survey 2010", https://www.gov.uk/government/publications/national-travel-survey-2010

[16] As used in DECC/Ofgem Smart Grid Forum (2012), "Assessing the Impact of Low Carbon Technologies on Great Britain's Power Distribution Networks"; based on Element Energy's vehicle stock and uptake model (originally developed for the Energy Technology Institute in 2011 and extended for the Department of Transport in 2012).

[17] Baringa Partners & Element Energy (2012), "Electricity Systems Analysis: Future systems benefits from selected DSR scenarios".

[18] DECC/Ofgem Smart Grid Forum (2012), "Assessing the Impact of Low Carbon Technologies on Great Britain's Power Distribution Networks".

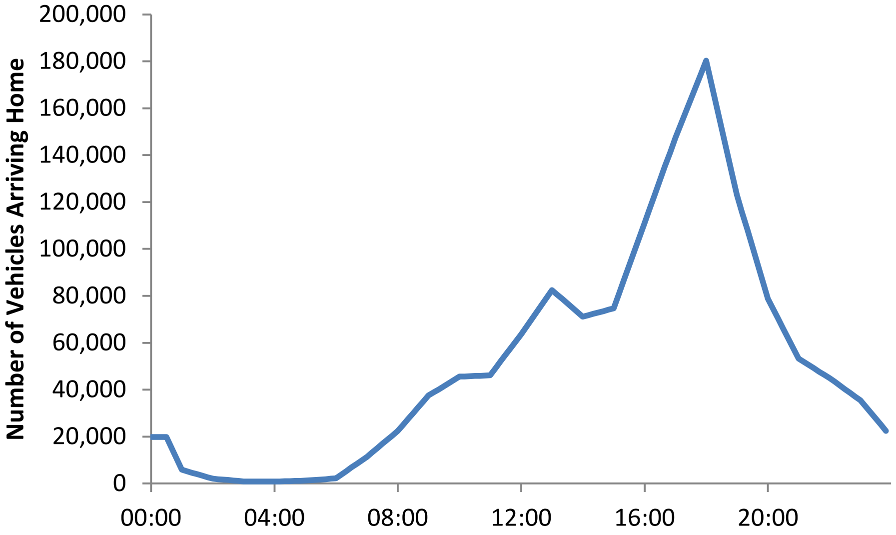

Figure 8: Number of electric vehicles arriving home, in 10-minute intervals, calculated from the National Travel Survey (2010) for 7.6 million vehicles.

3.2.2 Domestic heat pumps

In order to accurately determine electricity demand from domestic heat pumps, the thermal demand and outdoor ambient temperature must be well understood.

We model the operation of a typical heat pump based on the performance of a real device[19] with a water heating loop and a design flow temperature of 50°C and return temperature of 45°C. We assume no thermal loss in pipes leading from the heat exchanger to radiators, and 20 litres of water in the heating system per kW of electric heating power, with a target indoor temperature of 20°C, based on figures from a publication for the Energy Saving Trust where heat pumps underwent field trials[20]. In demand side response scenarios, we have modelled a hot water cylinder with a capacity of 180L, storing water at up to 50°C, based on the central test scenario from a recent study for DECC[21].

For each day in a given month, the mean temperature for each 10-minute interval has been calculated for a representative central England site that is

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[19] Dimplex (2007), “Heat Pumps - heating that doesn’t cost the Earth”, accessible from: http://www.fusiongsource.com/brochures/Dimplex%20%20Heat_Pumps_CPD_March07.pdf

[20] EA Technology (2011), “The effect of thermostatic radiator valves on heat pump performance”.

[21] Kiwa GASTEC at CRE (2013), “Investigation of the interaction between hot water cylinders, buffer tanks and heat pumps”.

not subject to urban heat-island effects. The location has been selected to be approximately representative of the wide range of conditions encountered across the UK. The mean temperature profiles for average days in the coldest and warmest months are shown in Figure 9. We also used aggregated average UK diurnal thermal demand profiles obtained from the Carbon Trust's Micro CHP trials.[22] For further technical details, including the control strategy for heat pumps, see Appendix 10.2.

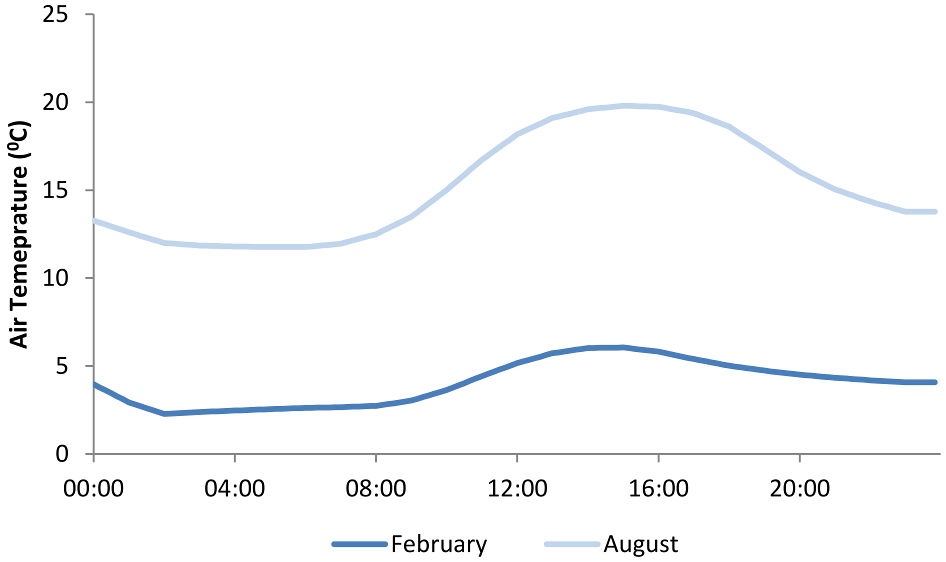

Figure 9: Temperature on an average day for the coldest (February) and warmest (August) months.

Heat pump performance is affected significantly by the source temperature, characterised by the coefficient of performance (COP). The COP values used in this model have been modelled after performance of a real life device[23] (a 2.2kW-electric heat pump, producing 8kW of thermal power at 7°C). A water flow temperature of 50°C is assumed for the heating circuit.

We consider both air source and ground source heat pumps in this study[24]. A schematic representation of the heat pump model and a comparison of the performance predicted by the heat pump model with published test data are given in Appendix 10.2.

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[22] The Carbon Trust (2011), "Micro CHP Field Trial".

[23] Dimplex (2007), "Heat Pumps - heating that doesn't cost the Earth", accessible from: http://www.fusiongsource.com/brochures/Dimplex%20%20Heat_Pumps_CPD_March07.pdf

[24] Due to the different source temperatures for air source and ground source heat pumps, there exist variations in the seasonal performance factor (SPF) calculated for each device.

3.2.3 Domestic solar photovoltaic systems

The number of domestic solar photovoltaic (PV) installations has increased rapidly in recent years, with over 480,000 systems of between 0 and 4kW$_P$ installed by November 2013[25]. On average, these systems are rated at 3kW$_P$ – the size assumed in this study for a typical household installation.

We have determined hourly PV generation profile shapes for each month using the PVGIS solar output estimation tool[26], for a tilted plane on a south-facing, 40° tilt roof in Market Harborough, Leicestershire. This has been scaled to give electricity production of 937kWh/kW$_P$, as given by the MCS PV Installation Guide[27].

3.2.4 Small-scale wind turbines

In this report, we assume a typical small-scale wind turbine installation with a rated power of 2.5kW$_P$ and 15% load factor, based on typical installations in a report by the Carbon Trust[28] and feed-in tariff generation statistics[29]. Monthly wind generation profiles for this size system were obtained by scaling 30 minute resolution wind-turbine data published by Ofgem and other literature sources[30,31].

3.3 Low carbon technology uptake and population growth

Uptake rates for electric vehicles, domestic heat pumps and domestic solar PV systems are based on DECC/Ofgem scenarios used by the Smart Grid Forum[32]. As there were no details on small-scale wind uptake in the DECC/Ofgem Smart Grid Forum data, projections of uptake rates in this case were based on historical growth rates for small wind turbines (≤15kW$_P$) from UK feed-in tariff statistics[33] over the period 2010-2014. We distinguish between Low, Central and High LCT uptake scenarios as provided in the Smart Grid Forum data (see Figure 10 to Figure 13). Household growth projections from the Office of National Statistics (ONS)

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[25] Department of Energy and Climate Change (2013), “Statistical data set: Weekly solar PV installation & capacity based on registration date”.

[26] European Commission, Joint Research Centre (2013), “Photovoltaic Geographical Information System (PVGIS)”.

[27] The Microgeneration Certification Scheme (2013), “Solar Irradiance Datasets, MIS 3002”. Note this source does not include inverter and charge controller losses, or any de-rating for soiling or shading.

[28] The Carbon Trust (2008), “Small-scale wind energy: Policy insights and practical guidance”.

[29] DECC (2013), “Feed-in Tariff generation statistics”.

[30] OFGEM (2012), “Renewable Obligation certificates”.

[31] Elexon (2012), “New Electricity Trading Arrangements”.

[32] DECC/Ofgem Smart Grid Forum (2012), “Assessing the Impact of Low Carbon Technologies on Great Britain’s Power Distribution Networks”.

[33] DECC (2013) “Monthly central Feed-in Tariff register statistics”.

have been interpolated to provide an estimate of the number of households in the United Kingdom from 2012-2030, shown in Figure 14, which is relevant for determining UK domestic demand implications from LCT uptake.

It is worth noting that the DECC/Ofgem Smart Grid Forum uptake projections are only for Great Britain (England, Wales and Scotland). We have assumed that the average household uptake is the same in Northern Ireland when forecasting the total UK household electricity demand.

Of all heat pump installations, 79% of these are expected to be air source heat pumps, with ground source units accounting for 21% of the installations. Only 9% of total heat pump installations are installed in household with existing primary electric heating systems[34], which are assumed to be displaced by the heat pump. No climate change impacts on average temperatures are considered in this report.

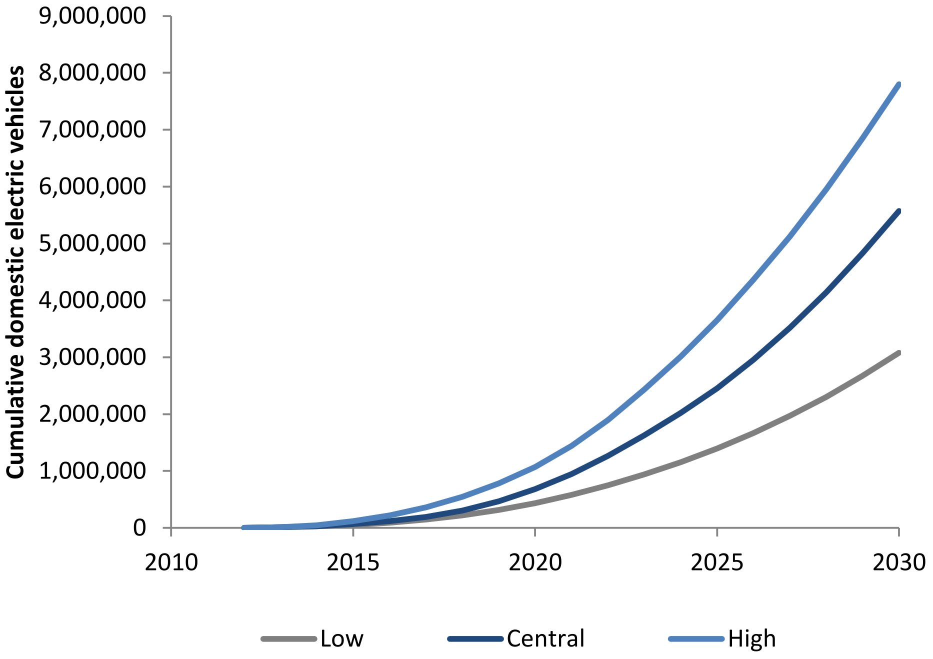

Figure 10: UK domestic electric vehicles uptake for 2012-2030.

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[34] DECC (2013), “Renewable Heat Premium Payment Scheme”.

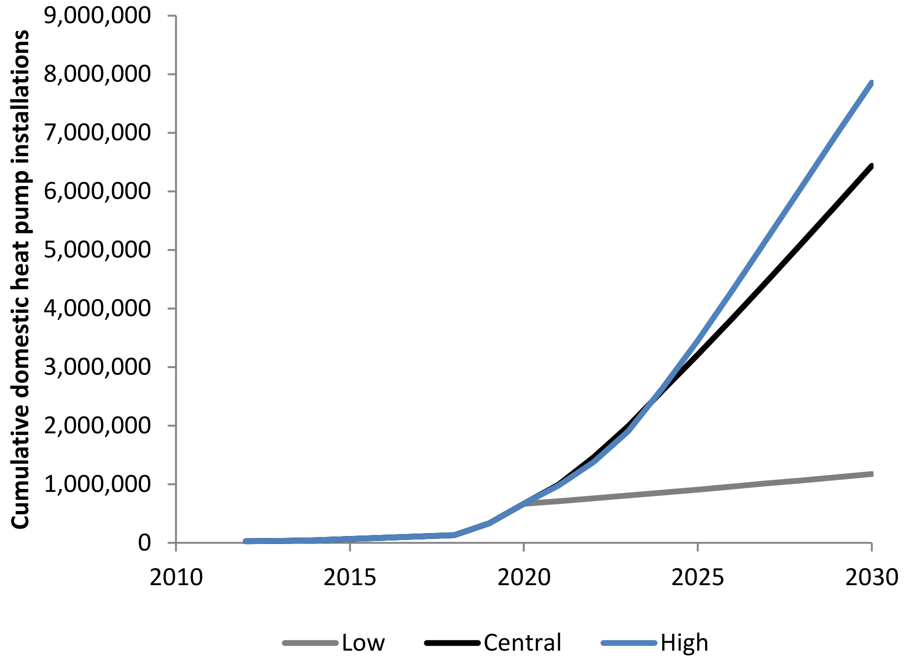

Figure 11: UK domestic heat pump uptake for 2012-2030.

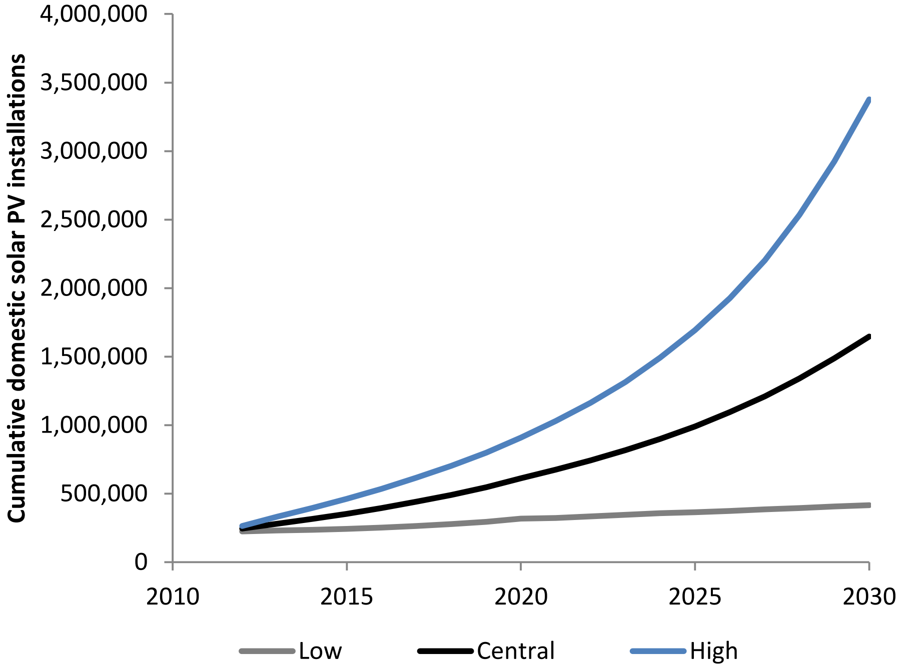

Figure 12: UK domestic solar photovoltaic systems uptake for 2012-2030.

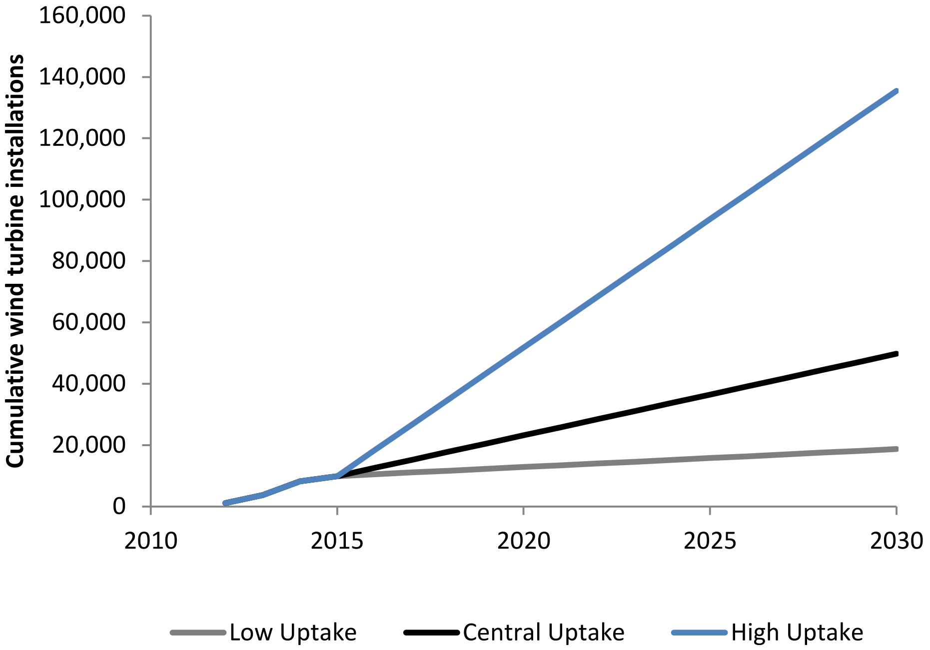

Figure 13: UK domestic small-scale wind turbine uptake in the UK for 2012-2030.

