Project FALCON
Load Estimation

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FALCON

Contents

Executive Summary

FALCON is a research and development project focussing on the 11kV network in and around Milton Keynes. It combined network trials of smart techniques, such as battery storage and dynamic asset rating, with the creation of a complex network planning tool, the Scenario Investment Model (SIM). This report is a summary of the findings of work in relation to energy modelling which was required to provide load forecasts for use within the SIM.

One of the defining features of Smart Grids is the greater use of information to enable the use of new technologies and techniques in a more dynamic way. Having a greater understanding of the power flows over our networks will enable us to optimise the operation of networks in real time and to improve the planning of future network investment. This is especially true for network management techniques where timing is important, such as battery charging / discharging cycles, automatic load transfer, dynamic asset rating and demand side management, all of which were trialled under FALCON.

A lot of work has been undertaken to better understand what tools and data are available now, what might be available and how to make better use of these. It is of course an area of continuing development, but we feel that FALCON has given us a much better picture of where we are heading and some good ideas for follow on work.

The objectives of the work within Project FALCON were to:

1. consider the way in which we estimate the loads at 11kV distribution substations;
2. determine whether estimation can be an effective substitution for monitoring, and;
3. provide estimates that could be used in the Scenario Investment Model (SIM).

The work included creating an initial view of network hotspots where there was the least headroom against voltage or thermal limits. This analysed the network at a greater temporal granularity by modelling over different seasons and days at half hourly intervals. This showed that the network generally had sufficient headroom but a small number of feeders were approaching their limits, and that data quality could greatly impact the assessment of network issues. It also showed that feeders did not all have peak load at the same time, validating the approach to model at greater temporal granularity.

The mechanism for estimating half hourly load used for settlement was applied to determine the load at distribution substations. Comparisons were drawn to monitored data which showed that substations with more customers were more accurately represented by these estimates. Other features of substations were examined to see how they related to estimate accuracy. Substation load, which often correlates with customer numbers, was seen to also influence estimation accuracy but other features such as the proportion of load which related to an off-peak tariff, did not.

The substation characteristics of load and customer numbers were used to cluster substations into a small set of types for which average estimate accuracies were calculated. Typical 11kV network feeders were populated with these representative substations to determine the average improvement to accuracy that would result from adding one or more monitoring devices. This found that for underground circuits monitoring mid-way along the feeder was optimal, but that benefits of additional monitoring devices reduced quickly. Overhead feeders appeared to have a slower decline in added value from additional monitoring such that more than one monitoring device may be appropriate. Ultimately the value for money calculation would need to quantify the benefits of additional accuracy, which would depend on the purpose of the monitoring.

The majority of the focus of the load estimation work was to support the development of the FALCON Energy Model by Energy Savings Trust in partnership with University College London which was used to provide the estimates of load for different demand scenarios.

In order to validate and improve the Energy Model, monitoring equipment was installed in 158 distribution substations throughout the trials area so that estimates could be compared to measured values. The sites were chosen to ensure a range of substation types, sizes and load mixes. A suite of quality metrics was developed to measure how well estimates reflected the actual values.

This found that substations with fewer customers were somewhat harder to model accurately and that substations dominated by domestic load were more likely to be modelled well. The quality metrics for estimates produced by the various methods suggest that the Energy Model provides better quality estimates than LV Network Templates or replicating the Elexon process and is considered fit for purpose. This is a positive outcome validating the work undertaken and giving credence to follow on analysis. One advantage is that it incorporates meter reading data for half-hourly metered customers. This will become applicable to more customers after April 2016 when the larger non domestic customers (profile classes 5-8) will move to settlement on half hourly metered data.

The analysis highlighted the general need to assess and, if validated, improve the quality of customer data and connectivity data which can be a factor in estimates that are not representative of the real loads. It is suggested that future development of the Energy Model could provide output at a lower level of aggregation to allow for comparison to LV feeder and phase monitoring data, or individual customer data for comparison to smart meter data.

Further work could also usefully include:

- providing estimates on a monthly rather than seasonal basis,
- further work on customer type identification, and
- obtaining rather than assuming opening hours.

SECTION 1

Introduction

1.1 Background to Project FALCON

The uptake in low carbon technology and generation is expected to require investment to avoid significant network issues. Reinforcement techniques that have traditionally been used, can be costly, can take a long time to implement and can have a disruptive impact on the general public. The 11kV network is the “backbone” of how electricity is delivered to homes and businesses and making these networks more flexible is critical to support the low carbon transition.

Project FALCON (**Flexible Approaches for Low Carbon Optimised Networks**) was designed to investigate how new 11kV techniques could be applied to the 11kV network to manage thermal or voltage constraints that have advantages over traditional reinforcement. The techniques were assessed by field trials within the Milton Keynes area to gain experience in the installation and operation of equipment and to compare the actual operation with the expected operation based on algorithmic models.

The techniques were also modelled within the Scenario Investment Model (SIM), a new piece of computer software to support highly branching simulations showing possible evolutions of the network from 2015 to 2050. The SIM carries out power flow analysis of a nodal model of the network to determine network issues which are then resolved by applying automatically generated network patches that apply the techniques to the network. Power flow analysis requires estimates of loads at each distribution substation which is the driver for FALCON’s load estimation work.

The new techniques within FALCON are:

- Dynamic asset ratings that free up capacity where real conditions are more favourable than the conditions assumed when setting static ratings.
- Automatic load transfer can redistribute load between 11kV feeders. This builds on algorithms currently used to manage interruptions and quickly restore customers' supplies.
- Meshed (interconnected) 11kV network in suburban and rural areas can increase network capacity.
- New battery technologies allow the flow of power on the network to be changed as the battery is charged or discharged. This can be applied to help resolve network constraints.
- Distributed generation can be used to increase capacity on the 11kV network using innovative commercial arrangements.
- Control of customer demand to alter the pattern of load on the network through commercial arrangements.

1.2 The Need for Better Load Estimation

The 11kV network is account for a substantial proportion of DNO networks, having feeders with a combined length of cable and overhead lines in the tens of kilometres. Yet HV feeders are likely to include relatively few remotely indicating measuring points other than in the primary substation or where associated with remote controlled devices. The design standards for 11kV networks should ensure that they operate with some headroom in terms of load capacity so that when networks are unavailable, due to faults or planned outages, the neighbouring networks can carry the additional load. This is typically known as 'N-1' when certain assets are unavailable.

The previous approach taken to the network is to ensure that the design is adequate for the most onerous conditions that are expected. Therefore designs have been based on estimates of the maximum load with assumptions made about the diversity of usage between customers.

The "fit and forget" approach , where there is no continuing feedback from monitoring devices, works well for networks with stable load profiles and low levels of load growth, however the proliferation of low carbon technologies is likely to impact both the maximum demand and the load profiles for network assets. There is a great deal of uncertainty surrounding low carbon technology in terms of the degree of uptake, the location and timing. This suggests that analysis should consider more than one scenario to assess the impact of different assumptions on expected outcomes.

Additionally the new techniques are dynamic, so that in addition to understanding the scale of peak loads we also need to know their timing and duration and what the load profile looks like before and after the peak. In order to model techniques such as dynamic asset rating, battery storage, automatic load transfer and DSR (Demand Side Response), time series data is required which also needs to reflect the variations between different days in the week or seasons in a year.

For the FALCON Project, it was decided to model load at half-hourly resolution as this fits well with existing industry systems. The five-season model used by Elexon for settlement was adopted with Weekdays, Saturdays and Sundays modelled separately. Three "peak" days were also included to model extreme conditions. Thus the Load Estimation workstream of FALCON provided load estimates as an input to the modelling within the SIM and provided estimates across

1. multiple load scenarios due to the level of uncertainty,
2. different seasons and day types to reflect that the most onerous conditions may not always be winter, and
3. at half hourly resolution to support the modelling of time dependent techniques such as dynamic asset rating and DSR.

1.3 Project Objectives

The objectives of the load estimation work within FALCON were as follows:

1. Create a first estimate of half hourly load at distribution substations from available industry data to support the creation of a “rough cut” hot spot map.
2. Compare estimated load values with measured load values to refine the calculation of distribution substation load estimates by feedback methods. Provide a set of improved distribution substation load estimates that can be used to refine the hot spot map.
3. From the comparisons of measured load with the improved load estimates, determine the likely error for derived data for different circumstances (e.g. overhead vs. ground mounted substations, numbers of customers, urban vs. rural). Determine the criticality of such errors in order to determine the optimum balance between derived and measured data required to support the trials in project FALCON.
4. Create an energy model to generate estimated consumption profiles for customers from configurable models of the drivers of consumption e.g. building efficiency, appliance efficiency, heating technology, electric vehicles and socio-economic factors. This should be applicable to the present day and should facilitate creating demand scenarios that run at least up until 2050 for comparison to other analysis. Improved estimates should be used to further refine the hot spot map and the view of measured vs. derived data as per objectives 2&3 above.
5. Determine new customer profiles that can be used to simplify the process of demand estimation and potentially improve the accuracy of the settlement process.
6. Define and create a set of load scenarios to be used by the SIM. This should include referencing existing published projects to determine which existing industry load scenarios should be replicated in addition to new scenarios. This will involve the creation of a tool for scenario design and editing, a process which will also investigate the technical details pertaining to such tools and which can continue to be used after FALCON.

During the project it became apparent that the FALCON trials did not require additional estimated data to support the activities such as scheduling of alternative load transfer operations, battery charging or initiating DSR operations as the monitoring that had been installed for these trials provided sufficient information. It also became clear that the Energy Model provided a more complex process than could be represented with a simple set of customer profiles, so those elements of the work were no longer required. This did not affect any of the Successful Delivery Reward Criteria (SDRC) requirements which were all fulfilled and documented in the five reports that were produced during the project.

There are links to these reports in the References & Links section. Rather than repeat the detail of the analysis contained within those reports, this document aims to provide a collective summary of the analysis that was performed and the key learning points. The report will, where appropriate, direct the reader to the appropriate source of detailed information.

SECTION 2

Initial Hotspot Map

2.1 Analysis Completed

This first work package was published in December 2012 and sought to carry out power flow analysis with a half hourly time resolution and for a variety of representative days. This would inform us of any network issues within Milton Keynes that we were not aware of and also serve as a way to gain experience that might be reflected within the design of the SIM.

The initial hotspot map used GROND, an 11kV planning tool that uses a nodal model for power flow analysis that was used in the East and West Midlands DNOs before they were part of Western Power Distribution. As GROND did not support modelling at half hourly resolution or for multiple days, this involved bespoke development work. The network data used for the power flow analysis was a legacy version which had been created prior to the takeover of Central Networks by Western Power Distribution. Ideally a more up to date version of the network would have been created but the update processes had been discontinued. However the use of legacy data does not invalidate the results that have been published.

The half hourly load estimates for the distribution substations were created by replicating the Elexon process for settlement but with custom configuration, so that the customer aggregation to create "super-customers" occurred at each distribution substation rather than at a bulk supply point.