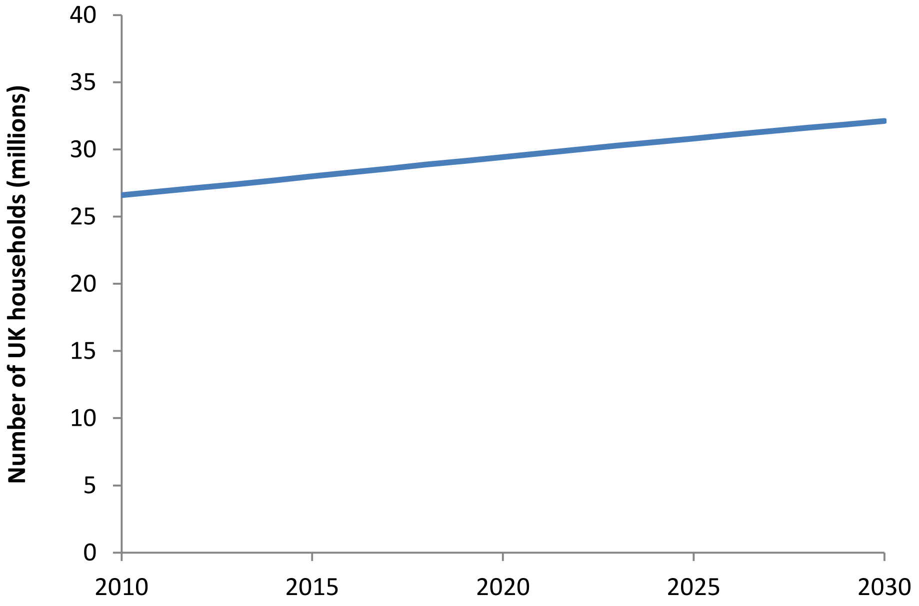

Figure 14: UK household growth, interpolated from ONS Household Projections[35]

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[35] Office for National Statistics (2010), “ONS Household Projections, United Kingdom, 1961-2033”, Table 401.

Considering all technologies together, we define the Low Uptake Scenario as Low EV Uptake, Low Heat Pump Uptake, Low Wind Uptake and Low PV Uptake, and similarly for the Central and High Uptake Scenarios.

3.4 National scale-up

The electricity demand from an average household is a function of the percentage of households taking up each low carbon technology. This is determined via the ONS household forecast and the uptake rates identified by the Smart Grid Forum – for example, if 10% of households take up EVs, then 10% of the EV demand profile is added to the existing HEUS profile. In this way, a new HEUS average profile is created, showing the electricity demand profile after adoption of all LCTs. We assume that the uptake of LCTs across the UK is consistent with the uptake in Great Britain. The regional clustering effect of technology uptake is not considered in this study.

Domestic electricity demand across the UK is calculated assuming the average household is representative, and the demand in each time step is multiplied by the projected number of households, to arrive at the instantaneous power demand from all domestic properties across the nation at a given time.

The domestic generation profiles from solar PV and wind technologies include the variability in solar and wind resource, and are indicative of the average generation for a representative day in each month. It is recognised that there will be periods of high solar irradiance across the nation, for example, where peak generation would be higher than indicated in the average profile. On a monthly scale, however, these effects are balanced out with periods of low irradiance.

3.5 Load Shifting Measures

To evaluate the load shifting potential of each low carbon technology, an existing time-of-use tariff, Economy 10[36,37], has been considered alongside an alternative DSR strategy in which diversity of consumer behaviour is maintained. We assume that all LCT users take up the DSR measures (and have the thermal storage capacity required to do so), in order to gauge the maximum potential for reducing peak demand.

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[36] We have assumed off-peak periods of 12am-5am, 1pm-4pm, 8pm-10pm for Economy 10 tariffs, based on available data.

[37] Electric Heating Company, “Economy 10 times”, accessible from: http://www.electric-heatingcompany.co.uk/wp-content/uploads/2012/03/ss-Economy-10-Times.pdf

4 The Household Electricity Usage Study demand profiles

The average annual consumption for the HEUS households is 4,194 kWh/year, slightly below the 2012 value of 4,226 kWh/year from the DECC Digest of UK Energy Statistics[38]. Only households that were monitored during the November to March space heating period were used when determining the average HEUS space heating demand (about 8.6% of total electricity use). The breakdown by appliance is shown below in Figure 15. It is important to keep in mind that the HEUS dataset is limited to owner-occupier homes in England and, therefore, only provides an approximation of the full UK domestic sector. However, the close approximation with the average annual domestic demand reported by the DECC Digest of UK Energy Statistics indicates that, in aggregate, this approximation is reasonable.

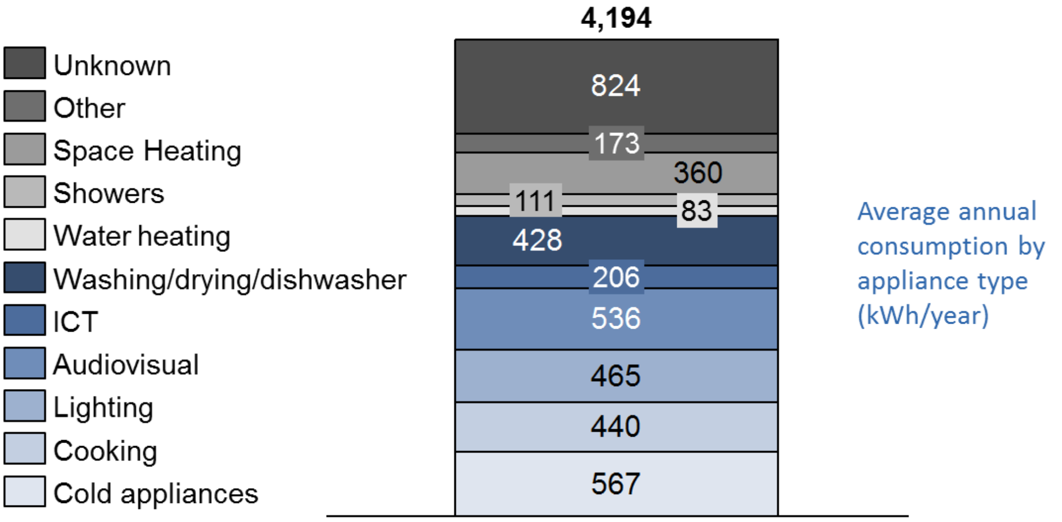

Figure 15: Average household electricity consumption, from the Household Electricity Usage Study.

Figure 16 below shows the contribution of each appliance type to the average demand profile for the HEUS sample households over a full year. A full breakdown of electricity demand profiles by month is provided in Appendix 10.1.

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[38] Department of Energy and Climate Change (2013), “Digest of UK energy statistics (DUKES)”.

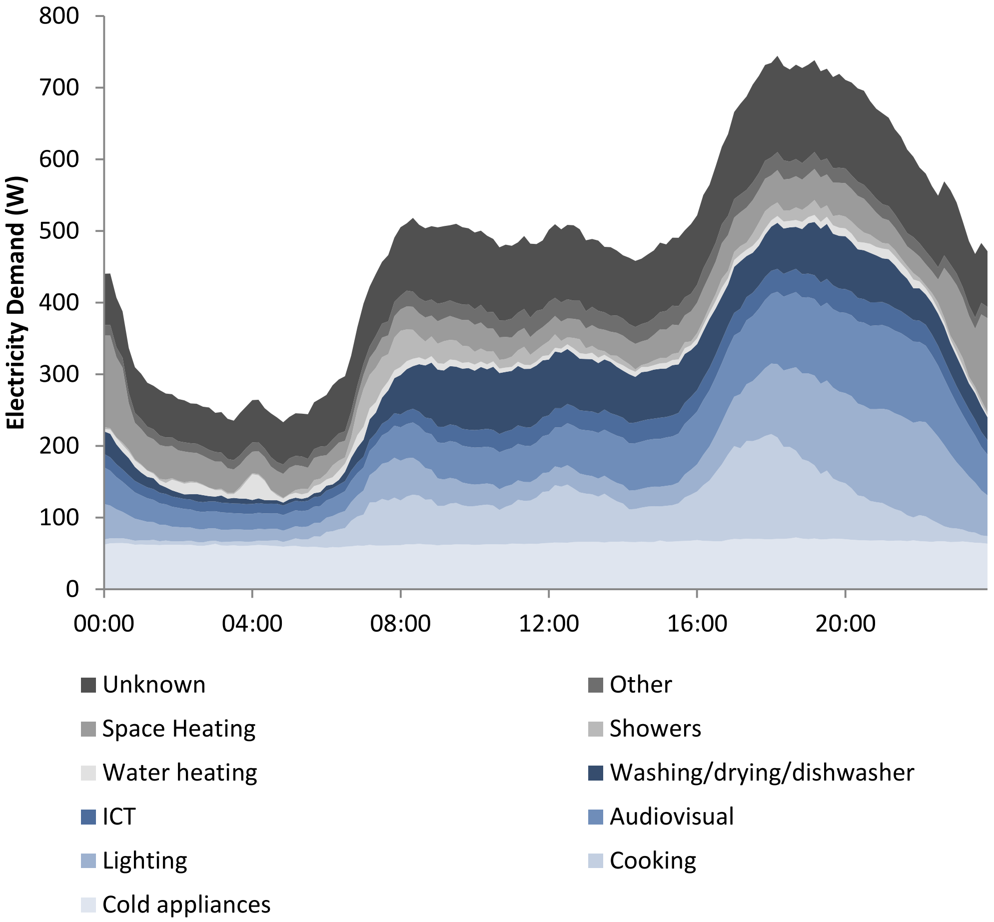

Figure 16: Average diurnal electricity demand profile of the 250 HEUS households over a whole year showing the contribution of each appliance type.

5 Low carbon technology profiles for a single household

In this chapter, we use the modelling approach outlined in Section 3.2 to quantify the electricity generation or demand profile for each LCT taken up by a single household.

5.1 Electric vehicles

The charging profile of a typical electric vehicle is aggregated here from an ensemble of vehicles (including PHEVs, RE-EVs and BEVs) and arrival times. That is, when determining the average charging profile for a single household, we average the charging profiles expected from a diverse population of multiple vehicle types and charging times. In the No DSR case (as shown in Figure 17) we assume charging commences as soon the vehicle returns home (see Section 3.2.1). This approach provides a scalable energy demand profile for a single household that reflects the expected national level distribution of vehicle types and home arrival times (see Figure 17).

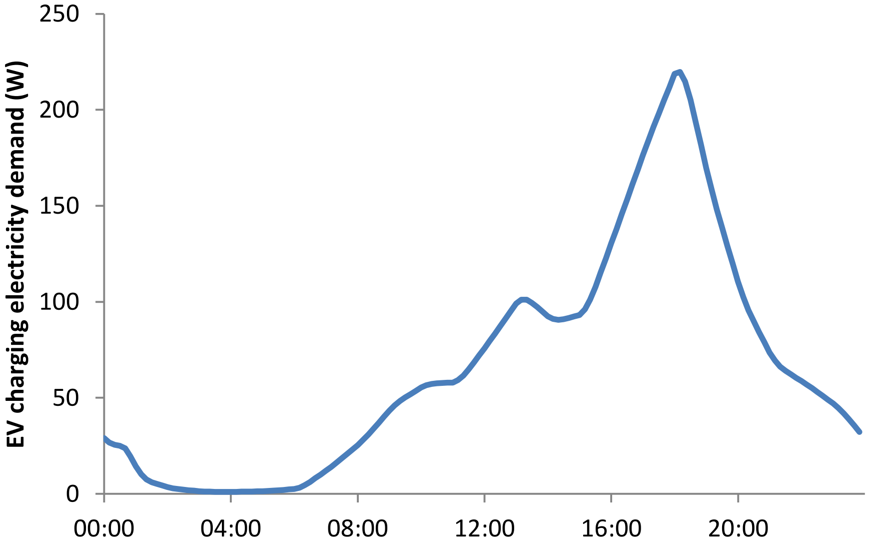

Figure 17: Average aggregated electricity demand profile for a single electric vehicle, at a single household without DSR measures.

Assuming vehicles begin charging immediately upon arrival, we anticipate significant electricity demand will arise in the early evening peak, from 6-7pm. This is a direct consequence of many drivers arriving home during this period.

5.2 Heat pumps

In this analysis, we model the electricity demand from air-to-water and ground source heat pumps. Given the lower water temperature (we have assumed 50°C) for efficient operation of domestic heat pumps relative to say, natural gas boilers (typically 60 to 80°C), the operating times required to meet household thermal demands are typically longer than other heating technologies during the colder months. Assuming UK consumers maintain their current thermal demand profile[39], preferentially requiring heating during morning and evening hours, heat pumps will add significantly to demand during the 6-7pm evening peak. Only fixed-speed heat pumps are considered in this report, but even variable-speed heat pumps will operate at their maximum power in times of high thermal demand, although they may offer advantages when demand is lower. Electricity demand from an air source heat pump is given in Figure 18 for representative[40] days during February and August.

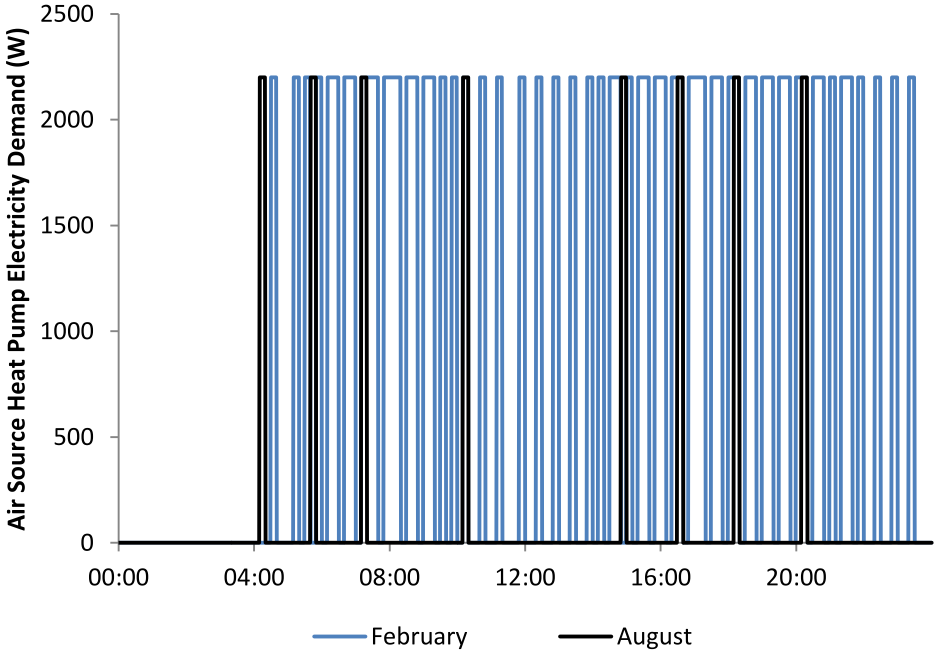

Figure 18: Electricity demand from an air source heat pump during representative days in February and August.

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[39] We have not considered improvements to thermal efficiency of the UK dwelling stock, however it is recognised that such improvements could influence both total heat demand and the options to move heat demand during the day.

[40] Representative days in these cases are chosen for the compatibility between the day and monthly mean air temperature.

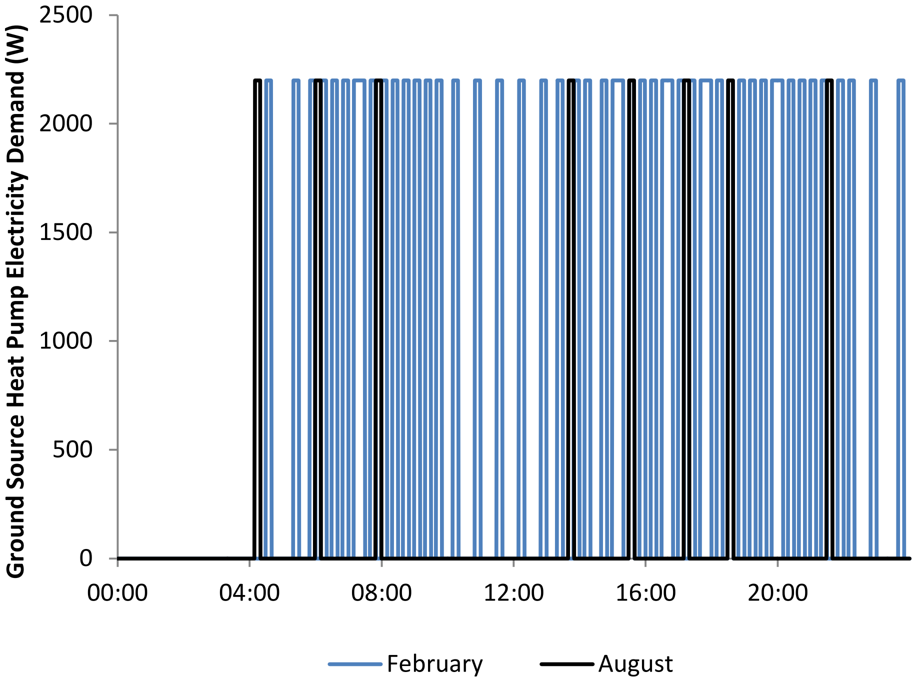

Figure 19: Electricity demand from a ground source heat pump during representative days in February and August.