Finally, to get a view of how well these estimates(based on the Elexon methodology) reflected the real loads , ahead of the installation of the monitoring equipment within Milton Keynes, the process to create estimates was repeated for substations in South Wales for which monitoring data was available as part of the LV Network Templates Tier 2 LCNF project. This comparison was later extended in the second report to be written, the Load Estimation and Monitoring Optimisation Initial Report.

2.2 Key Findings

The key findings fell into the following types:

Most onerous day type

The majority of networks experience their most demanding conditions at Winter peak, however there are several circuits that were found to already experience a significant Summer peak. This supports our decision to model a variety of day types.

Peak times

The peak time for networks is not always driven by the evening peak of domestic consumers. Some networks serving non-domestic customers are seen to have a mid-day peak suggesting scope for automatic load transfer schemes.

Existing capacity

Under the simplest test of single switching the networks are largely able to restore supplies without experiencing thermal constraints. There appears to be one feeder, Bletchley Feeder 07, Bean Hill, Neapland where the load on restoration from either of the normal open points would exceed 100% of rating for at least one section of the feeder. However, in reality load could be shared more widely by performing more than one switching operation. There were no examples of voltage limits being breached.

Hot Spots identified

The following feeders had the lowest thermal and voltage headroom.

Table 1: Feeders with lowest thermal and voltage headroom.

Thermal Rating		Voltage	
BLETCHLEY	>>07 BEAN HILL, NEAPLAND	NEWTON ROAD	>>08 SELBOURNE AVENUE MILTON
FOX MILNE	>>08 NORTHFIELD DRIVE, WAYSIDE	NEWTON ROAD	>>05 SHOULDER OF MUTTON BUCKI
BLETCHLEY	>>11 BURTONS REDMOOR	BLETCHLEY	>>11 BURTONS REDMOOR
NEWPORT PAGNELL	>>07 ALEXANDRA DRIVE, NEWPORT	MARLBOROUGH STREET	>>02 THE WOODLANDS LINFORD

Data Issues

One instance of low headroom was seen to result from the underlying nodal model being incorrect. This error demonstrates the potential for incorrect data to cause the SIM to assess healthy networks as having network issues and highlights the need for an accurate data import process. This was reflected in the design and operation of the Authorised Network Model which included features to find and resolve errors between different datasets. Where a comparison dataset is not available, errors may be harder to find and it is likely that there would be value in developing more complex inference rules and error checking to sense check the network data. The Authorised Network Model is a good starting point for such development.

Visualisations

The colouring of the network diagram in GROND is useful to show sections of network that are outside thermal or voltage limits at a point in time. However creating an aggregate representation of loading over different half hourly periods and different days of the year is harder to represent in a way which is intuitive. Using line width or intensity of colour is more likely to be interpreted as degree of overload / voltage issue at a single point in time rather than the frequency of issues occurring. Similarly more research is required to develop an icon to summarise the overall headroom at a Primary taking into account the different time periods.

SECTION 3

Load Estimation and Monitoring Optimisation Initial Report

3.1 Analysis Completed

This report was published in April 2013 and covered many areas of work aimed at establishing a general feel for the issues in load estimation that could be used to inform the development of the Energy Model. Areas of analysis included:

- how to assess estimate accuracy
- how well current methods performed
- the likely areas of difficulty for energy modelling, and
- the quality of available data.

  The work also covered a comparison of estimates from the Energy Model to actual values, which was the first stage of validation.

This report covered the following areas of work:

3.1.1 Comparison of SVAA estimates to versions using Elexon methodology within a database.

The two methods to produce estimates based on the Elexon methodology resulted from an issue with configuring the original SVAA routine used in settlement. A database was created which used the same profile coefficients as the SVAA routine but was a slightly simplified form of the process. These datasets were compared to see the impact of omitting the additional elements of the SVAA process, which were found to have little impact.

3.1.2 Analysis of EAC stability over time

It was originally intended that we would repeat the SVAA process over time and to replace the Estimated Annual Consumption (EAC) values, which are forward looking estimates with Annualised Advances (AA) which reflect actual meter readings in the past. This was intended to determine whether creating estimates based on AAs would improve estimate quality, however it was not possible to gain the appropriate consents from all the parties involved in providing the relevant data. An alternative to assess the suitability of EAC data was to consider how much this changed each quarter, as this would indicate the likely difference in scale between EACs and AAs. The more stable EAC data, the less difference there would be between EACs and AAs.

3.1.3 Comparisons of SVAA generated estimates to actual values for South Wales

The SVAA generated estimates were compared to actual values for a set of substations in South Wales where actual monitoring data was available.

3.1.4 Definition of Quality metrics

While visual comparison of estimated and actual values is thought to be useful, it is somewhat difficult to assess visually whether one set of estimated values is a better representation of actual values than another. Quality metrics were determined to quantify the degree of mismatch between estimated and actual values to allow for comparison between different methods of estimation and also to allow for better comparison between sub-sets of estimates.

3.1.5 Comparisons of Energy Model output to actual values for ten substations in South Wales

A set of ten substations for which monitoring data was available in South Wales were modelled using an early version of the FALCON Energy Model. This provided a range of feedback in terms of overall scale and proportion of off-peak heating.

3.1.6 Assessment of Substation Characteristics vs Estimate Accuracy

This assessment was based on the SVAA generated estimates and actual data for monitored substations in South Wales. Only ten substations for South Wales were included in the Energy Model so this did not provide sufficient sample size for the analysis at that stage. The cost and effort of obtaining all the relevant data for the South Wales substations was not warranted given that the same analysis was planned using Milton Keynes data at a later stage. This analysis looked to see what substation characteristics correlated with accuracy, with the longer term goal of being able to classify substations into different accuracy categories to help determine future monitoring requirements.

3.1.7 Monitoring Optimisation Calculations.

This analysis considered how the benefit of additional monitoring stages could be assessed if the type of substations, and their typical error margins, along the feeder were known. A methodology was created to determine the improvement resulting from placing monitoring at different locations, however establishing a *value for money* argument requires an assessment of the financial value of obtaining greater accuracy. This is likely to be application specific so no further generic analysis is planned.

3.2 Key Findings

- A proxy version of the SVAA process can be created using a database which gives a reasonable approximation to the results from the SVAA code itself.
- The standard deviation of the difference between estimates created by replicating the settlement process (SVAA estimates) and the actual measured values suggests that the SVAA estimates are within +/- 6.4 kWh of the actual value for the half hour 68.4% of the time.
- The accuracy of estimates created using SVAA is only clearly related to size and number of customers with other factors not having an apparent influence. The larger the substation the more accurate the estimates tend to be. As SVAA does not generate estimates for Half Hourly metered customers, their load is subtracted from the monitored value to allow for comparison. The lack of relationship between the proportion of domestic vs non-domestic customers and accuracy is likely to be affected by the removal of half hourly metered customer data.

- The set of estimation metrics was generally found to be useful; however the metrics for standard deviation were of less use because they generally reflected the size of the load. This can be corrected by calculating the standard deviation of an error expressed as a percentage.
- It will be important to develop these metrics into an industry standard to allow for comparison of different estimation methods. These have been presented at previous events.
- The accuracy of estimates created using SVAA does not allow us to observe a seasonal variation between spring and summer.
- There are two measures of annual consumption that are used within the settlement process. While Estimated Annual Consumptions (EACs), show a larger degree of annual variation than was expected, they are still preferred over Annualised Advances (AAs) as an input to estimation due to their availability across all DNOs.
- There are a number of data quality issues. While some of these are specific to WPD there are others that are likely to affect the wider industry such as difficulties in obtaining customer data and validating connectivity. Future projects are likely to touch on these issues and learning will be shared. When estimating the load in a section of network based on the addition of estimates for each substation the cumulative uncertainty can be reduced by applying one or more monitoring devices. The optimum location will be influenced by the network topology and the expected error associated with each substation. Topology appears to be the dominant influence. For underground circuits the value for money of additional monitoring declines sharply as these circuits are more likely to be composed of fewer substations with larger customer numbers and hence better monitoring accuracy. For more complicated circuits with a larger number of substations and a wider range of substation types there may be additional value in adding more than one monitoring point.
- Further work will be required to determine the business impact of different levels of estimate accuracy for different uses. Without this, *value for money* judgements cannot be made for the appropriate levels of monitoring or the appropriate investment to make improvements in the estimation methods themselves.

SECTION 4

Hotspot Map Update

4.1 Analysis Completed

The hotspot analysis was an evaluation of the 11kV network in the Milton Keynes area that determined the HV Feeders that were nearest to experiencing network issues in terms of thermal rating, high voltage or low voltage. The first iteration of the hotspot map is included in the report "Hotspot Map Initial Report" published in December 2012 This used the tools and datasets that were available early on in the project in order to get a feel for which areas of our network might already be likely to experience issues. The tools and datasets for the initial hotspot analysis were not representative of those that would be employed by the SIM (see table 2 below).

The aim of creating a revised hotspot analysis that used the network modelling tool and datasets used by the SIM, was to give the first validation that these components combined gave reasonable results by comparing results with the initial hotspot map.

Table 2: Features of the initial and revised versions of the hotspot maps.

Feature	Initial Hotspot Map	Revised Hotspot Map
Network Modelling Tool	GROND	IPSA
Network Model Source Data	GROND data set, at least a year out of date	ANM, up-to-date
Half Hourly Load data estimates	Based on Elexon settlement process	From FALCON Energy Model

It was also a way to prove some of the early development work within IPSA,(the Network Modelling Tool that forms part of the SIM) specifically the new features to handle sequential analysis of half hourly period load data and the additional data handling facilities to process the CSV files containing the data output by the Energy Model.

4.2 Key Findings

The key findings from this analysis can be summarised as follows:

IPSA Capability

IPSA was able to process data from the ANM and the Energy Model to carry out the analysis demonstrating the technical compatibility of the various inputs and outputs. The results of the analysis were generally consistent with expectations showing that there are no voltage or thermal constraints on the network under normal running configuration, no voltage constraints under N-1 conditions and only a small set of feeders indicating potential thermal constraints under N-1 conditions.

Temporal Granularity

The updated analysis also confirmed the benefit of analysing networks on a half hourly basis using different season and day types. Temporal variations are seen in the affected section of network identified as having least headroom and the location of the normal open point which would be the best selection.

Headroom & Hotspots

The updated analysis mostly identifies hotspot feeders that are different to the initial results, though one feeder was identified with low voltage headroom in both sets of analysis. There was, however, consistency with the previous analysis in terms of average maximum loadings and the frequency distribution curves of the results. The voltage drops under N-1 conditions are a little larger in the revised analysis but are still within the expected range.

Where there were differences between the initial and updated hotspot analysis, it was not possible to determine which factor(s) had driven this. The analysis has not been designed to determine the impact of each factor individually by changing one variable while holding all the others constant. This is partly driven by the practicalities of creating the required experimental conditions. For example, it would be time consuming to create a revised network model in the GROND format and to create additional Elexon estimates for any new substations etc. Given that we do not expect to export from the Authorised Network Model to GROND in the future, this development would not be a useful exercise and would not alter the choice of network model for the SIM.

Overall System Validation

The results obtained are sufficient to conclude that the components of the SIM are working well together and can generate credible results. The only caveat to this conclusion is that the Energy Model, while working well for feeders that are dominated by domestic load, was seen to overestimate loads on feeders dominated by industrial or commercial (I&C) customers. Where this was evident, by comparing the Energy Model estimates with representative values from SCADA, such results could be excluded from the analysis as they would inevitably show a greater degree of thermal overload than is actually the case.

SECTION 5

FALCON Scenarios Report

5.1 Report Summary

The SIM is a network analysis tool supporting complex optimised branching simulation over multiple years. It is a combination of a network modelling tool (IPSA) which performs power flow analysis on a nodal model representing the network, and a harness which manages the overall process of the simulation and passes data to and from the network modelling tool. The SIM can be used as an 11kV planning tool, a strategic planning tool to develop a long term plan for an area, or as a tool for supporting policy decisions. It is in the areas of policy development and strategic planning that scenarios are of greatest relevance, but also of interest to other stakeholders.

The SIM can be used for strategic planning by developing scenarios that reflect the expected load profiles for different years at distribution substations, likely future costs of applying techniques and other variables.

The SIM uses a number of different scenarios to reflect the degree of uncertainty about low carbon technology uptake in the future. Using a variety of credible scenarios should create a set of likely results showing the range within which the future outcomes are expected to lie.

While the SIM can be tailored to include as many scenarios as required, the intention was to focus analysis on four. The scenario analysis will be complemented by sensitivity analysis so, for example, we will assess the impact of different cost assumptions, or different proportions of peak time vs. off peak electric vehicle charging without creating new scenarios for every possible combination of variables. This has been finalised in a set of SIM Runs, documented within the SIM Final Report.

The commitment to consult on the scenarios and their implementation was to ensure the credibility and validity of the results of the SIM, by ensuring the credibility and validity of its input data. This SDRC requirement was determined before the Transform model, which itself uses values from scenarios developed by DECC, had been developed. While we are not limited in our choice to replicating those four scenarios used for ED1 planning, we feel that this is the most useful selection. This is partly because their use in ED1 planning means that they are already familiar to the industry and considered credible, but it also allows a comparison of the results when modelling with different approaches. By keeping the underlying assumptions the same it should be possible to compare results using the TRANSFORM approach, based on representative network types and assumed values for headroom provided for the different solutions, to the very detailed modelling in FALCON which uses power flow analysis of a nodal network model. FALCON’s modelling approach should, in theory, provide a more accurate view of the actual headroom on the network and the real impact of solutions in an area than the use of standard network types.

While the aim is to replicate the scenarios as closely as possible, because the SIM and the TRANSFORM model operate in different ways, with different data and processes, it is not possible to import the complete set of assumptions and parameters that define a Load Scenario from one system into another. The Scenarios Report therefore outlines the process by which the Load Scenarios have been created and the underlying assumptions that have been made with a view to obtain feedback from stakeholders so that those stakeholders can have confidence in the output of the SIM.

To the same end another report was issued at the same time as the Scenarios Consultation validating the output of the Energy Model against monitoring data for substations in Milton Keynes. This report, Energy Model – Comparison of Estimates to Actuals is discussed in section 6.

Consultees who included other DNOs and National Grid were asked to answer the questions below

> Q1. Are the selected scenarios appropriate? If not, what other scenarios would be more useful and why?
>
> Q2. Is the methodology to recreate scenarios within the Energy Model appropriate?
> If not, then what practical improvements could be made to the methodology to implement the scenarios?
>
> Q3. Where parameter values have been assumed are these reasonable?
> If not, what values should be used in preference?
>
> Q4. Are there other variables that have not been included in the Scenario definitions that are expected to have a major impact on the future loads at distribution substations?
> If so, what are these and how can they best be addressed?

5.2 Summary of Consultation Responses

The consultation responses suggested that the selected scenarios were generally seen as appropriate and the similarity with scenarios used in other modelling work was seen as a positive benefit. One respondent suggested that the scenarios should not deviate from the TRANSFORM/DECC assumptions until new information was available to support this.

It was noted that the DECC scenarios were possible means by which the carbon targets could be achieved and that there were no probabilities associated with the scenarios. It was also noted that National Grid’s *No Progress* scenario represented a case where the carbon targets are not achieved which should be borne in mind when comparing results between scenarios.

There was interest in seeing the impact of DSR, or for smart meter enabled time of use tariffs and this has consequently been included as a sensitivity test in the SIM RUN set and analysis.

Respondents also noted the difficulty in creating long term projections with relatively little data and a great deal of uncertainty around the key variables. Not only is there uncertainty about the future levels of uptake for low carbon technologies and how this varies temporally and spatially, but also that technological developments are likely to alter the consumption profiles of low carbon technologies. We agree with this comment and confirm that the results are indicative and general in nature and therefore cannot provide accurate forecasts of reinforcement expenditure to 2050. However in order to validate benefits we have undertaken a run of the SIM to exclude all techniques in order to see the likely cost of conventional reinforcement so that they can at least be a comparative baseline. We feel that this is still a validation check worth carrying out. Respondents agreed with the principle of allocating low carbon technologies using information about housing type, heating systems, metering class and demographic information.

One respondent questioned whether the specific impact of legislation had been taken into account in future lighting consumption projections. We believe that future legislation is likely to have less impact than that already enacted to prevent the sale of incandescent bulbs, but additionally that lighting energy reduction will be influenced to a greater degree by the improvements to the quality and reduction in cost of low energy lighting options.

Two respondents raised the issue of housing association / council housing becoming active installers of PV for their own housing stock. This has been addressed by altering the range of clustering factors for PV as described in section 3.2 of the report.

A general comment was made that more work is needed to determine how profiles for heat pumps and EV charging profiles will be in the future, rather than how they appear now. The continued substation monitoring associated with FALCON and LV Network have the potential to show the impact of these devices on substation profiles, as they are connected to the network, however this will not indicate the potential for load shifting. There are a number of projects that are likely to involve EV charging points arising from the funding available for smart cities or the Transport Systems Catapult which may offer further opportunities to understand charging profiles further.

Alternative EV charging profiles have been created for use in sensitivity analysis. These have been based on data obtained from UK Power Networks' project , Low Carbon London and is a positive example of sharing learning.

5.3 Scenario Output Validation

To sense check the Energy Model output for the various scenarios some comparison was made to other UK scenarios. Comparisons were made for the change of total annual demand and the change in total peak demand over two time periods, 2012-2030 and 2012 – 2050

Sources for comparison data were;

- The National Grid Scenarios (2014 edition)
- UKERC analysis
- Output from the Transform model
- ENA Report (Smart Meter Benefits)

This demonstrated a wide range in the expected outcomes from different sources but that the Energy Model scenarios were within the expected range.

5.4 Energy Model Profiles

Following the consultation some changes were made to the Energy Model parameters. A selection of the load profiles created after these modifications were made is given in Appendix 1. These demonstrate the changes in load profiles over time and between different day types and scenarios.

SECTION 6

Energy Model – Comparison of Estimates to Monitored Data

6.1 Analysis Completed

The FALCON Energy Model is the tool created by Energy Savings Trust together with University College London to provide half hourly average load estimates for network modelling within the SIM. This combines a physics model for energy requirements for heating and hot water with profiling mechanisms to suggest what proportion of load relates to different end uses such as cooking, lighting, refrigeration etc. To validate the Energy Model, actual consumption data was collected for substations in Milton Keynes by installing monitoring and telecommunications equipment. Comparing estimates to the actual values was expected to show whether the model had particular issues for substations with a common feature e.g. off-peak heating, so that the model could be improved.

This report replicates some of the analysis that was originally carried out using estimates created using the SVAA methodology contained in the Load Estimation and Monitoring Optimisation Initial Report.

The quality metrics that had been defined in that report were calculated for different seasons and for different days of the week. They were also used to investigate how substation characteristics were related to the quality of the estimates produced.

Sample size was investigated to see if this had any impact on the quality metrics, but was found not to be an influencing factor.

Finally, instances where the Energy Model estimates were a very poor representation of the actual loads were investigated and the results detailed within the report.

6.2 Key Findings

The analysis shows that the Energy Model gives acceptable results. For most substations the estimates are a good representation of the actual monitored results. The quality metrics for the Energy Model are better than those for the estimates created using the LV Network Templates Classification tool (a tool created from another LCNF project run by Western Power Distribution as part of the LV Network Templates project) and this is believed to be driven by the inclusion of half hourly metered customer profiles which can be incorporated into this highly detailed model more successfully than using a small number of statistically derived templates.

The substation characteristics linked to good or bad quality estimates are consistent with the findings of previous analysis for LV Network Templates and for earlier analysis within FALCON using estimates created by replicating the settlement process. Good quality estimates are more likely for substations serving a larger number of customers and where these customers are domestic, particularly those in profile class one. Substations serving a smaller number of customers are less likely to give good quality estimates as are those with a larger proportion of non-domestic customers though this relationship is weaker.

There are some substations for which the Energy Model overestimates load and others where it underestimates load, either consistently or for a particular part of the day, usually the early hours of the morning where economy seven heating is assumed to be a contributory factor. While the Energy Model has an overall tendency to overestimate load, the degree of overestimation is small for winter weekdays. As winter peaks are still the most onerous conditions for the majority of the network, this is unlikely to result in "false positives" within FALCON's Scenario Investment Model (SIM) suggesting unnecessary intervention.

Correlation and R squared (R^2) values appear to be better for high summer and summer and worst for spring. It is not clear why this should be the case, but one possibility is that temperature and lighting changes occur most rapidly in spring and autumn and it may be that average values for temperature and lighting are less representative. Summer and high summer are shorter seasons and may show less temperature variation. The Elexon definition of winter is extremely long and it may be better in the longer term to create a set of seasons that minimises the differences in weather variables within a season.

Weekends tend to have better values than weekdays. We have previously found that non-domestic load is harder to estimate and this may reflect the fact that domestic load forms a greater proportion of the total load on weekends compared to weekdays.

Investigation of substations that gave poorer estimates suggested that these estimates were poorer due to data quality issues in associating customers with their relevant substations or their associated consumption data rather than any systematic error with the calculations contained within the Energy Model. There were some substations that seemed "hard to model" due to having an erratic load pattern dictated by external events that did not occur in a routine pattern. An example would be a sports stadium or entertainment arena where events are not held every night and there is a considerable difference between days when functions occur and those when they do not. Such cases would need to include a fixtures list to be modelled more accurately.

SECTION 7

Recommendations for further work

The development of the Energy Model was focussed on providing the estimates required for the SIM. While the Energy Model has served its purpose and been proven to work there would be potential enhancements that could be made if this were to be developed into a fully-fledged system. This system would support 11kV planning, preparation of long term plans for price controls, and policy development.

Lower level of Aggregation.

While the Energy Model calculates energy use for each customer the output file provides data for the whole substation. Providing the output for an individual customer or allowing aggregation by LV feeder and Phase would allow for use in LV network analysis. This would also assist the process of validation by enabling comparison with feeder and phase level data from the monitoring at Milton Keynes, or smart meter data (This may also require improvements in customer-phase data availability).