5.3 Solar photovoltaic systems

Electricity generation from domestic solar photovoltaic systems occurs only during daylight hours, and hence peaks around noon. Although large amounts of electricity can be generated, this is not well matched to the times of peak domestic demand. The seasonal variation of the solar resource also plays an important role, resulting in greater generation during summer months. Depending on the season and cloud cover, a 3kW$_P$ domestic solar PV system offers between 550-1300W of power during the noon peak (see Figure 20).

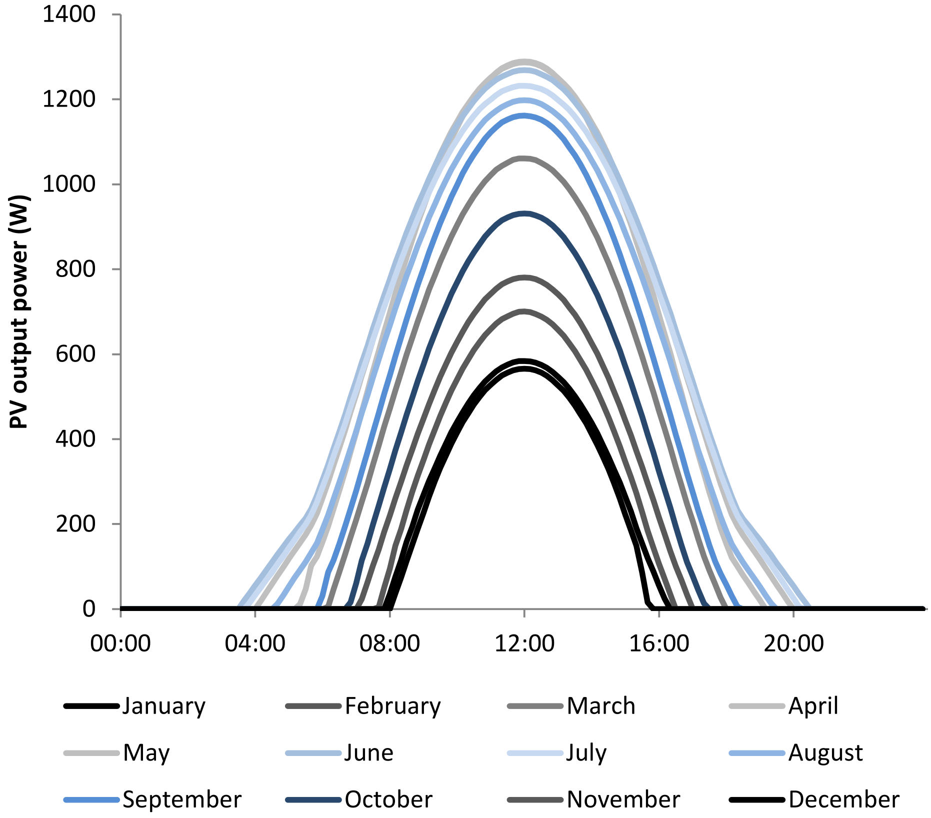

Figure 20: Modelled electricity generation from a typical domestic solar photovoltaic system, rated at 3kW$_P$.

5.4 Small-scale wind turbines

Small-scale wind turbines have the potential to generate electricity throughout the course of a day, without direct dependence on the solar position. Again, there are significant daily and seasonal variations in the wind resource, but, on average, it offers a relatively stable generation profile when compared to solar PV over a typical day. We expect that a 2.5kW$_P$ system could offer approximately 400W of electricity generation on a typical day, averaged over an annual period (see Figure 21).

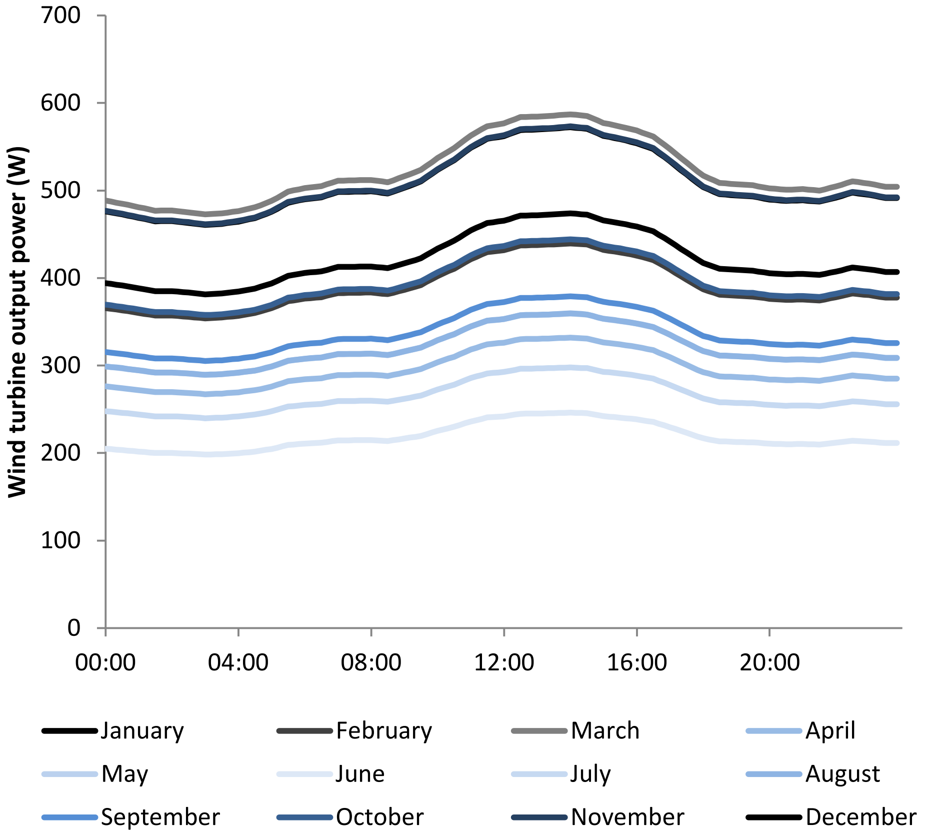

Figure 21: Modelled electricity generation from a typical small-scale wind turbine, rated at 2.5kW$_P$ with capacity factor of 15%.

6 Interaction of low carbon technologies with household electricity usage

In this chapter, we examine the expected change in average household electricity profile on a monthly and annual basis when the four LCTs described above are introduced to the average HEUS household. In reality, not all households in the UK will be suited to all of these new technologies (e.g. occupants of multi-storey flats may not be able to home charge their EVs or install ground-source heat pumps, solar PV or wind systems) which is reflected in the uptake rates used in subsequent chapters.

6.1 Demand technologies

Heat pumps and electric vehicles both substantially increase household electricity demand, particularly during the evening peak from 6-7pm (see Figure 22 to Figure 25).

Due to higher temperatures, thermal demand is significant reduced in the summer months, represented by August in the figures below. In addition, the higher temperatures in summer lead to a greater COP, allowing the heat pump to provide more thermal energy for a given electricity input.

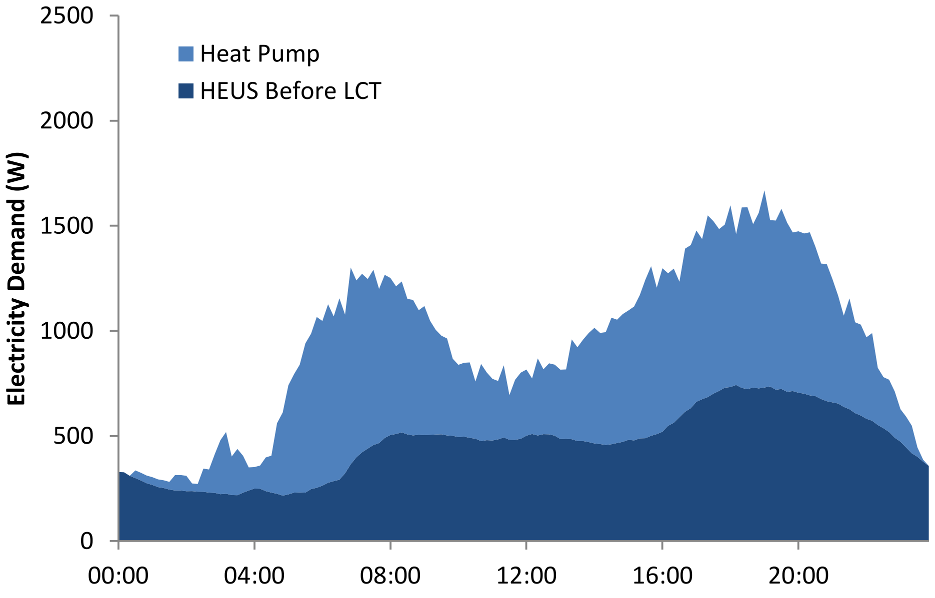

Figure 22: Annual average diurnal electricity demand for a single household using an aggregated average heat pump profile (reflecting the forecast UK composition of air-source and ground-source heat pumps). Any displaced primary electric heating has been removed and no DSR is assumed.

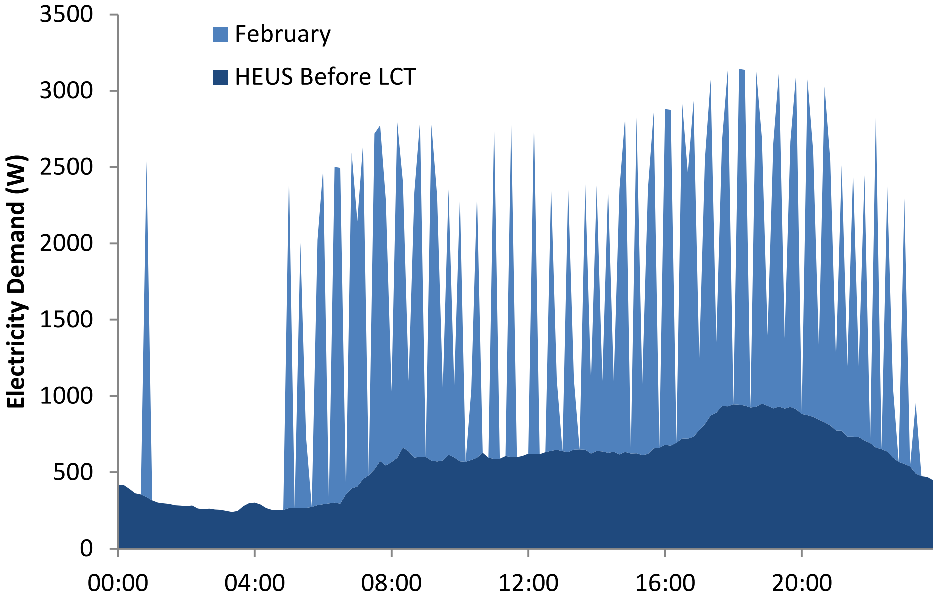

Figure 23: Average diurnal electricity demand of a representative heat pump profile for February, overlaid on the average HEUS household profile (with any displaced primary electric heating removed) for an average day in February.

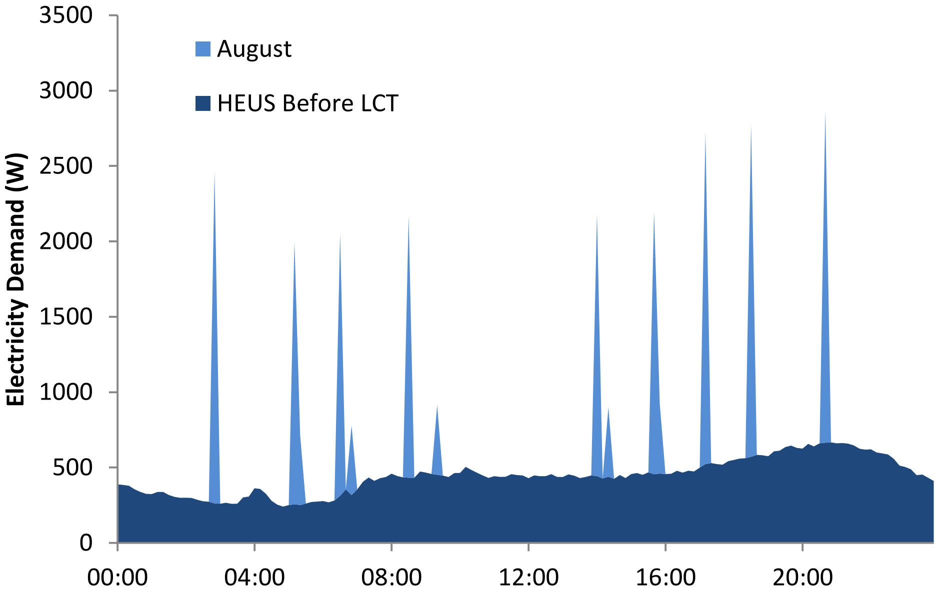

Figure 24: Average diurnal electricity demand of a representative heat pump profile for August, overlaid on the average HEUS household profile (with any displaced primary electric heating removed) for an average day in August.

All electric vehicles are considered to be driven the same distance on each day, though in reality, the distance driven does vary slightly with the time of arrival and between weekdays and weekends. Due to concentration of vehicles arriving at their home locations in the evening, peak demand during 6-7pm is expected to rise.

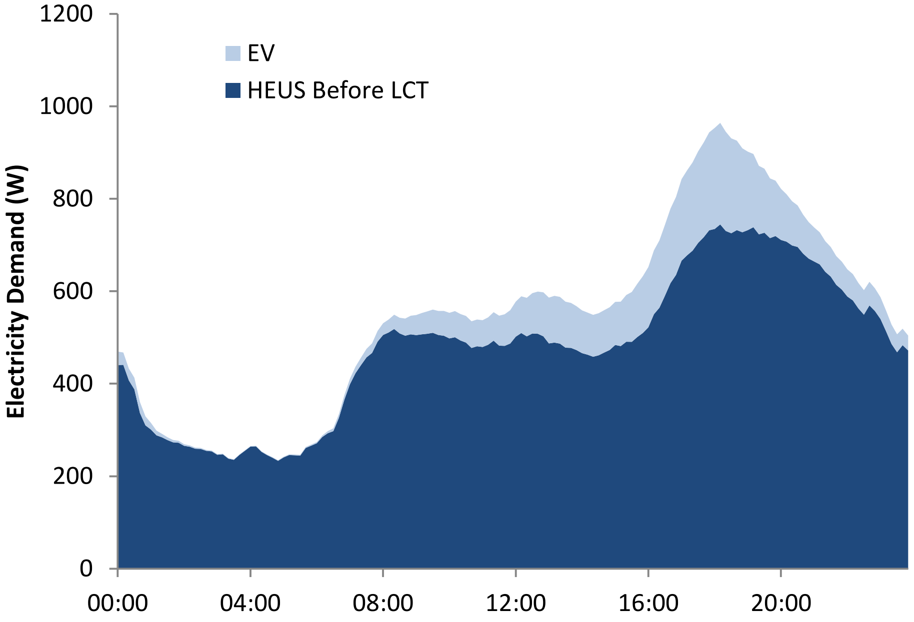

Figure 25: Annual average diurnal electricity demand from an electric vehicle overlaid on the average HEUS household profile. The electric vehicle profile is for a single vehicle that reflects the aggregated average charging patterns and vehicle types expected in the national EV stock[41].

6.2 Generation technologies

A solar photovoltaic system offers substantial electricity generation during daylight hours, but makes no significant contributions to reducing the evening peak demand (without energy storage), particularly in winter months, when daylight hours are short.

During winter months, low solar irradiance and higher daytime demand result in on-site consumption of all solar PV generated electricity, as illustrated for December in Figure 26. In summer months, much of the solar electricity must be exported, due to a combination of high solar irradiance and insufficient demand during the daytime, shown in Figure 27 for May. For the annual average diurnal profile, there is a net export of electricity to the grid for an average household with an average-sized solar PV

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[41] Element Energy modelling of the GB vehicle stock (originally developed for the Energy Technology Institute in 2011, extended for the Department of Transport in 2012, updated in 2013 and currently in use by the DfT).

installation (see Figure 28). Due to the variable nature of the solar resource and current consumption patterns, the amount of electricity exported peaks in the summer months, as shown in Figure 29.

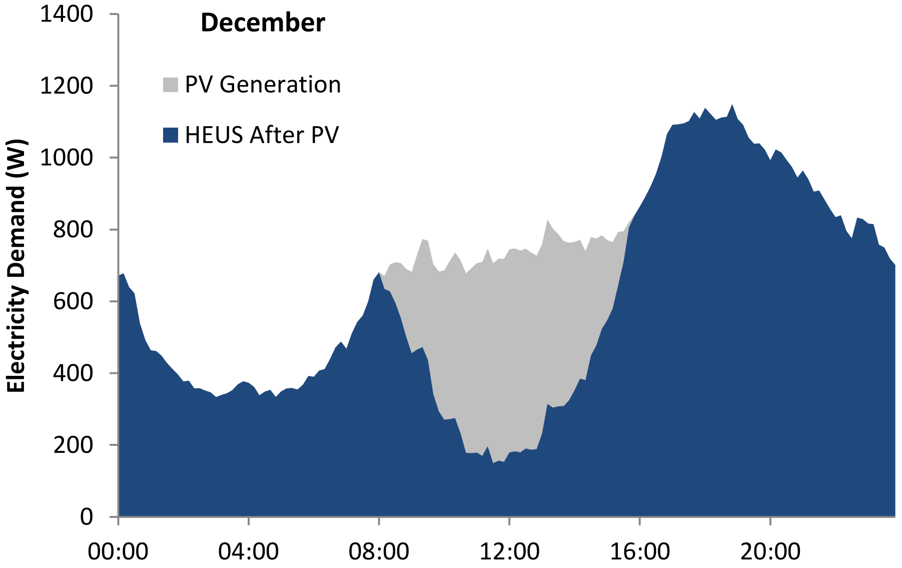

Figure 26: Average diurnal electricity generation of a domestic solar photovoltaic system (3kW capacity) in December, overlaid on the average HEUS household profile for December.

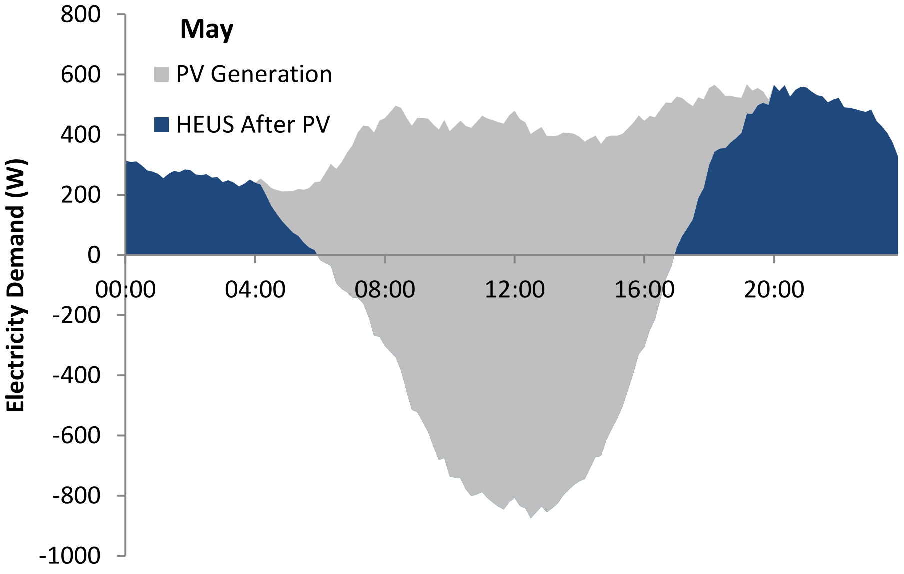

Figure 27: Average diurnal electricity generation of a domestic solar photovoltaic system (3kW capacity) in May, overlaid on the average HEUS household profile for May. Negative demand denotes export to the electricity network.

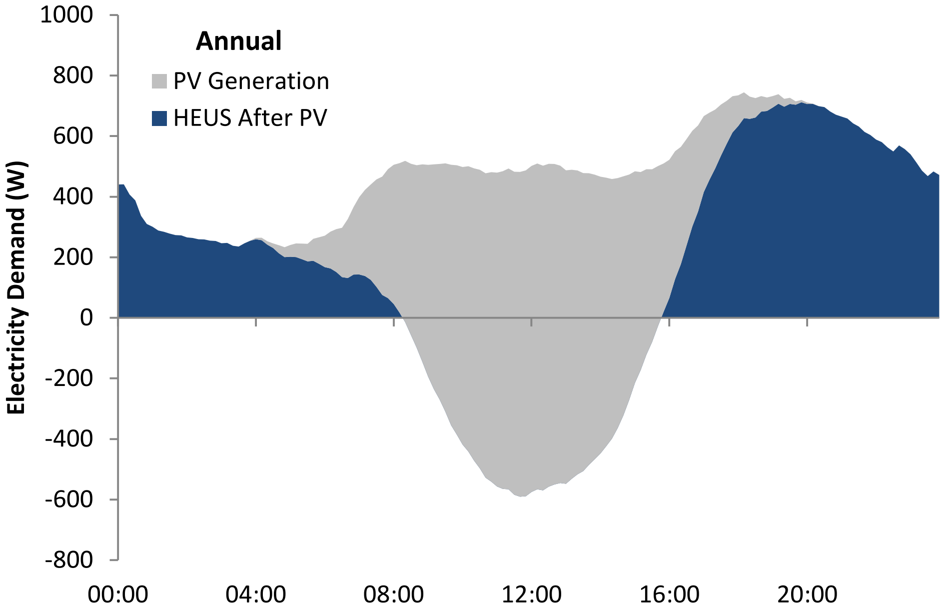

Figure 28: Annual average diurnal electricity generation of a domestic solar photovoltaic system (3kW capacity) overlaid on the average HEUS household profile for a whole year. Negative demand denotes export to the electricity network.

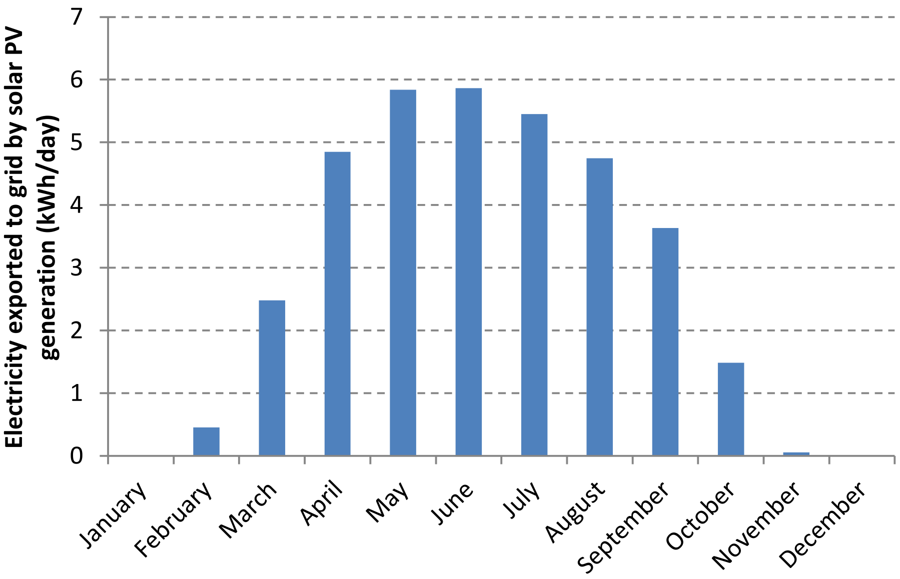

Figure 29: Average diurnal exported electricity by month, for an average household with the HEUS household profile, and a solar PV installation only.

A small-scale wind turbine offers a more uniform generation profile than solar PV when averaged, and satisfies most of a typical household's electricity demand, as shown in Figure 32. It is important to bear in mind that this is an averaged profile and, as such, does not reflect the variability of supply within a given day which is still a concern for households generating electricity using wind. Since electricity from wind generation is less dependent on the availability of sunlight than solar PV, it is better able to reduce grid demand during peak evening hours.

The availability of wind resource is strongly dependent on season, and is approximately the reverse of solar irradiance – winter months are characterised by high resource, whilst calm conditions in the summer months result in less electricity generation from turbines during that period. The months with the highest and lowest export are March and June, respectively, and are a consequence of both household electricity demand and wind resource in those periods (see Figure 30 to Figure 33).

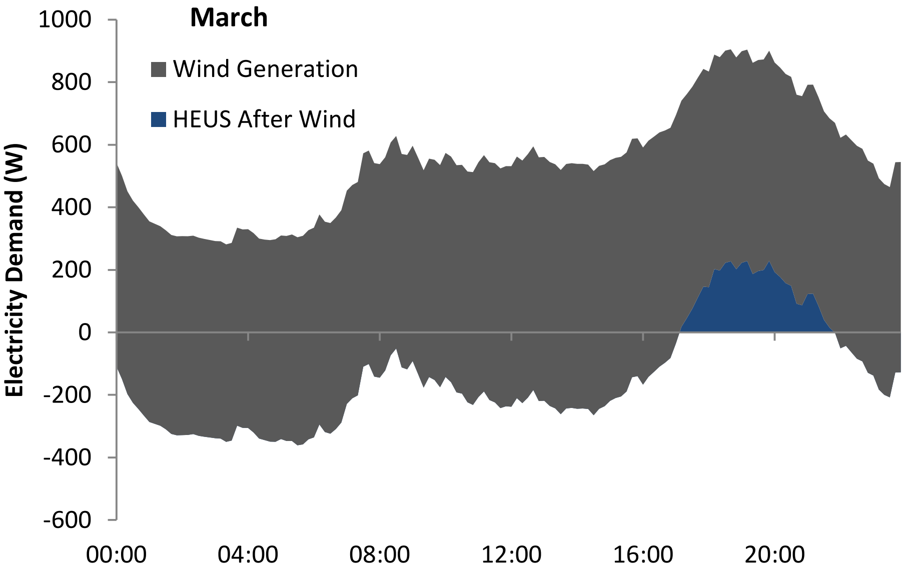

Figure 30: Average diurnal electricity generation of a typical small-scale wind turbine (2.5 kW$_P$) in March, overlaid on the average HEUS household profile for March. Negative demand denotes export to the electricity network.

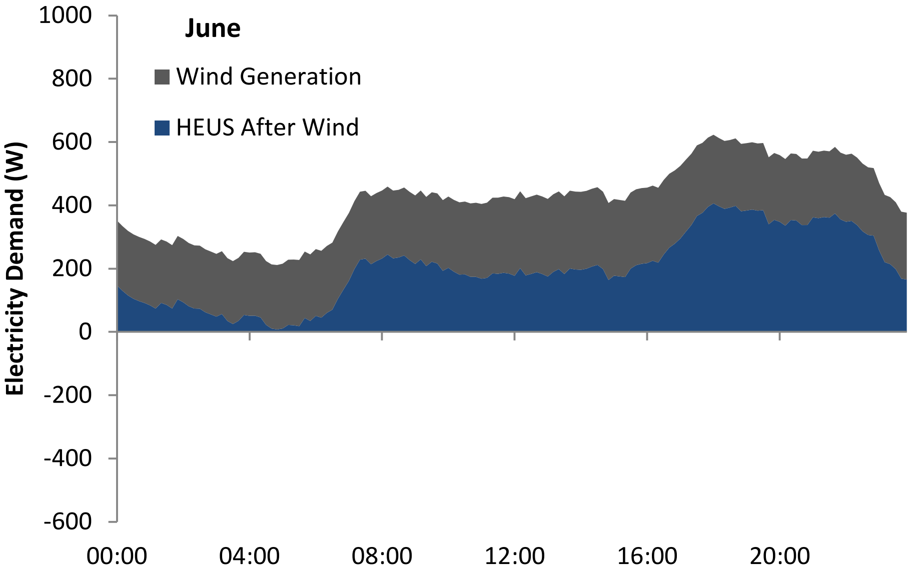

Figure 31: Average diurnal electricity generation of a typical small-scale wind turbine (2.5 kW$_P$) in June, overlaid on the average HEUS household profile for June. Negative demand denotes export to the electricity network.

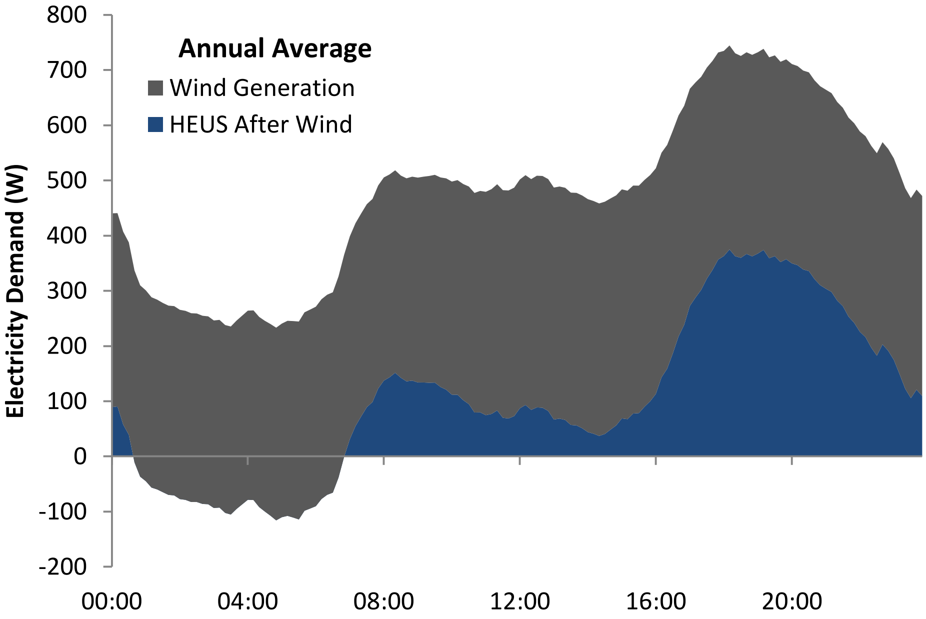

Figure 32: Annual average diurnal electricity generation of a small-scale wind turbine (2.5 kW$_P$) overlaid on the annual average HEUS household profile. Negative demand denotes export to the electricity network.

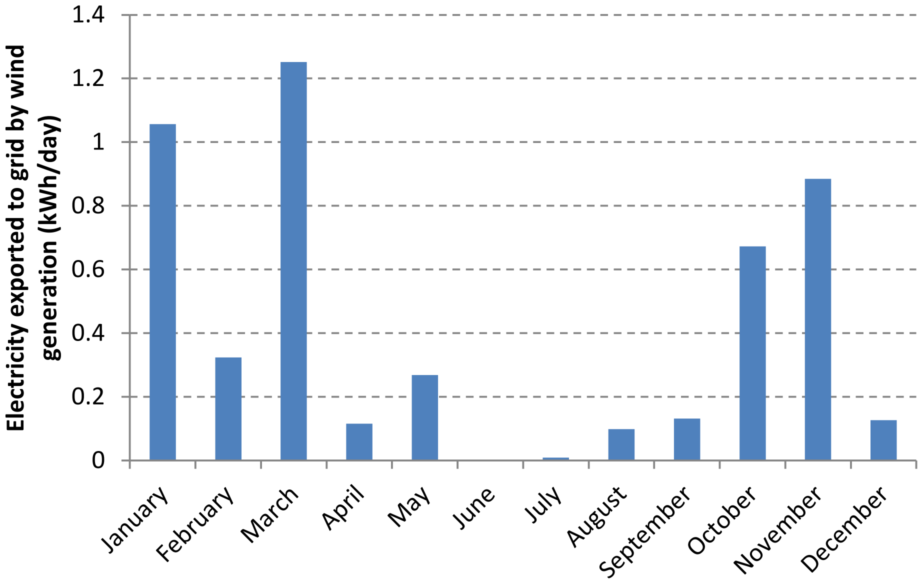

Figure 33: Average diurnal exported electricity by month, for an average HEUS household with a small wind turbine installation (2.5kW$_P$) only. Export is a function of both wind resource and household demand.

6.3 Aggregate impact of a single household taking up all LCTs

The case in which a household takes up all four LCTs is considered in Figure 34. Obviously, this scenario will not be possible in all UK households and would not be expected to be a common occurrence pre-2030, but it does given an interesting insight into future implications for domestic demand and generation at the household level under high LCT uptake scenarios. Over a full year, such a household would demand 14% less electricity from the grid than the same household without these technologies in place. The annual average peak demand in the 6-7pm period would rise to ~1.8 kW, more than double the peak demand for the current average HEUS household, driven by demand from heat pumps and electric vehicles which cannot be completely met by the generation technologies.

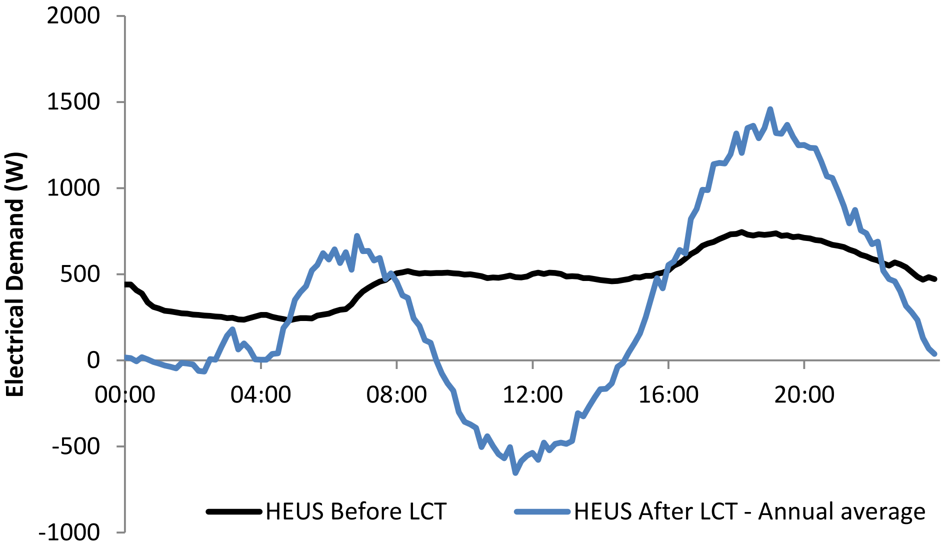

Figure 34: Annual average diurnal electricity demand for the HEUS households before and after uptake of all four low carbon technologies (i.e. a heat pump, electric vehicle, solar PV and wind turbine). Negative demand denotes export to the electricity grid.