Customer Type Identification

The matching rates between WPD data for non-domestic customers and the data sources to determine SIC codes, business type, building attributes etc. were generally of low levels. The Half Hourly Metered Customer Archetype Project, funded under IFI, included analysis of half hourly metered customer data to determine whether a set of profiles could be determined to represent a set of customer archetypes. As part of the project matching techniques were developed which have built on and extended the process used in the Energy Model and could be reflected back into the model. Similarly, the archetypal profiles that were developed for different types of organisation could be used as default profiles within the Energy Model where no better profile data is available.

Opening Hours and Occupancy Profiles

Work to improve customer type identification could also obtain better information about operational hours. This would allow for better assumptions for occupancy profiles for non-domestic customers.

Alternatives to Experian Data

The customer level data from Experian which was used to suggest the most likely occupancy pattern and also to drive the clustering factor calculations is costly, to the point of being prohibitive we believe for a more widespread roll-out. Alternative sources of data that could be used as indicators should be considered to reduce overall cost.

Software Implementation

The Energy Model is not a complete system in itself, but requires a significant amount of data preparation. While some of this is included in another executable program there are elements which are calculated manually on spreadsheets with the results then transferred to the relevant tables. A full scale implementation of the Energy Model would need to develop more workable alternatives in keeping with enterprise level software and provide proper system administration tools. Where possible the development should be adapted to support sharing and integration e.g. by handling smart meter data and load estimates in a format consistent with the emerging Common Information Model (IEC standards 61850, 61968, 61970).

Short Term use with Weather Forecasts

The Energy Model uses weather inputs as part of the calculations. For the purposes of generating output for the SIM these were set to seasonal averages. However it would be potentially of great value to see whether the Energy Model could be used with real weather forecast data as an aide to scheduling DSR or similar activities.

Validation Using HV Monitoring

The lack of HV monitoring options has prevented the improvement in accuracy that mid-feeder monitoring could bring to feeder level power flow estimates. This could be incorporated in future projects that already involved extensive monitoring to see the improvement from the application of the calibration calculations.

Alternatives to Elexon Seasons

The length of the Elexon Winter season appears to impact the accuracy of the model. It should be possible to create estimates for each month rather than the Elexon seasons which should reduce some error in the estimates for weather data. This would be especially beneficial for short term forward estimation. While this would generate a larger number of potential day-types these should not all be required for strategic planning.

SECTION 8

References & Links

8.1 References

Document Title	Content	Date Issued
Hotspot Map Initial Report	Results of power flow analysis for Milton Keynes area using GROND tool with estimates created by replicating Elexon Settlement process	10th December 2012
Load Estimation and Monitoring Optimisation Initial Report	Initial comparison of estimates to monitored data to determine factors likely to influence estimate accuracy.	29th April 2013
Hotspot Map Update	Results of power flow analysis for Milton Keynes area using IPSA tool with estimates created using the Energy Model	30th September 2013
FALCON Scenarios Report	A description of the scenarios to be used for the analysis by the SIM and the underlying variables in the Energy Model	30th October 2014
Energy Model – Comparison of Estimates to Monitored Data	A comparison of the estimates produced by the Energy Model to the substation monitoring data collected in Milton Keynes.	30th October 2014
Half Hourly Metered Customer Archetypes - Final Report	An IFI project related to improving the modelling of non-domestic customers	11th March 2015
Low Voltage Network Templates Report - Final	The Final Report of a Tier 2 LCNF project based in South Wales.	5th December 2014

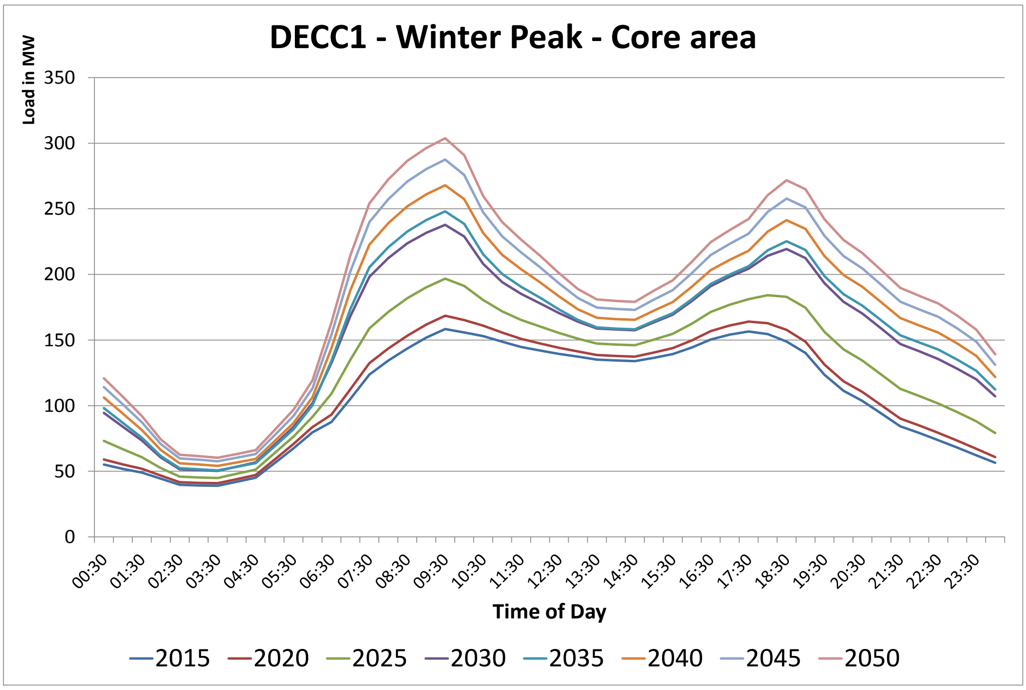
SECTION 9

Appendix 1 Updated Load Profiles

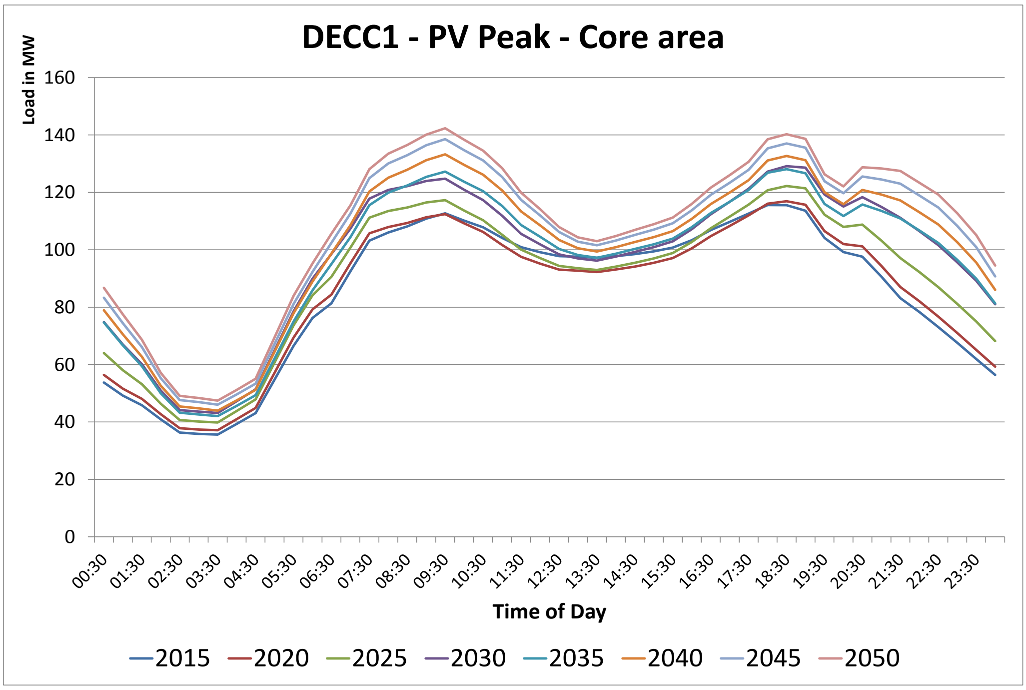
This section contains load profiles for different years and scenarios to demonstrate how these vary. These are given for the "Peak" days, Spring Weekday and Winter Weekday as these are likely to present the most onerous conditions for the network. The profiles are a summation of the profiles for all the distribution substations supplied by the primary substations identified as being part of the core FALCON area.

9.1 DECC1

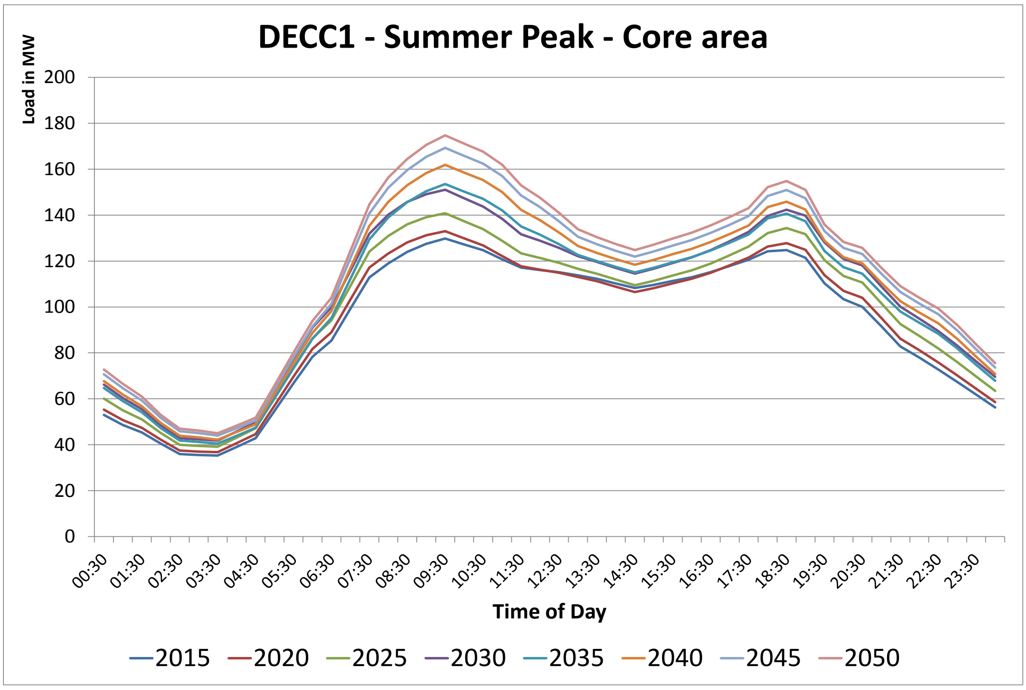
DECC1 is characterised by having high levels of uptake for heat pumps and medium levels of uptake for EVs and PV.