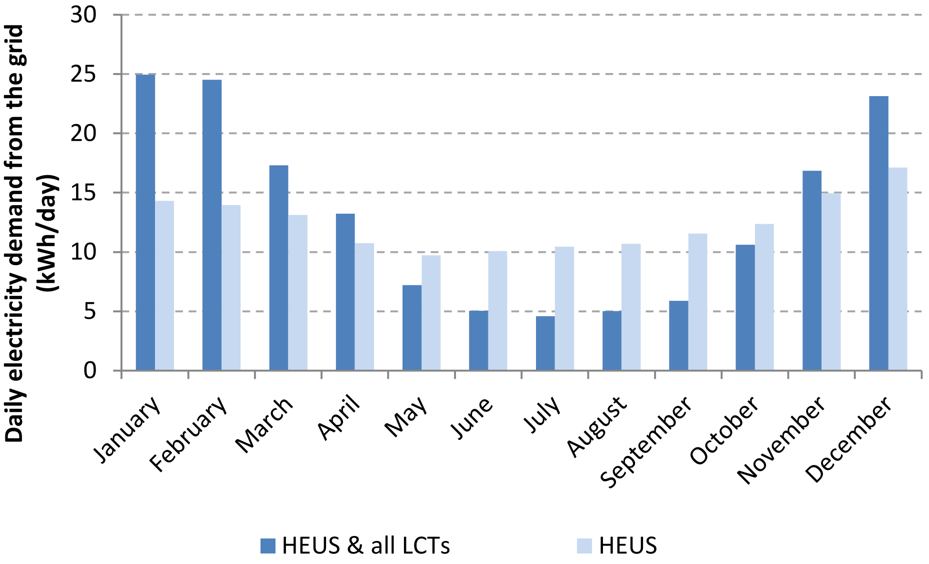

Figure 35: Average daily electricity demand from the grid in each month for a single household with and without all low carbon technologies (i.e. a heat pump, electric vehicle, solar PV and wind turbine).

Over the whole year, the hypothetical household would need to export ~15% of its generated electricity to the grid, with a peak export power of ~1 kW. Depending on the season, the peak export power can range between

0.2-1.2kW. On representative days, peak export coincides with the period of greatest solar PV generation (i.e. from 12pm to 1pm).

Taking up all the given low carbon technologies results in a highly variable demand for grid electricity; from 4kWh/day in July, to 25kWh/day in February when demand for heating is at its greatest. Were this to become a common occurrence in households across the UK, a great deal of redundancy in the electricity transmission and distribution networks will be required to deal with seasonal changes in demand.

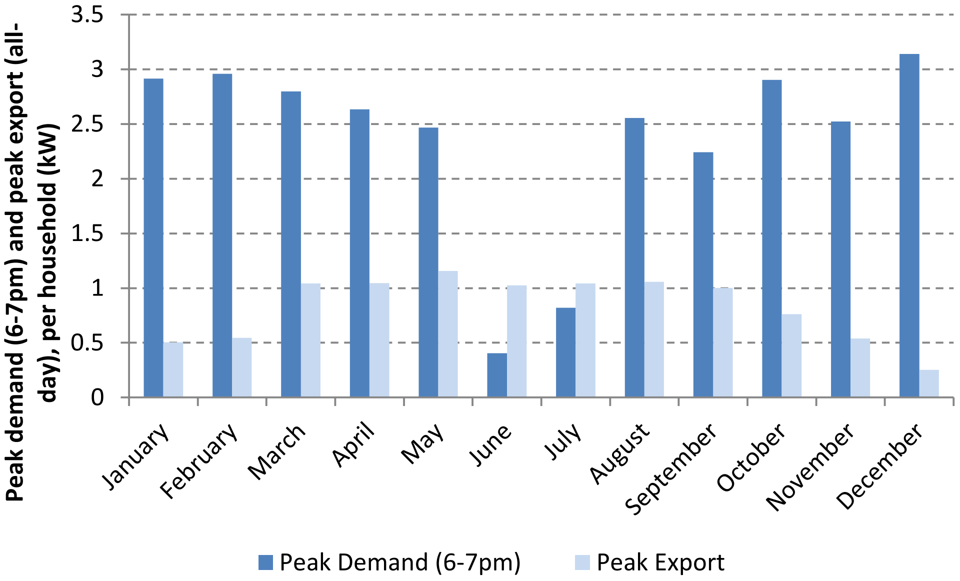

Figure 36: Peak demand from the grid and peak export to the grid from a single household with all LCTs in each month. Peak export to the grid typically occurs at 12-1pm in all months, coinciding with highest solar PV generation. Peak demand from the grid remains in the 6-7pm period.

Given the uptake rates identified in DECC and Ofgem's Smart Grid Forum[42], only a small fraction of households are likely to have taken up all four of these LCTs by 2030. However, the results shown here reveal the challenges that LCT uptake could present in the long-term for the UK electricity network, particularly in terms of seasonal variability in demand from the grid. As an illustration of this point, a household taking up all four LCTs would demand 6 times more electricity on an average day in February compared to an average day in July (see Figure 35).

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[42] DECC/Ofgem Smart Grid Forum (2012), "Assessing the Impact of Low Carbon Technologies on Great Britain's Power Distribution Networks".

7 Load shifting potential of low carbon technologies

Given the expected increase in peak load due to LCT uptake, it is important to consider demand side response (DSR) measures that can be implemented to promote behaviours that reduce peak demand[43]. With this in mind, this chapter explores measures aimed at delivering reductions in electricity use at peak times for electric vehicle charging and heat pump operation. To illustrate the maximum DSR potential, we assume all households equipped with these LCTs engage in the DSR measures being modelled.

7.1 Load shifting potential of heat pumps

Assuming heat pumps undertaking DSR measures have access to 180 litres of hot water thermal storage (with negligible heat loss), up to 2.6kWh of thermal demand can be satisfied from a fully charged store which is approximately equivalent to half of the thermal demand between 6-7pm in the coldest months. This correlates well with the findings of GL Noble Denton’s work for the Smart Grid Forum[44].Though beyond the scope of this report, the requirement for a dedicated hot water storage system for heat pump DSR presents implementation challenges in terms of installation footprint, highlighted by the current uptake of combination (or “combi”) boilers in the UK and the accompanying move away from hot water storage cylinders.[45,46]

In our modelling, we simulate heat pumps charging thermal storage to capacity in low-tariff periods, and discharging the thermal storage during peak periods. Only when thermal demand cannot be satisfied by the thermal storage do the heat pumps operate during peak periods.

When modelling time-of-use tariffs (TOUT) such as Economy 10 (in which the evening high-tariff period begins at 4pm[47]), we find that typical hot water cylinders can satisfy much of the demand during 4-5pm, but have insufficient thermal energy to shift a significant amount of electricity demand from the 6-7pm peak to later times, as indicated by Figure 37.

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[43] Department of Energy and Climate Change (2012), “Demand Side Response in the domestic sector- a literature review of major trials”.

[44] DECC/Ofgem Smart Grid Forum (2012), “Assessing the Impact of Low Carbon Technologies on Great Britain’s Power Distribution Networks”.

[45] International Energy Agency Demand Side Management Programme (2012), “Heat pumps for cooling and heating”.

[46] P. Strachan et al. (2013), “Modelling of High Energy Performance Buildings”, International Workshop: High Performance Buildings, Brussels.

[47] Electric Heating Company, “Economy 10 times”, accessible from: http://www.electric-heatingcompany.co.uk/wp-content/uploads/2012/03/ss-Economy-10-Times.pdf

Alternatively, targeted DSR measures that specifically aim to reduce demand during 6-7pm can substantially lower consumption in that timeslot (as shown in Figure 38) though this does little to address the high demand immediate before and after this period. In this approach, the filling of thermal storage tanks has been delayed to the early morning hours, 12am-5am.

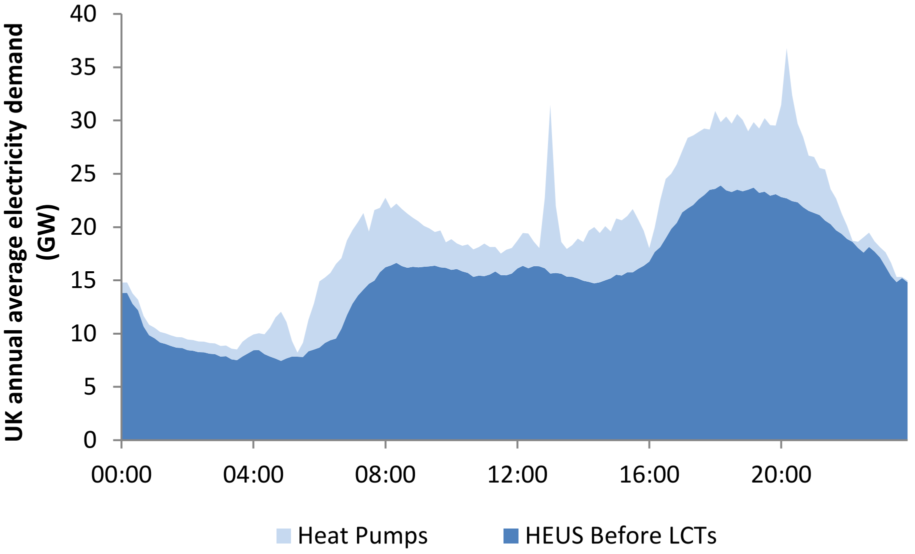

Figure 37: UK annual average diurnal electricity demand from heat pumps optimised for the Economy 10 tariff, in the 2030 DECC High Uptake Scenario.

In the Economy 10 case, it is important to note that new peaks are formed at the start of off-peak periods (in this case at 1pm and 8pm) if the low-tariff periods are assumed to be the same across the UK (see Figure 37). These peaks are related to the loss in consumption diversity as devices whose demand has been postponed during the high-tariff periods all activated at the same time. This problem is only evident where TOUTs are widely adopted and delayed loads are significant. Since these are two of the goals of future DSR strategies, consumption diversity is an important consideration.

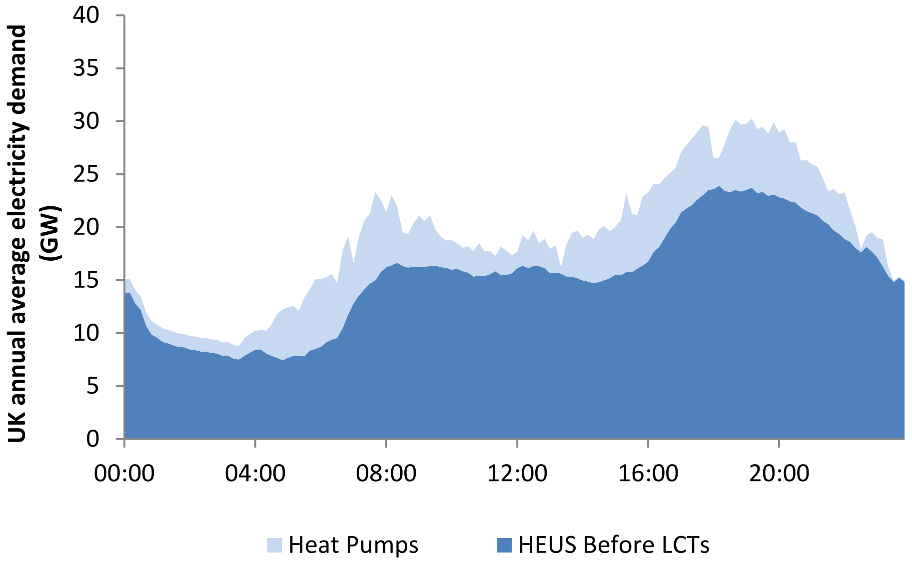

Figure 38: UK annual average diurnal electricity demand from heat pumps with targeted DSR during the 6-7pm period for the 2030 DECC High Uptake Scenario.

Some examples of how consumption diversity could be maintained within DSR strategies include:

- Set up TOUT offerings with staggered start times for low-tariff periods. This consideration needs to be factored in even at the local level since local distribution networks will suffer from these same peaks if times are only staggered between different geographical regions of the UK.
- Direct control strategies can be triggered at appropriate times and with sufficient spatial distribution to avoid national and local peaks.
- Similarly well monitored and targeted dynamic time-of-use tariffs can be established so as to ensure appropriate diversity levels are maintained.

Using a variety of DSR strategies, such as those listed in the examples above, will also help to maintain diversity in electricity consumption patterns. In this way, diversified DSR measures can distribute the domestic demand reduction potential over the evening hours. An example where the demand reduction potential is distributed over the 4pm-9pm period is shown in Figure 39. Again, the recharging of thermal storage tanks has been shifted to the early morning hours, 12am-5am.

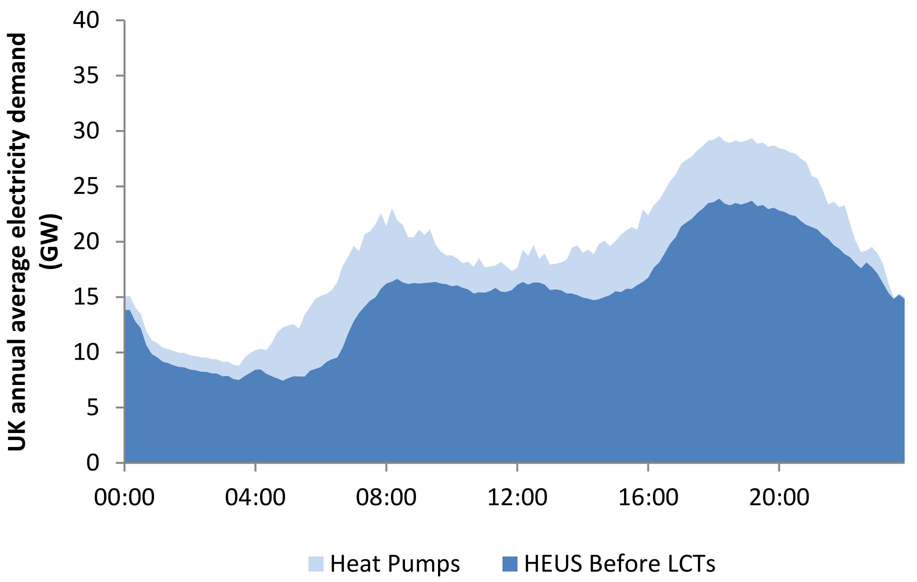

Figure 39: UK annual average diurnal electricity demand from heat pumps, with diversified DSR measures distributing demand reduction potential over the 4pm-9pm period in 2030 for the DECC High Uptake Scenario.

7.2 Load shifting potential of electric vehicle charging

In addition to heat pumps, we find the charging behaviour of electric vehicles has the potential to influence load shifting in the 6-7pm period. To evaluate the potential impact of DSR measures for EV charging we have considered four EV charging scenarios for 2030, under the DECC High Uptake Scenario.

A. **No DSR, standard EV charging (3kW):** All electric vehicles begin charging when they arrive home.

B. **Basic DSR:** Consumers arriving home before 12am delay charging until start of the night Economy 10 period (12am-5am)[48] and then charge normally at 3kW.

C. **Diverse DSR (distributed start times):** As in scenario B, but the beginning of late-evening low-tariff times are now distributed evenly over 3 hours (between 12am and 3am) in 10-minute increments.

D. **Slow-Charge DSR:** As in scenario B, but the EV charge rate is substantially reduced to 1kW.

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[48] Electric Heating Company, “Economy 10 times”, accessible from: http://www.electric-heatingcompany.co.uk/wp-content/uploads/2012/03/ss-Economy-10-Times.pdf

The UK's electricity demand from domestic EVs for each of these charging scenarios is shown in Figure 40.

Scenario B illustrates the extreme case in which electric vehicle DSR measures are widely adopted and charging is shifted to a common late-evening start time, coinciding with the beginning of Economy 10 low-tariff rates. While there may currently be some geographical variability in Economy 10 and Economy 7 time bandings between different distribution networks, there is still potential for formation of problematic local demand peaks coinciding with the beginning of low-tariff periods.

To address this problem, we consider two potential solutions for vehicle charging involving load distribution measures that minimise the magnitude of new peaks (Scenario C with distributed late-evening low-tariff start times and Scenario D with vehicle charging rates restricted to 1kW). In Figure 40, both approaches show a substantial reduction in late evening peak electricity demand when compared to scenario B, where no additional measures are taken.

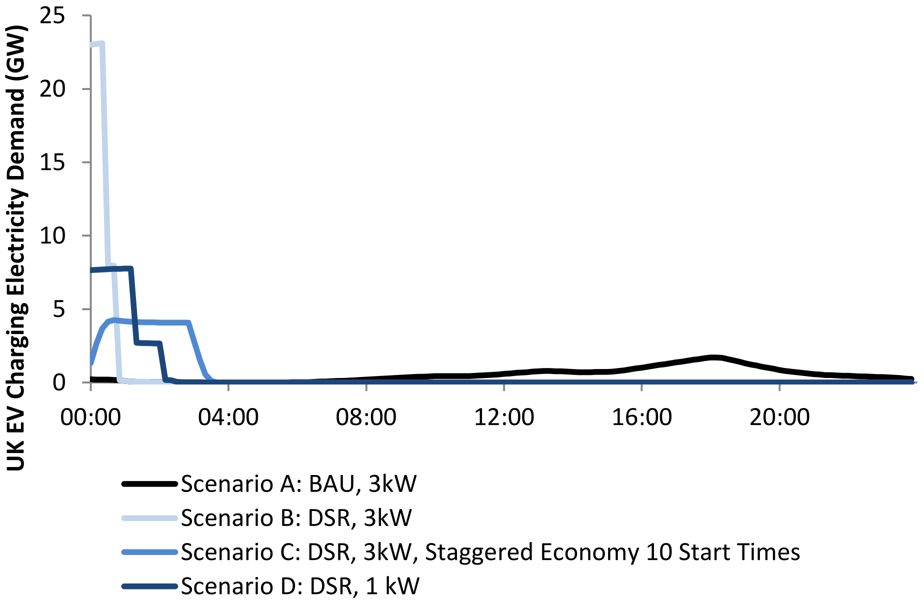

Figure 40: UK domestic electricity demand from domestic electric vehicles in 2030 under the DECC High Uptake Scenario, with No DSR (A), Basic DSR (B) and Smart DSR (C, D) scenarios. Compared to the Basic DSR approach, the magnitude of the late-evening peak is considerably reduced in both Smart DSR cases.

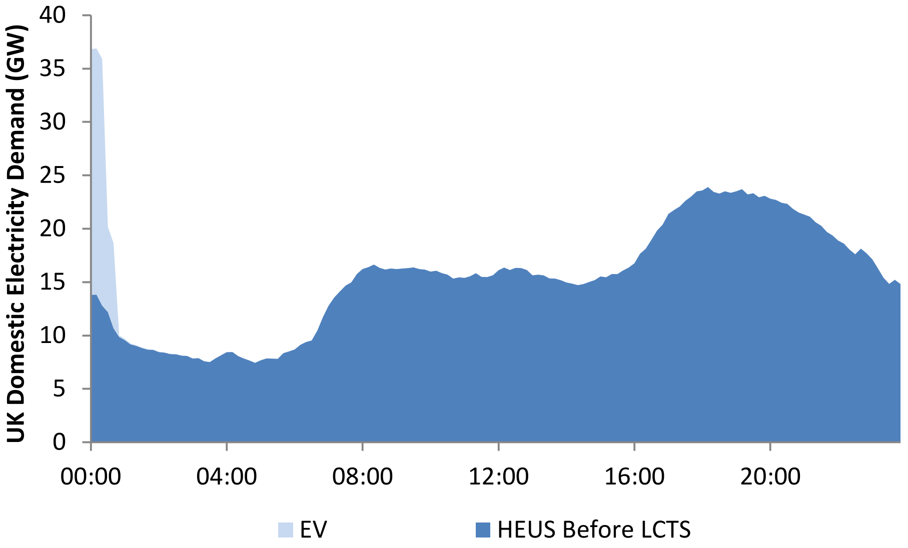

Figure 41: The electric vehicle contribution to UK annual average diurnal electricity demand under Scenario B (basic DSR).

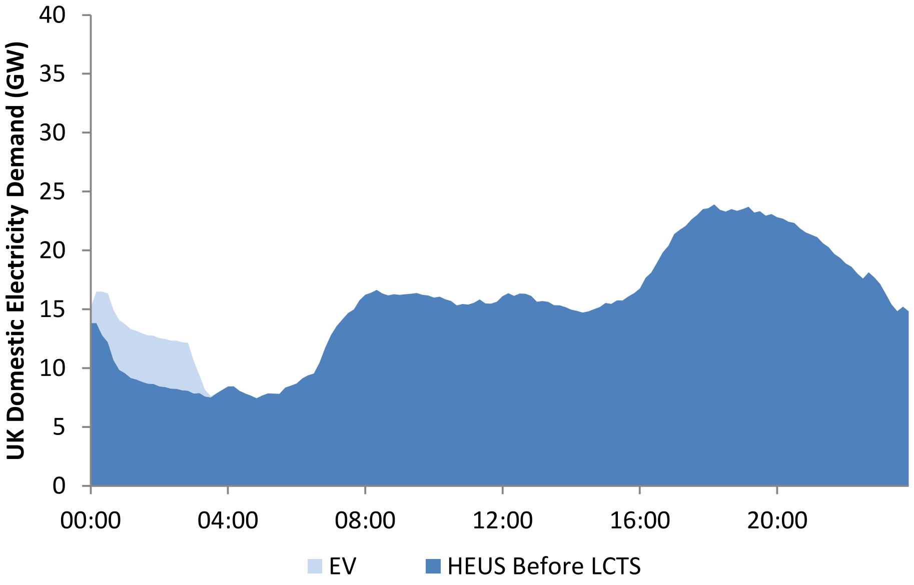

Figure 42: The electric vehicle contribution to UK annual average diurnal electricity demand under Scenario C (diverse DSR).

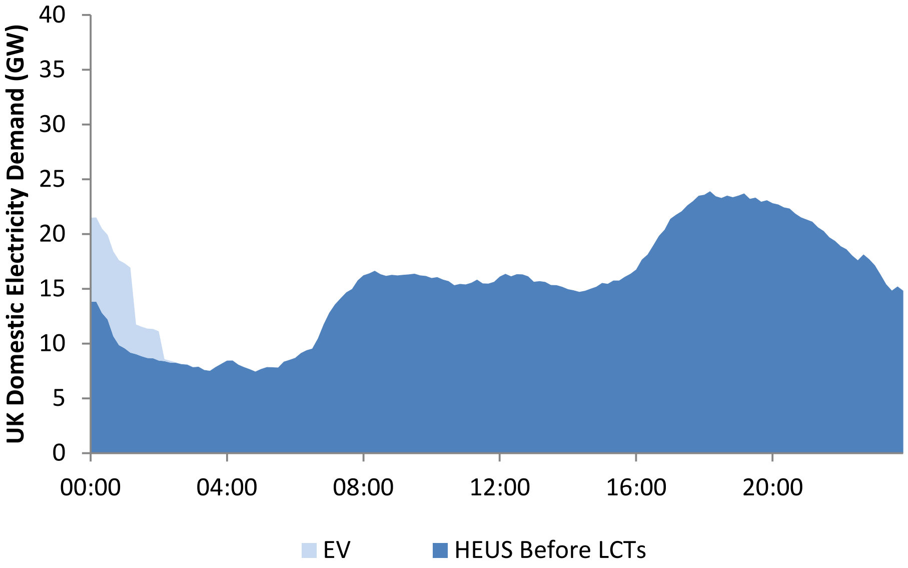

Figure 43: The electric vehicle contribution to UK annual average diurnal electricity demand under Scenario D (slow charging DSR).

8 National Implications of low carbon technologies

In this chapter, we explore the impact of LCT uptake on UK domestic demand and distributed generation using the technology uptake rates and growth in number of households identified in Section 3.3. Here we use the HEUS average household profile (which is based on 250 English households between 2010 and 2011) as a close approximation for the average UK household demand (see Chapter **Error! Reference source not found.**). For simplicity, we do not consider underlying changes in the household demand profile due to improvements in energy efficiency and changing lifestyle trends between 2010 and 2030, which are covered elsewhere[49,50].

8.1 Annual electricity consumption trends

Figure 44 shows the contribution of each LCT to domestic electricity demand and generation in the UK out to 2030 for the three DECC LCT uptake scenarios. Nationally, domestic electricity demand on the grid in 2020 is expected to increase modestly relative to 2010, driven primarily by population growth (on a per household basis renewable generation uptake largely offsets new demand from EVs and heat pumps). A substantial increase in domestic electricity demand from the grid is forecast for 2030, largely due to the uptake of heat pumps. These results are broadly in line with the trends identified by the Smart Grid Forum[51].

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[49] Element Energy (2013), “Further Analysis of Data from the Household Electricity Usage Study: Increasing Insight and UK Applicability”.

[50] Cambridge Architectural Research, Element Energy, Loughborough University (2013), “Electrical Appliances at Home: Tuning in to Energy Saving”.

[51] DECC/Ofgem Smart Grid Forum (2012), “Assessing the Impact of Low Carbon Technologies on Great Britain’s Power Distribution Networks”.

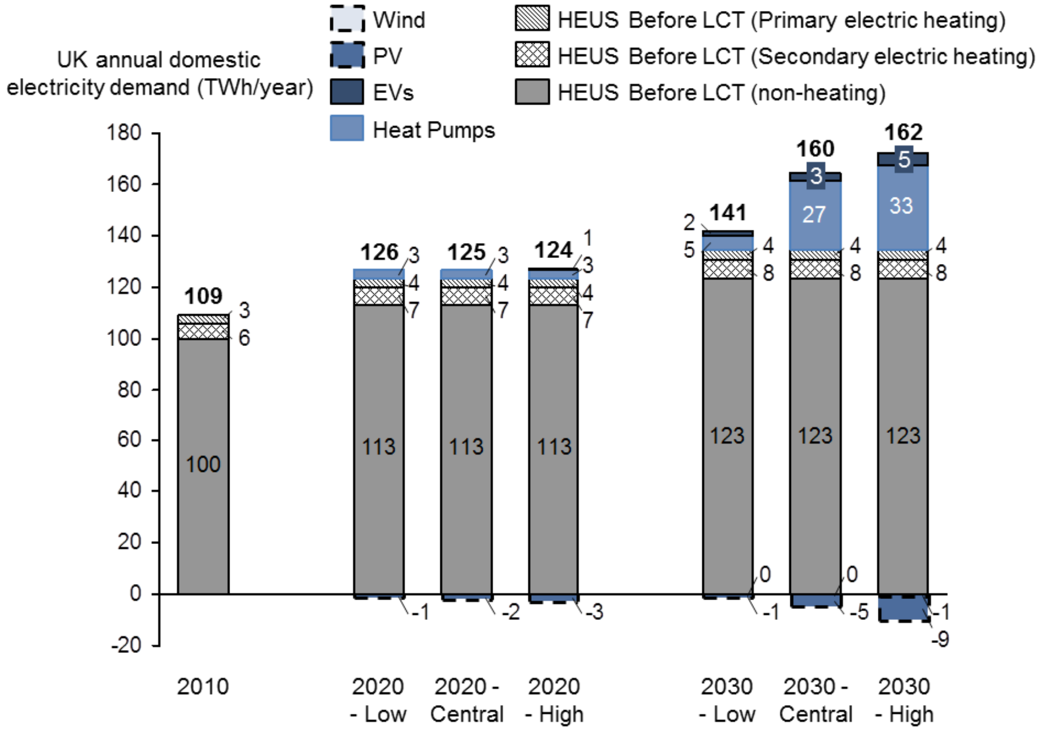

Figure 44: Forecast UK annual domestic electricity demand. Substantial increases in demand are forecast for 2030 under all low carbon technology uptake scenarios. Increases in the baseline HEUS demand are a result of population growth. Improvements in energy efficiency are not considered.

8.2 Forecast Diurnal Demand and Generation Profiles by Uptake Scenario

Figure 45 and Figure 46 below show the estimated domestic demand and generation profiles in the UK for 2020 and 2030 under the DECC Low, Central and High Uptake Scenarios (described in Chapter 3.3), without any DSR.

In the Low Uptake Scenario, LCTs are expected to have negligible impact on the demand profile of an average household, even by 2030. In the Central Uptake Scenario, demand on the grid around midday, when solar PV generation is highest, is reduced by 2020. However, this reduction is countered by increasing demand from electric vehicles and heat pumps by 2030. In the High Uptake Scenario, demand from the grid during the middle of the day is substantially reduced in 2020 and 2030, due to the high adoption of solar PV (and to a lesser extent, wind), however, the morning and evening peaks are considerably larger by 2030, primarily due to the uptake of heat pumps.

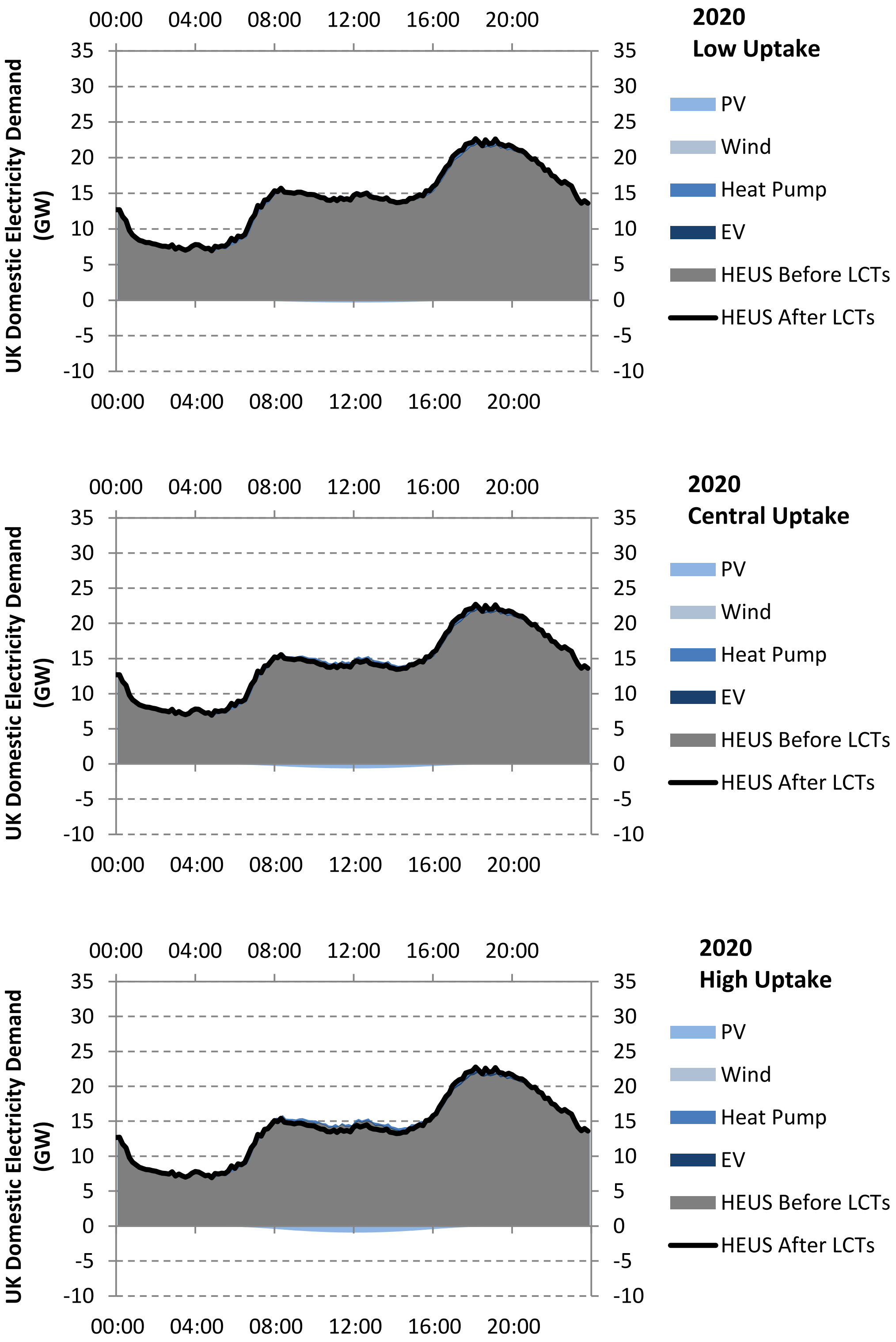

Figure 45: UK annual average electricity demand and generation profiles for the DECC Low, Central and High Uptake Scenarios in 2020, with no DSR.

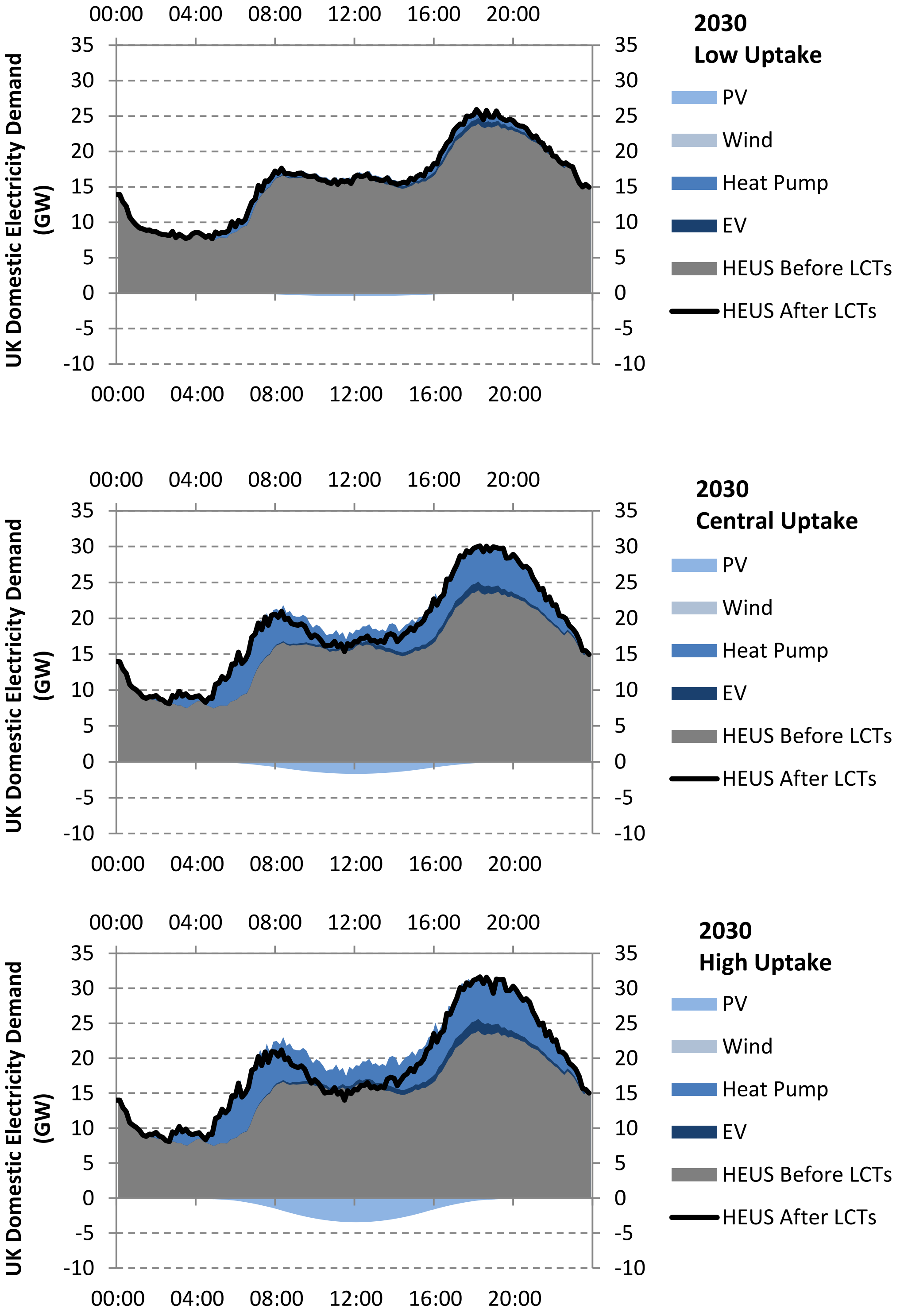

Figure 46: UK annual average electricity demand and generation profiles for the DECC Low, Central and High Uptake Scenarios in 2030, with no DSR.