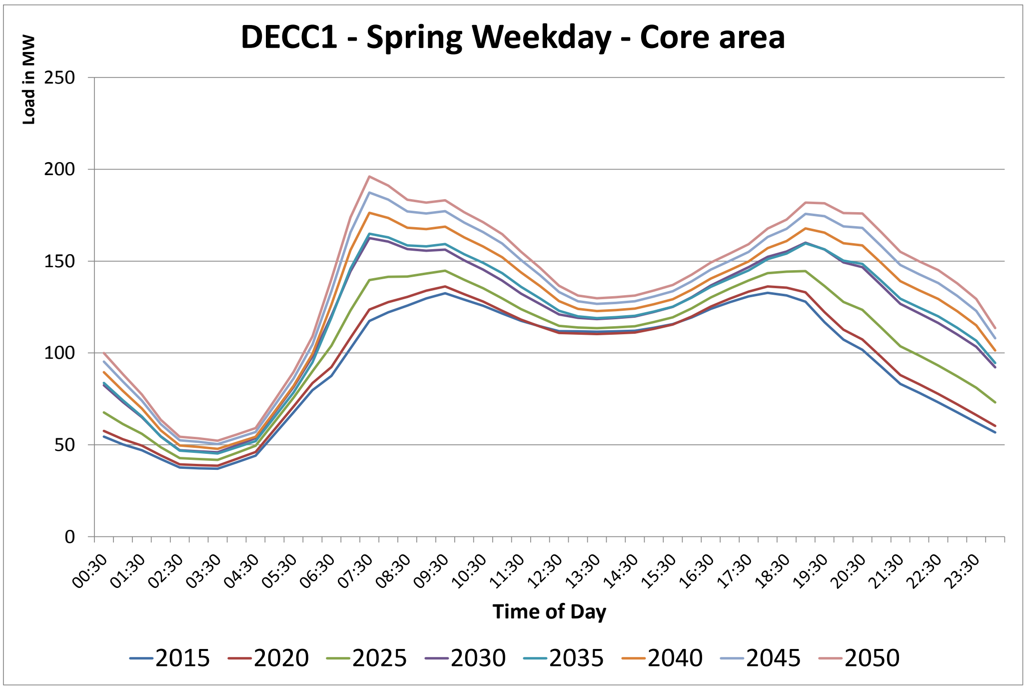
The Winter Peak day load estimates suggest that in 2050 the peak load will be approximately double that in 2015. The load shape shows more pronounced peaks with the morning peak becoming larger than the evening peak.



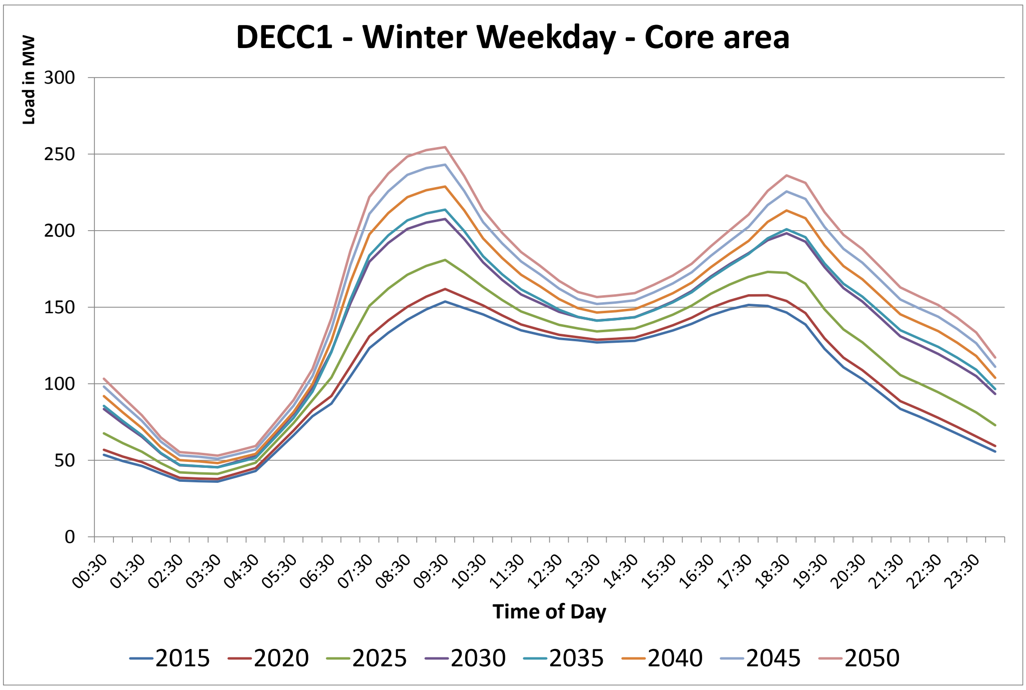
The PV Peak day shows that load growth for the period around midday is far less than that for the morning and evening peaks due to the impact of increased PV. The increase in load at midday for the PV Peak day is less than that for the Winter Peak day which shows the impact of reduced PV and higher heating requirements for winter peak. The levels of PV do not result in net export from the Milton Keynes area, neither do they create a new system minimum suggesting that there would not be widespread high voltage issues.



The Summer Peak shows more divergence in morning load than evening load which is expected to reflect the impact of EV charging profiles.



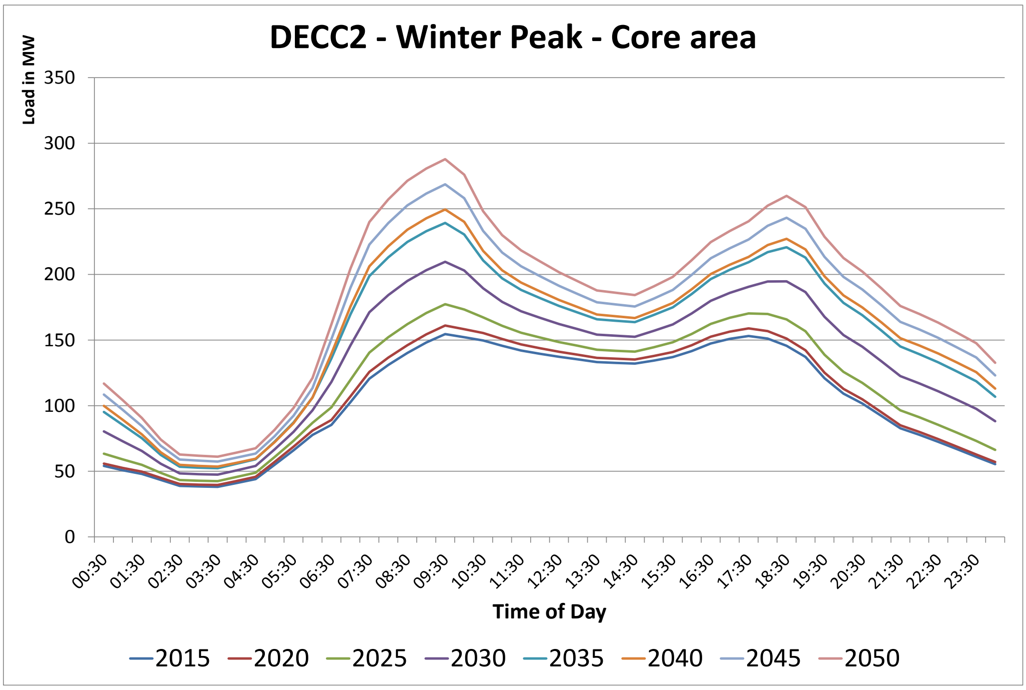
The Spring Weekday morning peak loads exceed those seen for the Summer Peak explaining why network issues are frequently seen for this day type.

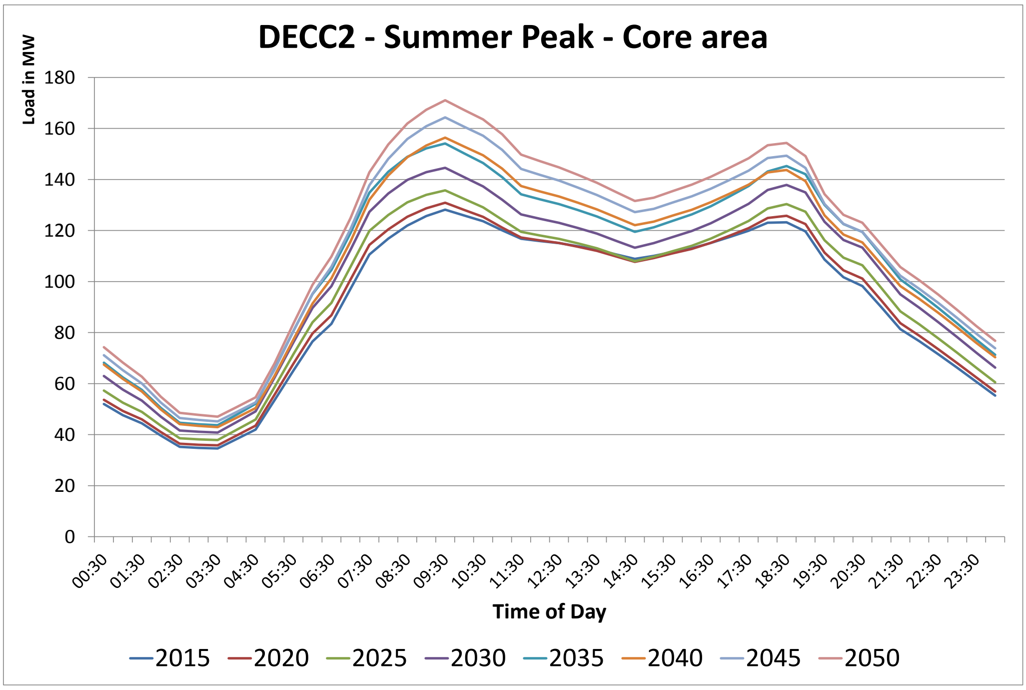


The Winter Weekday show a similar pattern to the Winter Peak day. There are significant increase in peak loads, more pronounced peak times and the maximum load occurring in the morning.

9.2 DECC2

DECC2 has a high level of uptake for EVs but medium levels for heat pumps and PV. Increase in peak load is not quite as high as under DECC1 or DECC3 but is still an increase of over 85%. The same general observations can be made that load for the Winter Peak day and Winter Weekday increases to a greater degree than for Summer Peak or PV Peak, the morning peak exceeds the evening peak for most days, and the Spring Weekday has peak loads that exceed the Summer Peak.