With LCT uptake, total daily domestic electricity demand exhibits a greater dependence on season, primarily due to the increased uptake of heat pumps and the relatively low generation of PV during the winter months.

Plans for future electricity networks need to ensure this new pattern can be met, increasing the redundancy required in the UK electricity network in terms of both generation and network capacity. This phenomenon will be particularly acute for regions with high concentration clusters of LCT uptake.

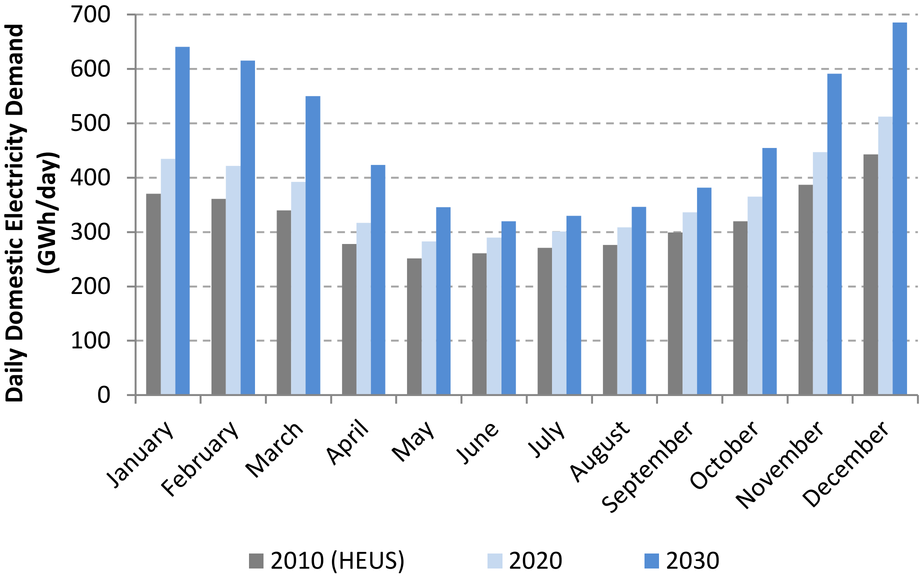

Figure 47: Forecast average daily electricity demand from domestic consumers, under the DECC High Uptake Scenario compared to the 2010 HEUS monthly averages. By 2030, demand on an average day in December increases to more than double that of demand on average days in the summer months.

8.3 Impact of Demand Side Response on Load Shifting

DSR measures can potentially reduce demand during the current 6-7pm evening peak period. In order to consider the load shifting potential attributable to LCTs, two possible cases have been modelled:

1. **Basic DSR – Economy 10**: A total of 10 hours of off-peak electricity is provided per day, from 12am-5am, 1pm-4pm, 8pm-10pm. EV charging occurs during 12am-5am only. Heat pumps operate preferentially in off-peak periods. EV charging rates are at 3kW.

2. **Diversified DSR**: A scenario in which DSR response is better distributed for heat pumps and electric vehicles using the scenarios described above (i.e. heat pump demand reduction potential is

spread over the 4pm-9pm period) and EV charging commences for different households at staggered times between 12am and 3am).

To illustrate the maximum domestic DSR impact from LCTs, we assume all households adopt the DSR measures being examined in each case. The annual average diurnal load profile for each of these DSR cases can be found in Figure 48 and Figure 49 for the DECC High Uptake Scenario.

In the Basic DSR case, substantial new peaks at the start of off-peak periods are forecast, with only a small demand reduction in the 6-7pm period, as static time-of-use tariffs with the same off-peak periods are adopted nationally for heat pumps and electric vehicle charging. These new peaks exemplify the loss of consumption diversity created when all LCT devices in all households activate at the same time at the start of the low-tariff period.

In the Diversified DSR case, load distribution measures are introduced in such a way as to maintain diversity in consumer behaviour, as discussed in Section 7.1 and 7.2, avoiding the formation of the new peaks observed in the basic DSR case. Though maintaining consumption diversity requires a more nuanced and complex approaches to DSR, the overall benefits for peak reduction are clear in Figure 49 which demonstrates an average demand reduction of 2.5GW during the 6-7pm peak period relative to the no DSR case shown in Figure 46.

The monthly breakdowns for average load during 6-7pm are given in Figure 50 for the DECC Low, Central and High Uptake Scenarios. These figures demonstrate the seasonal dependence of DSR impact. For example, in the DECC High Uptake Scenario, the potential savings from LCT DSR in 2030 vary between 4.1GW in January relative to 0.5GW in June.

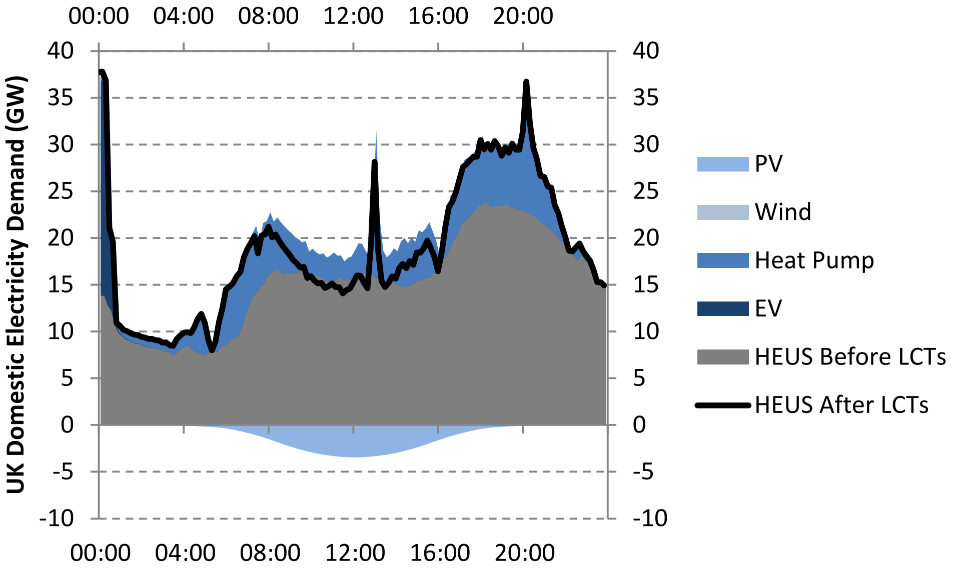

Figure 48: UK annual average electricity demand and generation profile for 2030 in the DECC High Uptake Scenario with basic DSR following Economy 10 tariff bandings.

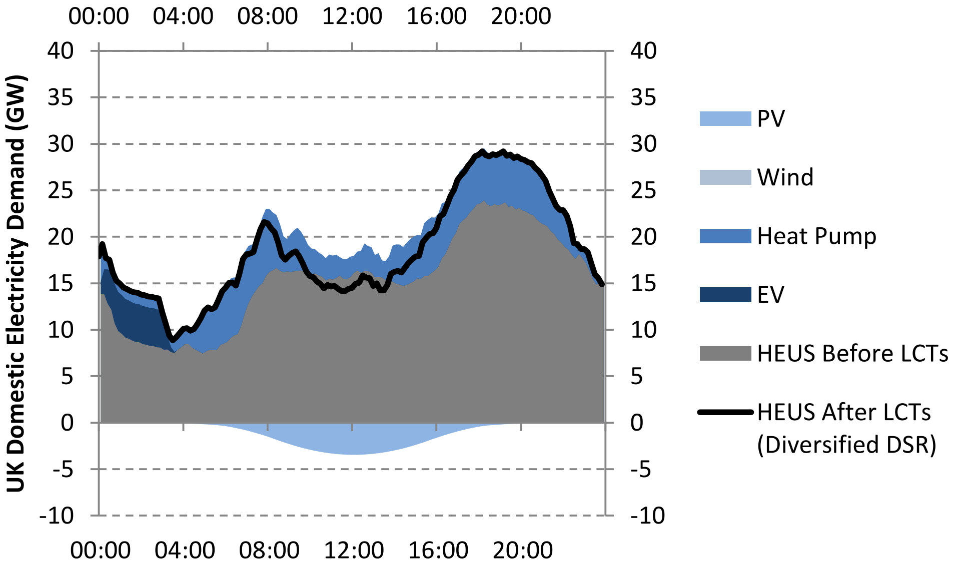

Figure 49: UK annual average electricity demand and generation profile for 2030 in the DECC High Uptake Scenario with diversified DSR.

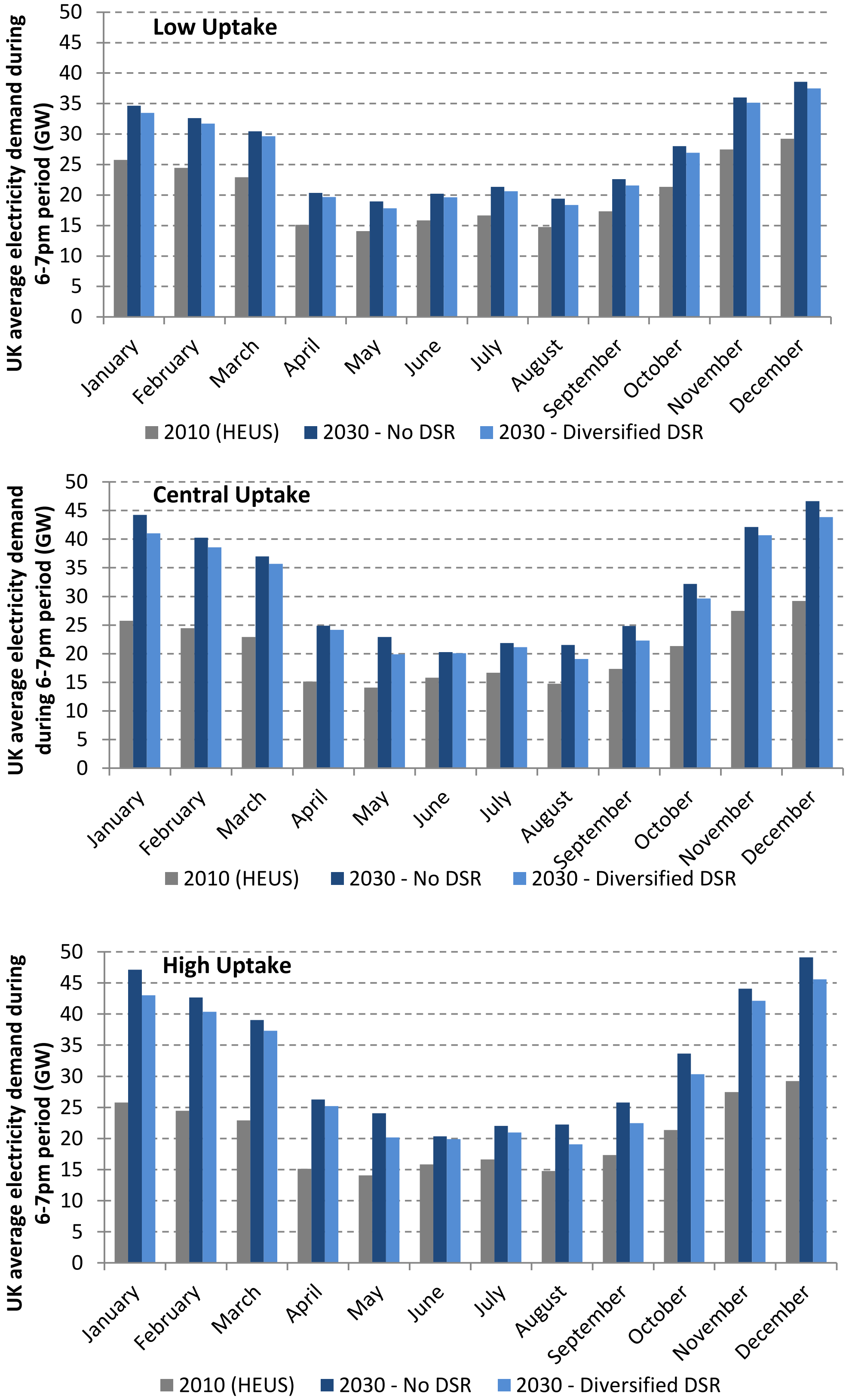

Figure 50: Average electricity demand during the 6-7pm peak period with No DSR and Diversified DSR for the DECC Low, Central and High Uptake Scenario relative to those observed for the HEUS.

9 Conclusions and recommendations

- UK domestic electricity demand from the grid is likely to rise substantially, to as much as 48% over current levels, by 2030 driven by a combination of population growth and demand from heat pumps and electric vehicles, which are offset to some extent by embedded small-scale wind and solar generation. Annual electricity demand from domestic consumers rises in all scenarios, reaching as much as 162TWh/year by 2030 in the High Uptake Scenario (see Figure 1)[52].

- The seasonal dependence of electricity consumption is set to markedly increase in the Central and High Uptake Scenarios. Average daily domestic electricity demand in December is expected to be 685GWh/day, more than double the demand forecast for the summer months. This ratio is expected to rise from 1.76 in 2010 to 2.15 in 2030 in the High Uptake Scenario.

  Recommendation: Planning for generation and network capacity needs to take into account the increasing seasonal dependency of domestic electricity demand and the resulting system redundancies this requires in the electricity networks. This highlights the importance of comprehensive industry planning and analysis work in this area, such as that initiated by DECC and Ofgem's Smart Grid Forum. Since these impacts will vary considerably for different regional demographic compositions, behavioural trends, building types, LCT uptake characteristics and levels of technology clustering, future work will need to focus on how the investment required for network reinforcement over the coming decades (estimated by the Smart Grid Forum to be between £20-£60 billion cumulatively to 2050[53]) will vary for different network regions and assets in the UK.

- The implications for peak-time demand from LCT uptake are also significant with an approximately 40% and 60% increase in demand during the morning and evening peaks, respectively, by 2030 for the DECC High Uptake Scenario relative to the average domestic profile

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[52] This includes the impact of population growth on base demand, but for simplicity we have not included any effects due to increases in energy efficiency as these have been examined elsewhere:
Element Energy (2013), "Further Analysis of Data from the Household Electricity Usage Study: Increasing Insight and UK Applicability", where a UK-wide technical potential saving of 15TWh/year from energy efficiency was identified.

[53] DECC/Ofgem Smart Grid Forum (2012), "Assessing the Impact of Low Carbon Technologies on Great Britain's Power Distribution Networks".

from the HEUS. The majority of this additional demand originates from the operation of heat pumps.

> **Recommendation:** The increased "peakiness" of domestic diurnal demand highlights the importance of DSR strategies as LCT uptake increases. Further work is required to understand how the variations in peak shifting potentials for different consumer archetypes[54,55] map to the likelihood of LCT uptake, which will have important implications for the total amount of peak-time demand that can be shifted. Further work is also required to understand how daily peaks in domestic demand from the grid, and the ability to level them, will vary for different regions and network assets in the UK. More region and asset specific information on how peaks in domestic demand will interact with commercial and industrial loads is also needed.

- We have modelled several DSR scenarios for heat pumps and electric vehicles to determine the extent to which the morning and evening peak increases could be mitigated. We find that simple time-of-use tariffs (such as the current Economy 10 tariff), if widely deployed with uniform time bandings, could potentially create network load problems related to loss of diversity in UK electricity consumption. Heat pumps and electric vehicle charging that are automated to avoid high-tariff periods will create significant peaks at the beginning of static low-tariff time-periods as these devices all activate at the same time.

> **Recommendation:** When designing peak-shifting strategies, care must be taken to ensure behavioural diversity is maintained. For example, in the case of time-of-use tariffs, staggered start-times for different consumers, both locally and nationally, could be used to ensure that new peaks, corresponding to the beginning of low-tariff periods, are not created if these schemes are widely adopted. The formation of new peaks could also be mitigated by the use of a suite of DSR technologies and incentives (also including direct remote control of LCT devices, well-monitored dynamic time-of-use tariffs, etc.).

- We modelled the effect of diversified DSR approaches to determine the optimised technical potential for DSR. In this case, an average reduction of 2.5GW can be achieved in the evening peak period. The heat pump component of this shift (approximately 50-80%, depending

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[54] Element Energy (2013), "Further Analysis of Data from the Household Electricity Usage Study: Consumer Archetypes".

[55] Element Energy (2013), "Further Analysis of Data from the Household Electricity Usage Study: Increasing Insight and UK Applicability".

on season) is based on access to a 180L thermal storage tank – a consideration which must be balanced with its physical footprint in a typical household.

Recommendation: Further research is required to assess the physical capacity, consumer attitudes, and likelihood of uptake for hot water tanks in UK domestic heat pump installations since this is a critical element for significant domestic DSR as LCTs are more widely adopted in the UK.

10 Appendix

10.1 Household Electricity Usage Study – Demand profiles by month

Electricity demand is seasonally dependent – the highest demand on an average day occurs in December, whilst the lowest demand is noted in May. In all months, peak demand occurs between 6-7pm.

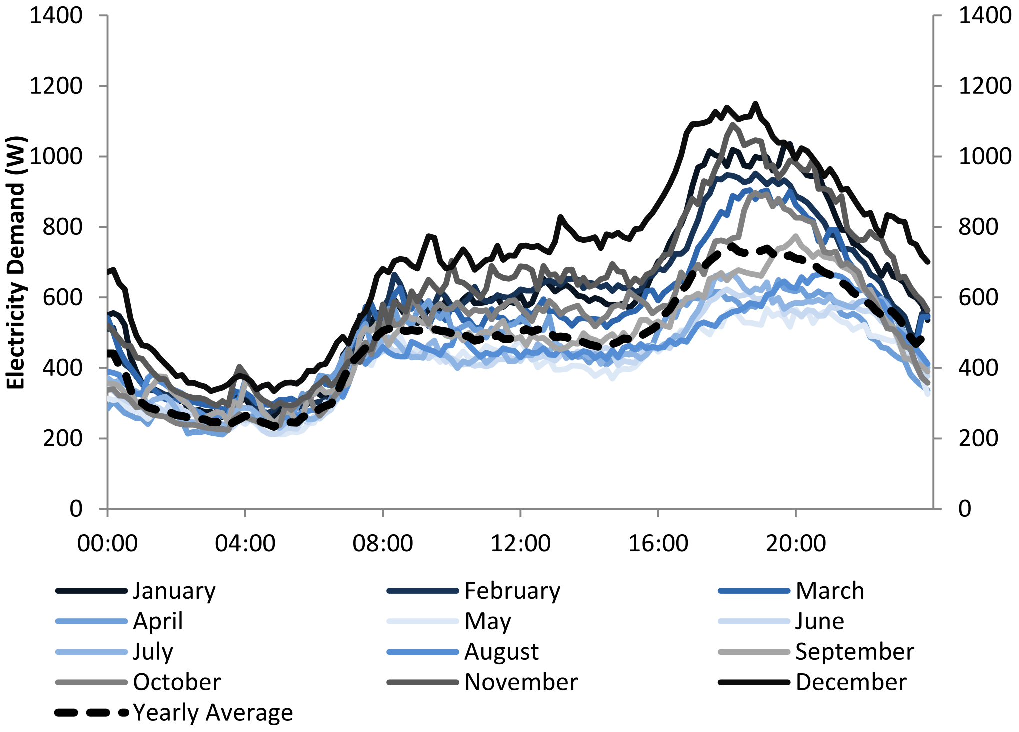

Figure 51: Average electricity demand by month from the Household Electricity Usage Study.

10.2 Heat pump operation logic

The simulated heat pump will attempt to satisfy all household thermal demand. We have modelled a single-speed heat pump that can either be on or off for the entirety of the 10-minute period being considered.

Thermal demand can be satisfied by either operating the heat pump, or discharging thermal storage (in the heating loop and dedicated hot water cylinder). If the demand occurs during a peak period, the heat pump will attempt to avoid operating by discharging storage if there is sufficient stored thermal energy, emulating the 4-pipe system presented in a previous heat pump study[56]. A control system is assumed to be implemented such that during off-peak periods, the heat pump operates to replenish the thermal storage. We assume a flow temperature of 50°C and a return temperature of 45°C in the household heating circuit, with 20 litres of storage within the heating loop per kW of rated thermal output power required[57]. For DSR scenarios, we assume a thermal storage with 180 litres of water, maintained at 50°C with a return temperature of 45°C. The required rated thermal output power (related to the number of radiators and their rated output) is calculated using data from the Heat Emitter Guide[58].

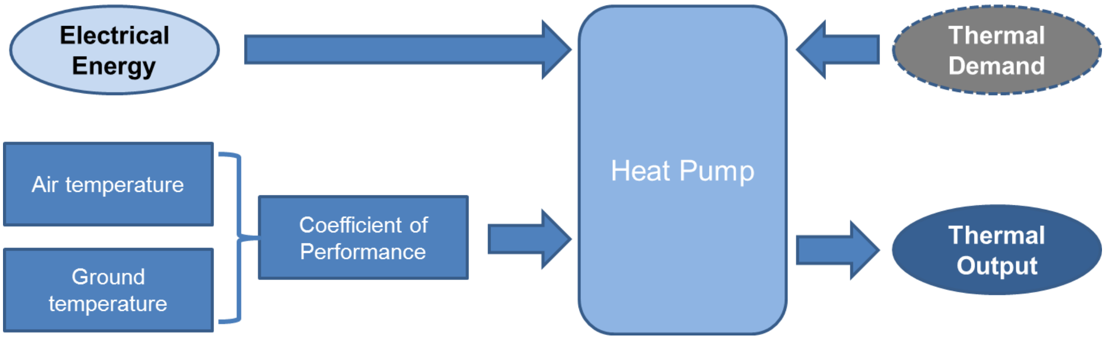

Figure 52: Schematic of the heat pump model and its inputs and outputs.

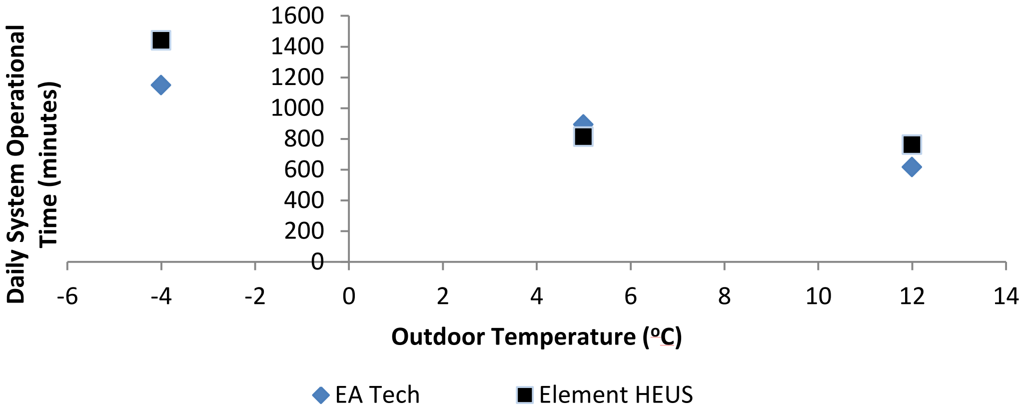

Figure 53: Heat pump operation time as a function of constant ambient temperature. EA Technology results are measured, Element HEUS results are modelled.

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[56] EA Technology (2011), “The Effects of Cycling on Heat Pump Performance”.
[57] EA Technology (2011), “The effect of thermostatic radiator valves on heat pump performance”.
[58] The Microgeneration Certificate Scheme – “MCS 021/MIS 3005 - Heat Emitted Guide for Domestic Heat Pumps”, 2013.

10.3 Electric vehicle assumptions[59]

The modelling of electric vehicles shown in this report assumes battery capacities of 8kWh for PHEVs, 16kWh for RE-EVs, and 22kWh for BEVs. The annual mileage assumptions (Figure 54) and EV vehicle type distributions (Figure 55 to Figure 57) under each scenario are shown below. Vehicle efficiencies are assumed to be consistent with EU tailpipe emission regulations (which decrease to 70gkm by 2030).

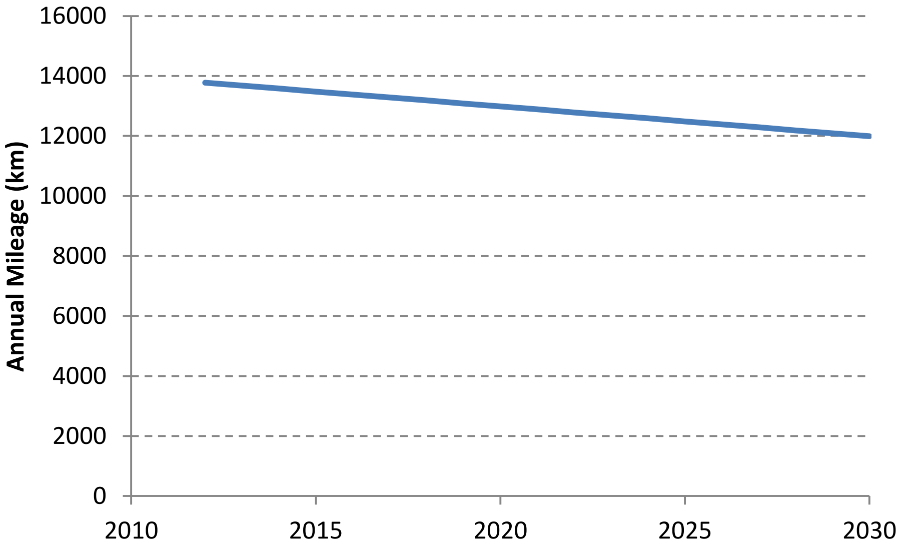

Figure 54: Annual electric vehicle mileage (km) as a function of year.

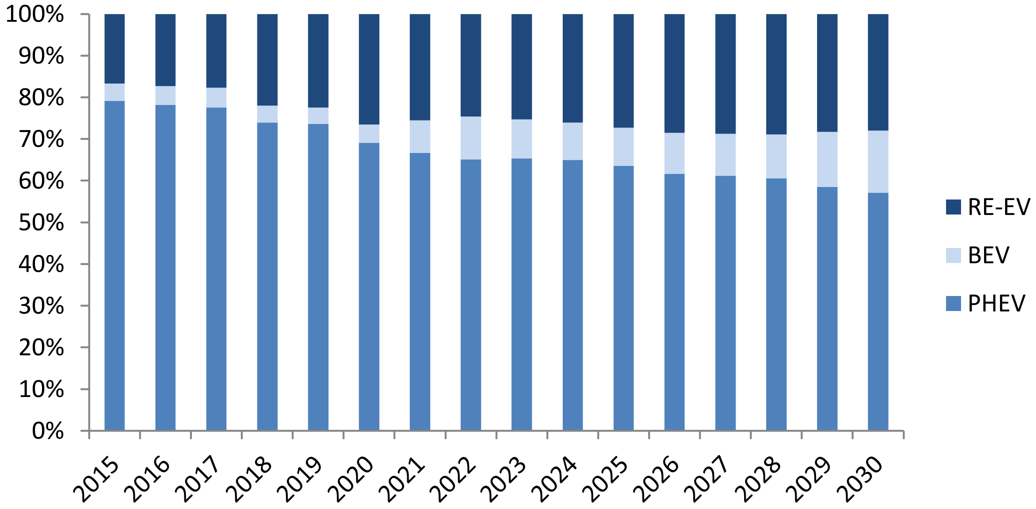

Figure 55: EV type distribution, DECC Low Uptake Scenario.

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[59] Baringa Partners & Element Energy (2012), “Electricity Systems Analysis: Future systems benefits from selected DSR scenarios” for DECC.

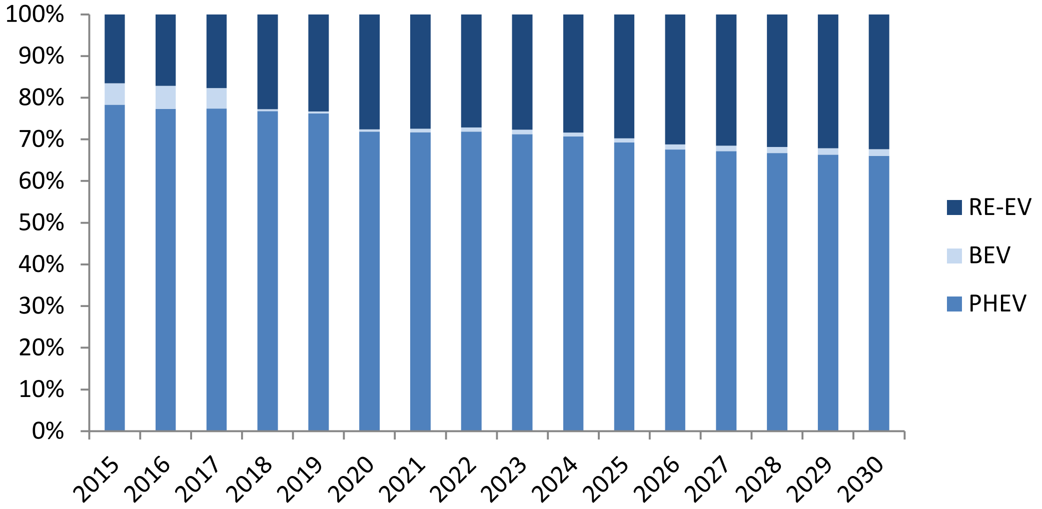

Figure 56: EV type distribution, DECC Central Uptake Scenario.

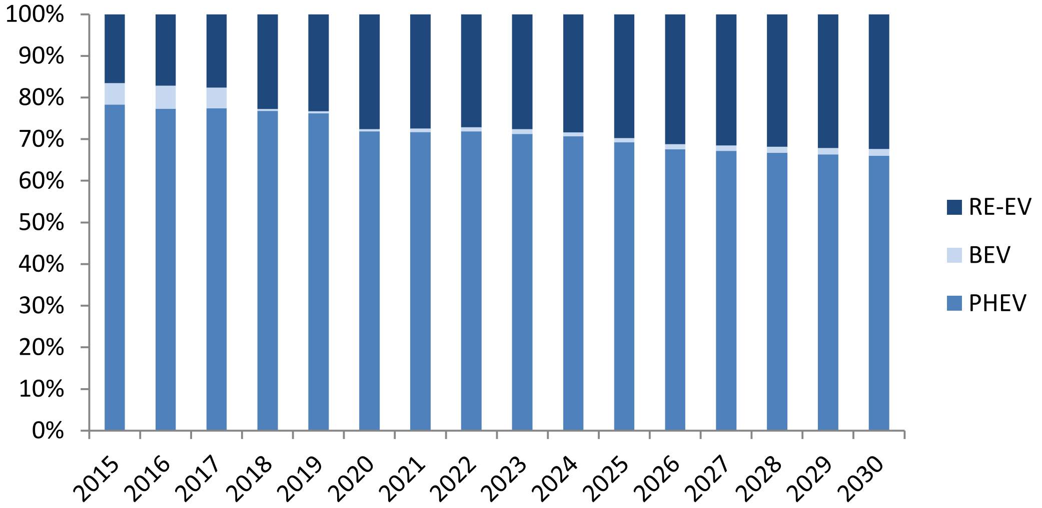

Figure 57: EV type distribution, DECC High Uptake Scenario.

10.4 Air and ground average temperature profiles

Modelled air temperature from a Defra Air Pollution station[60], based in Market Harborough, England, has been used to create the temperature profile for average days in each month (see Figure 58).

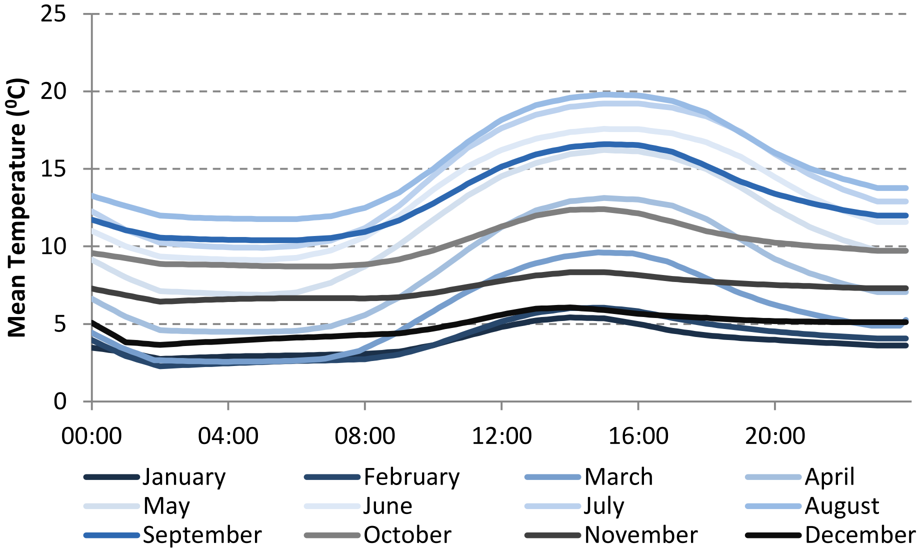

Figure 58: Mean air temperature for each 10-minute time step, for Market Harborough, England.

Ground temperatures for the Midlands were taken from MCS guidance for ground source heat pump design[61] and combined with seasonal ground temperature profile data from the Energy Saving Trust[62] (see Figure 59).

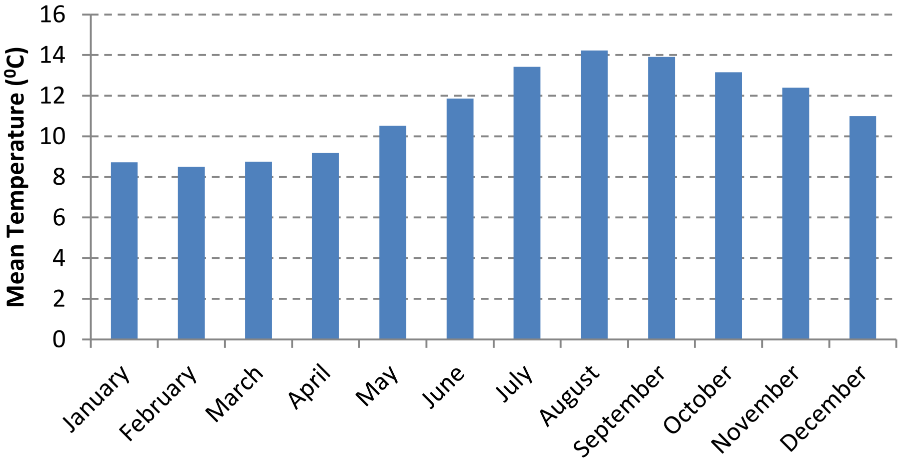

Figure 59: Ground temperature by month, for the Midlands, England.

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[60] Department for Environment Food and Rural Affairs (2013), “Data Archive”, accessible from: http://uk-air.defra.gov.uk/data/data_selector

[61] MSC (2011), “MCS 022: Ground heat exchanger look-up tables”.

[62] Energy Saving Trust (2004), “Energy Efficiency Best Practice in Housing - Domestic Ground Source Heat Pumps: Design and installation of closed-loop systems”.