DECC2 - Summer Peak - Core area
Load in MW
180
160
140
120
100
80
60
40
20
0
00:30
01:30
02:30
03:30
04:30
05:30
06:30
07:30
08:30
09:30
10:30
11:30
12:30
13:30
14:30
15:30
16:30
17:30
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Time of Day
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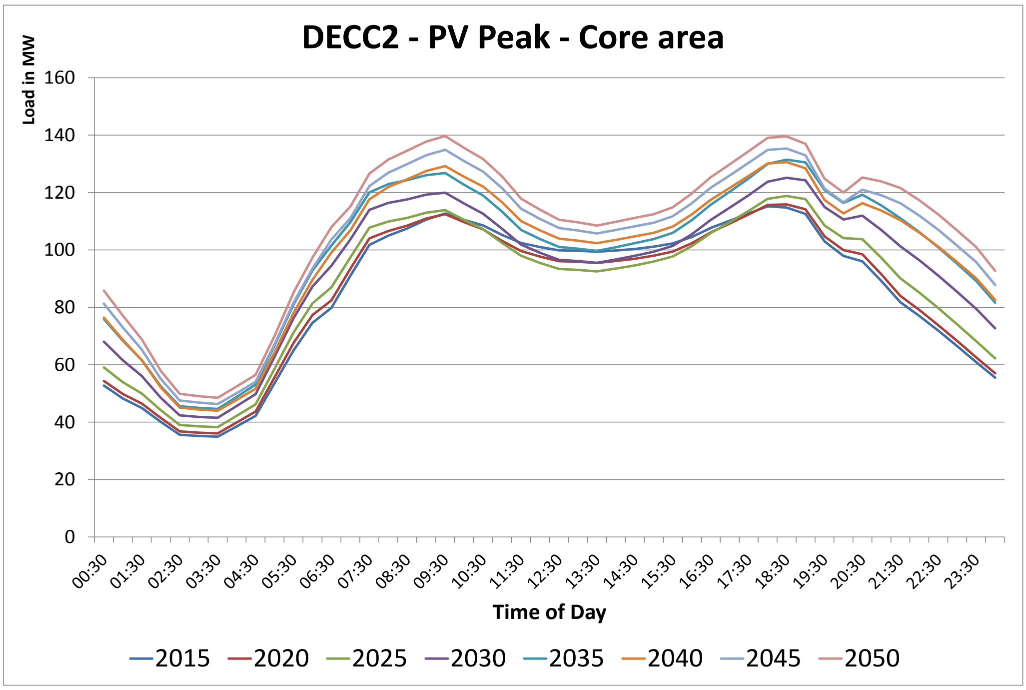
2050


DECC2 - PV Peak - Core area
Load in MW
160
140
120
100
80
60
40
20
0
00:30
01:30
02:30
03:30
04:30
05:30
06:30
07:30
08:30
09:30
10:30
11:30
12:30
13:30
14:30
15:30
16:30
17:30
18:30
19:30
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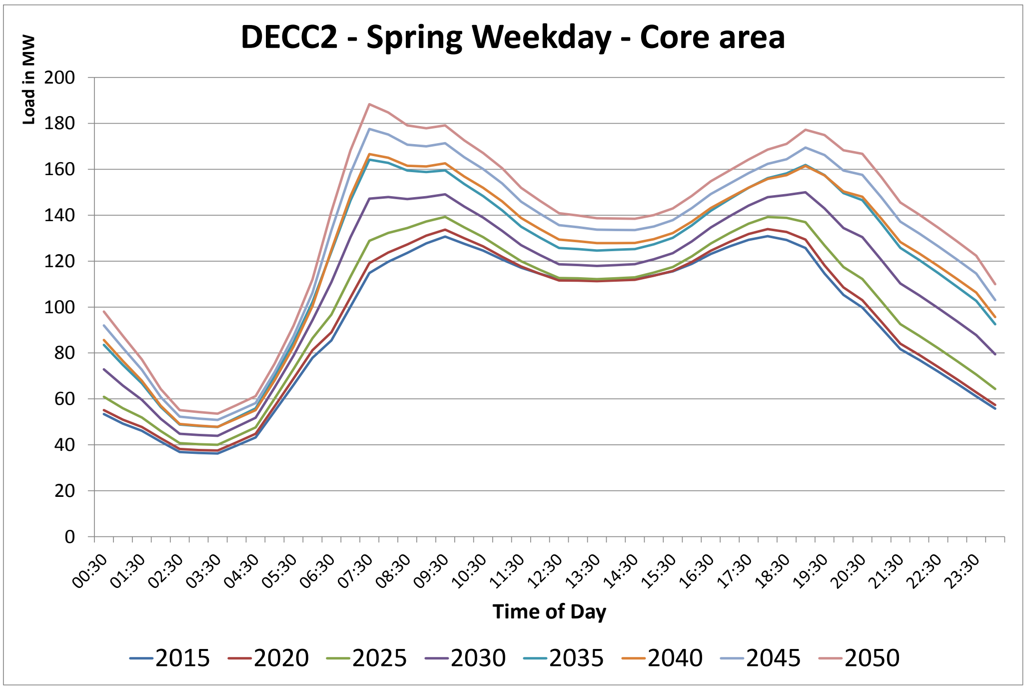
23:30
Time of Day
2015
2020
2025
2030
2035
2040
2045
2050


DECC2 - Spring Weekday - Core area
Load in MW
200
180
160
140
120
100
80
60
40
20
0
00:30
01:30
02:30
03:30
04:30
05:30
06:30
07:30
08:30
09:30
10:30
11:30
12:30
13:30
14:30
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16:30
17:30
18:30
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Time of Day
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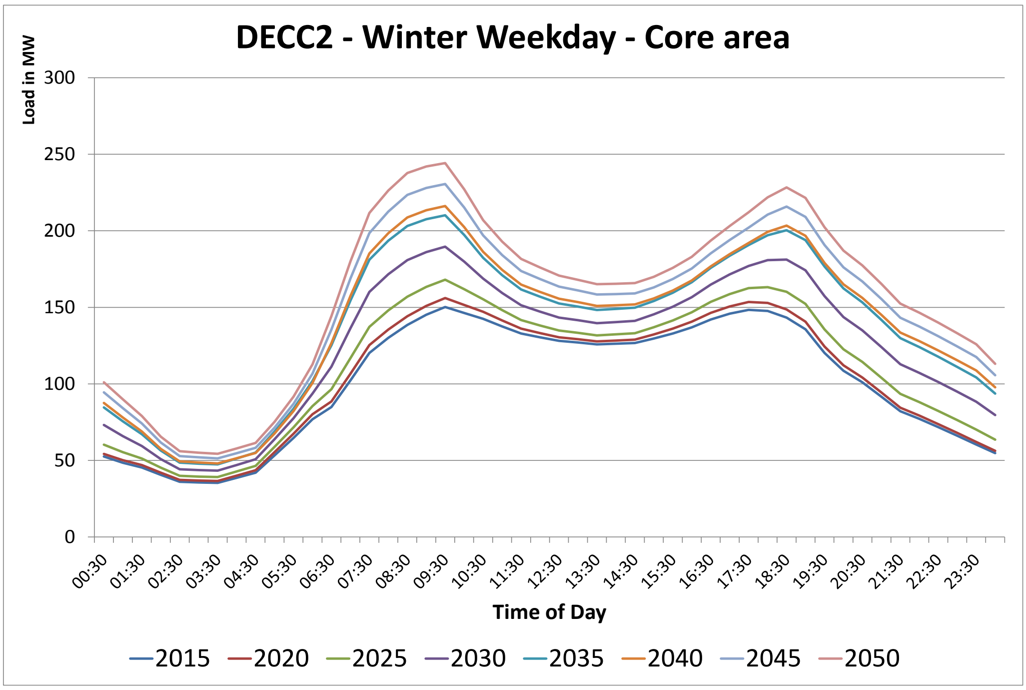
DECC2 - Winter Weekday - Core area
Load in MW
300
250
200
150
100
50
0
00:30
01:30
02:30
03:30
04:30
05:30
06:30
07:30
08:30
09:30
10:30
11:30
12:30
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18:30
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Time of Day
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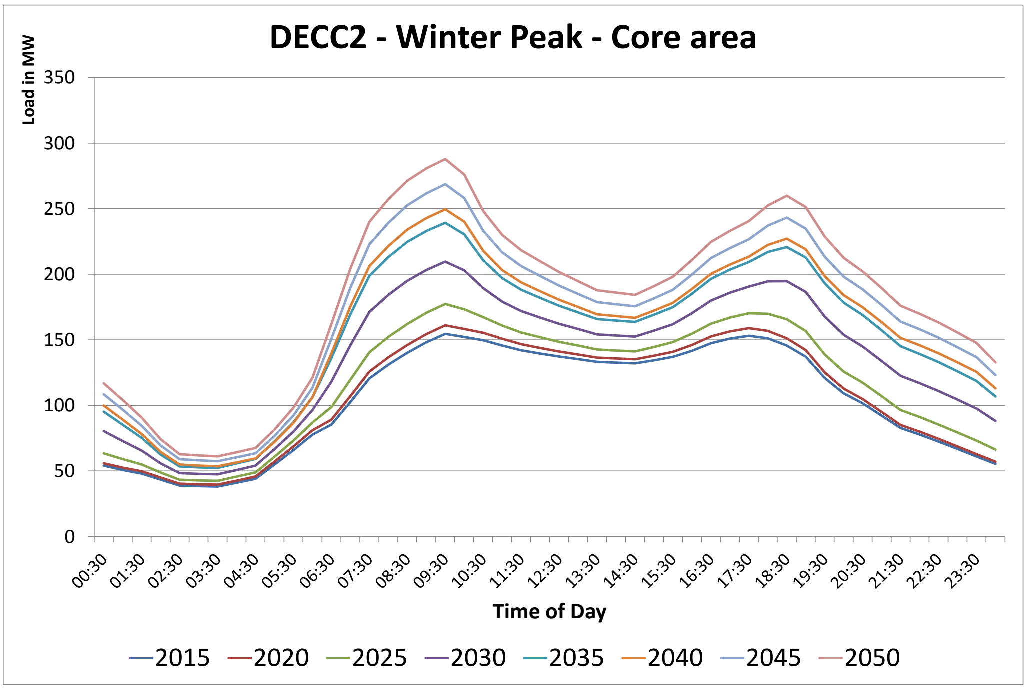
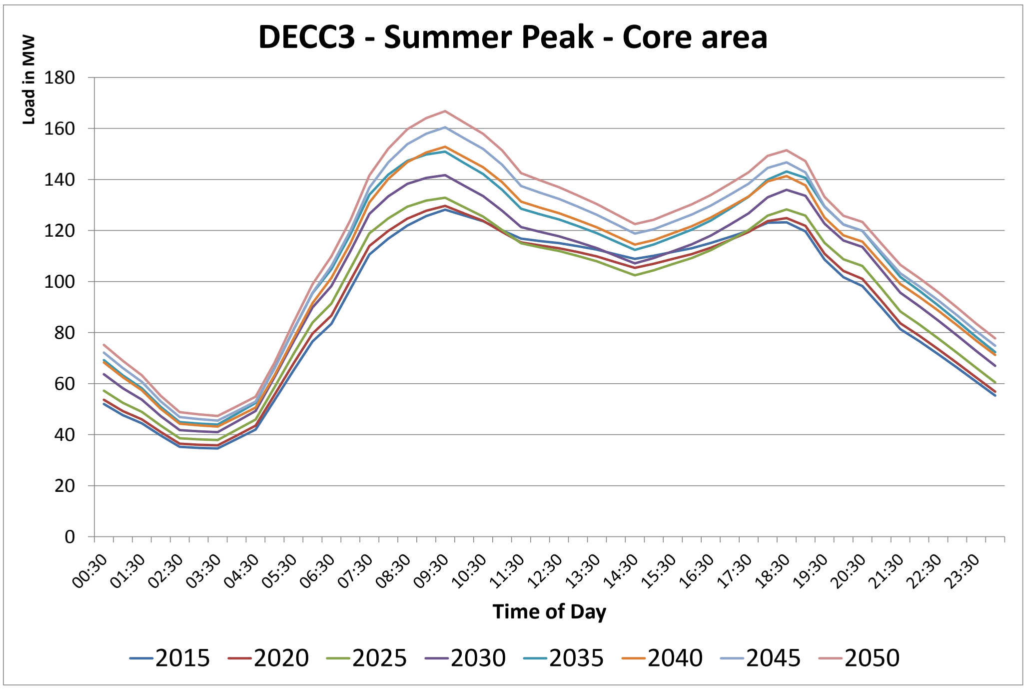
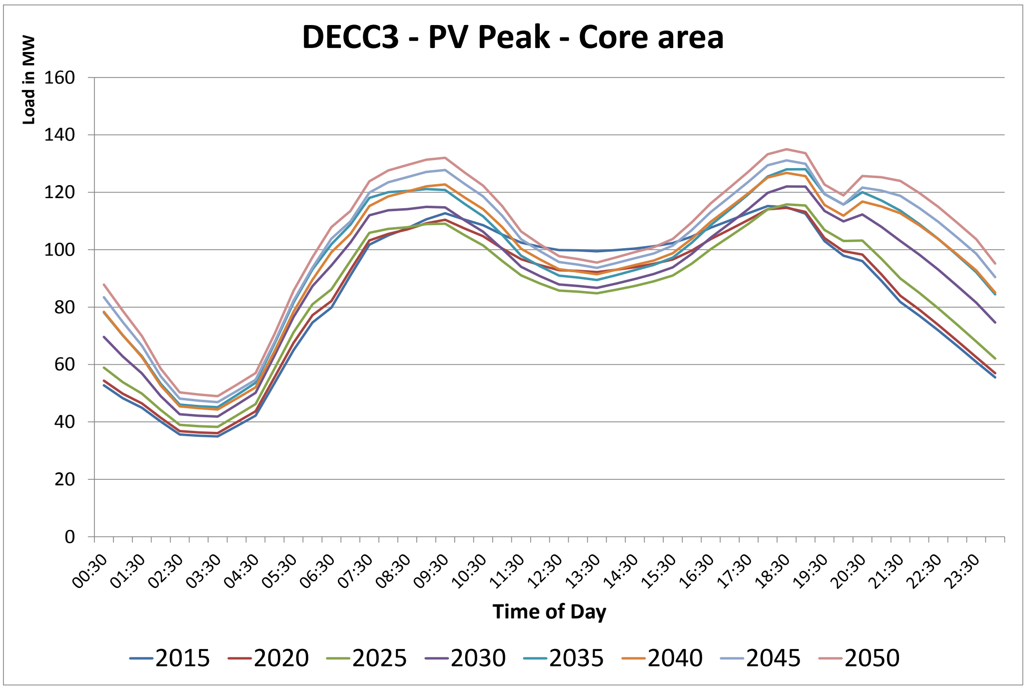
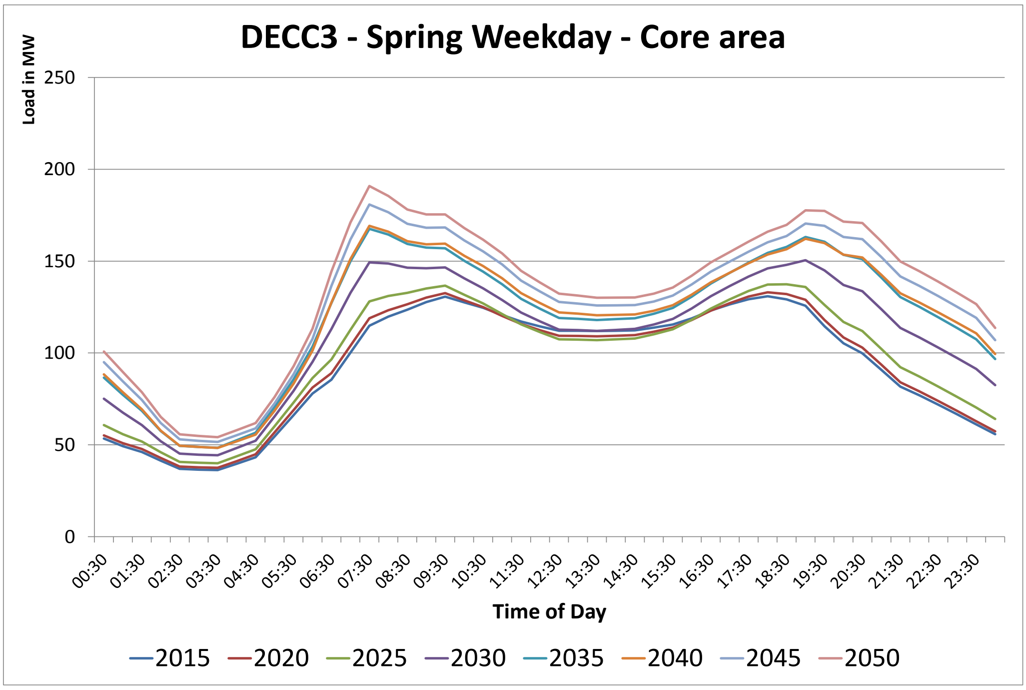
9.3 DECC3

DECC 3 has high values of uptake for EVs, heat pumps and PV. This makes it onerous in terms of peak load with the highest load for the Winter Peak day for 2050 being approximately double the value in 2015. As for DECC1 the overall load profile develops higher peaks for the morning and evening with the morning peak having the highest load. This increase in load is most significant for Winter Peak day and Winter Weekdays with relatively little increase for the PV Peak day.




DECC3 - Summer Peak - Core area
Load in MW
180
160
140
120
100
80
60
40
20
0
00:30 01:30 02:30 03:30 04:30 05:30 06:30 07:30 08:30 09:30 10:30 11:30 12:30 13:30 14:30 15:30 16:30 17:30 18:30 19:30 20:30 21:30 22:30 23:30
Time of Day
2015 2020 2025 2030 2035 2040 2045 2050


DECC3 - PV Peak - Core area
Load in MW
160
140
120
100
80
60
40
20
0
00:30 01:30 02:30 03:30 04:30 05:30 06:30 07:30 08:30 09:30 10:30 11:30 12:30 13:30 14:30 15:30 16:30 17:30 18:30 19:30 20:30 21:30 22:30 23:30
Time of Day
2015 2020 2025 2030 2035 2040 2045 2050


DECC3 - Spring Weekday - Core area
Load in MW
250
200
150
100
50
0
00:30
01:30
02:30
03:30
04:30
05:30
06:30
07:30
08:30
09:30
10:30
11:30
12:30
13:30
14:30
15:30
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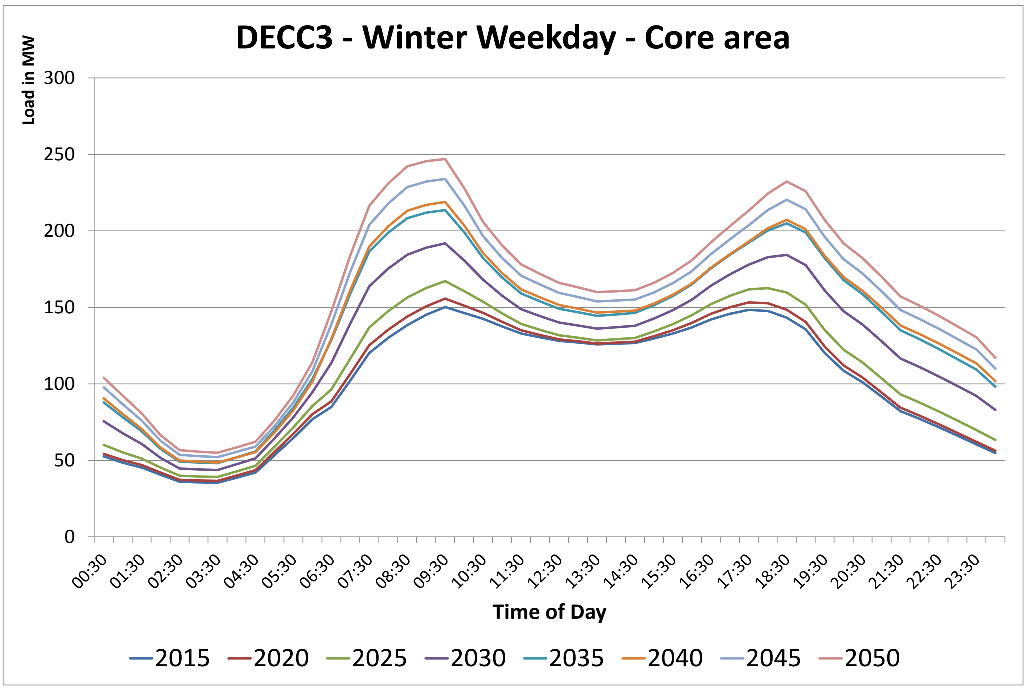
DECC3 - Winter Weekday - Core area
Load in MW
300
250
200
150
100
50
0
00:30
01:30
02:30
03:30
04:30
05:30
06:30
07:30
08:30
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16:30
17:30
18:30
19:30
20:30
21:30
22:30
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Time of Day
2015
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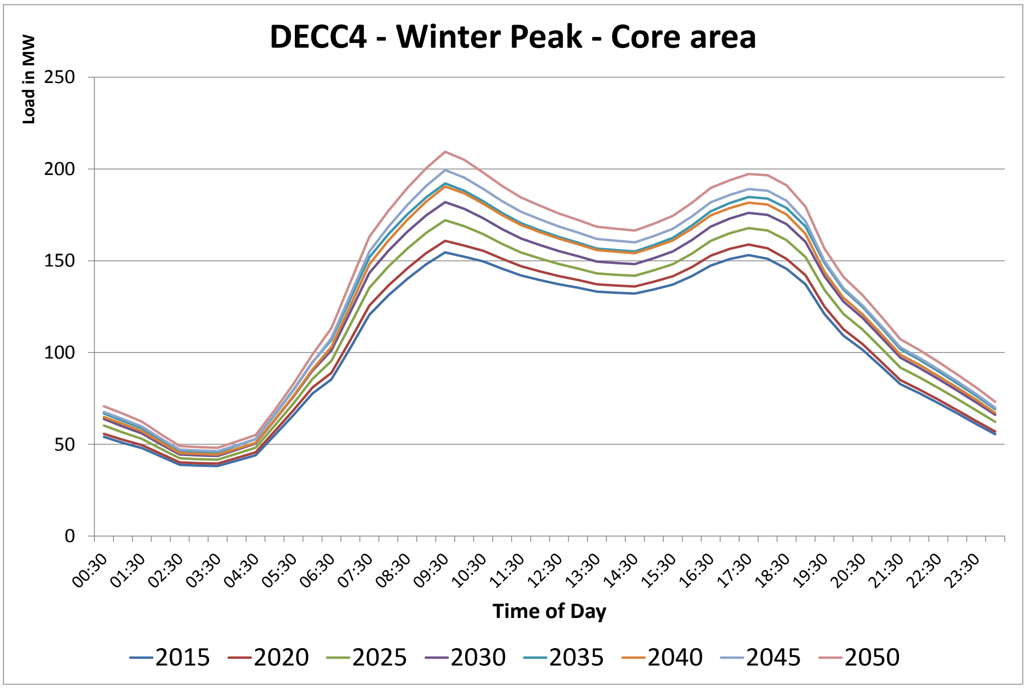
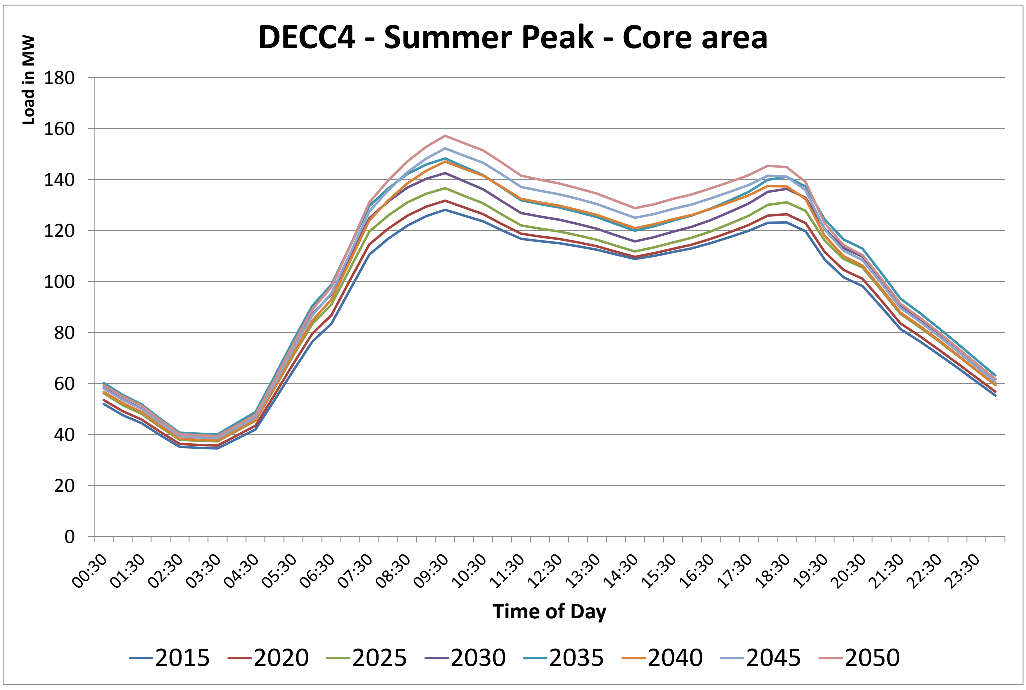
2050

9.4 DECC4

DECC4 assumes the lowest levels of low carbon technology with low levels of uptake for EVs, heat pumps and PV. As a result the increase in peak load is by approximately a third, rather than doubling as seen in DECC3 and DECC1. The degree to which the load profile shape changes is less, and while the peak time shifts to the morning for some days under this scenario the difference between morning and evening peaks is less pronounced.




DECC4 - Summer Peak - Core area
Load in MW
0
20
40
60
80
100
120
140
160
180
00:30
01:30
02:30
03:30
04:30
05:30
06:30
07:30
08:30
09:30
10:30
11:30
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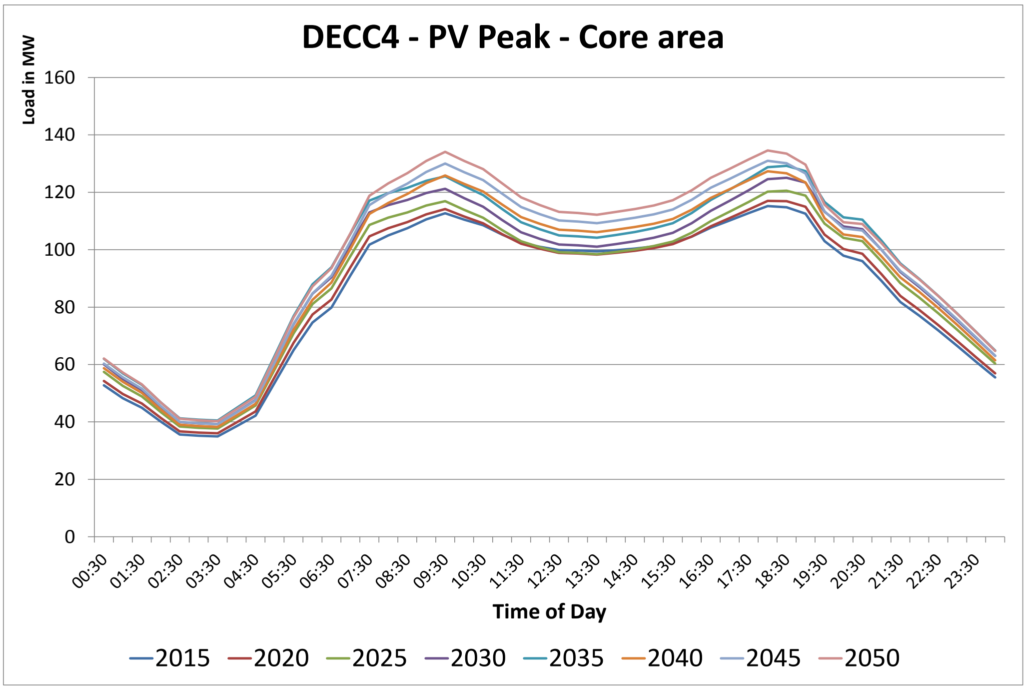
DECC4 - PV Peak - Core area
Load in MW
0
20
40
60
80
100
120
140
160
00:30
01:30
02:30
03:30
04:30
05:30
06:30
07:30
08:30
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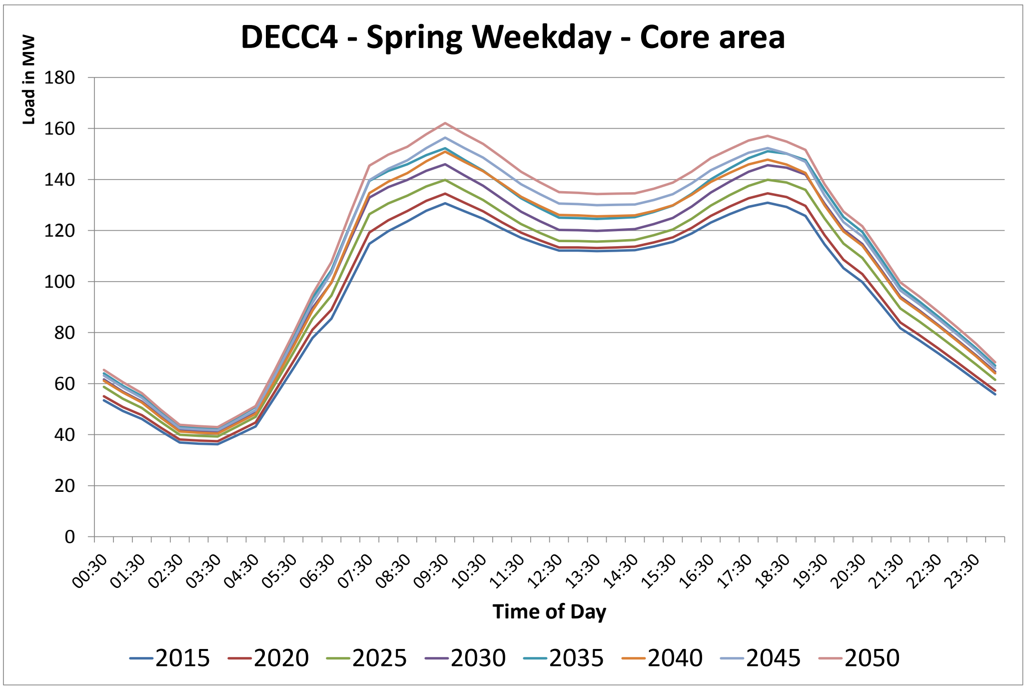
DECC4 - Spring Weekday - Core area
Load in MW
180
160
140
120
100
80
60
40
20
0
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02:30
03:30
04:30
05:30
06:30
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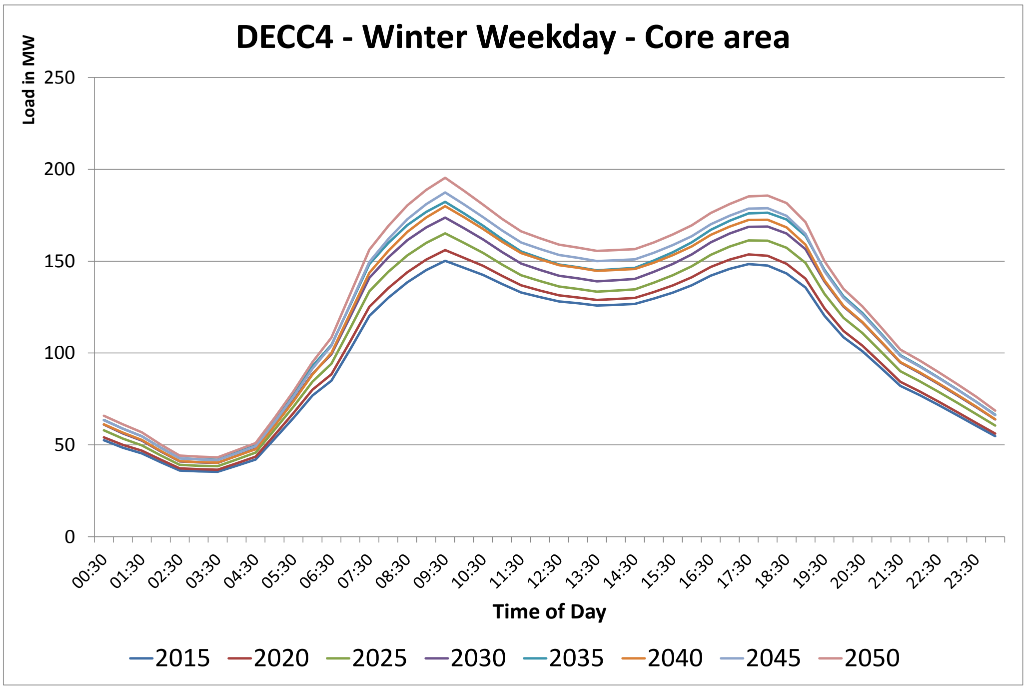
DECC4 - Winter Weekday - Core area
Load in MW
250
200
150
100
50
0
00:30
01:30
02:30
03:30
04:30
05:30
06:30
07:30
08:30
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Western Power Distribution (West Midlands) plc
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Western Power Distribution (South West) plc
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Western Power Distribution (South Wales) plc
Registered in Wales No. 2366985
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