The University of Manchester

Title: **Deliverable 3.5 “Creation of aggregated profiles with and without new loads and DER based on monitored data”**

Synopsis: This document presents the methodology adopted by the Low Voltage Network Solutions project to create aggregated load profiles with and without new special loads (e.g., electric vehicles, electric heat pumps)and generation (e.g., PV) based on monitored data (when available).

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Prepared For: Rita Shaw
Future Networks Engineer
Electricity North West Limited, UK

John Simpson
LCN Tier 1 Project Manager
Electricity North West Limited, UK

Dan Randles
Technology Development Manager
Electricity North West Limited, UK

Prepared By: Dr Tuba Gozel
The University of Manchester
Sackville Street, Manchester M13 9PL, UK

Alejandro Navarro
The University of Manchester
Sackville Street, Manchester M13 9PL, UK

Revised By: Dr Luis(Nando) Ochoa
The University of Manchester
Sackville Street, Manchester M13 9PL, UK

Contacts: Dr Luis(Nando) Ochoa
+44 (0)161 306 4819
luis.ochoa@manchester.ac.uk

Executive Summary

This report corresponds to Deliverable 3.5 "Creation of aggregated profiles with and without new loads and DER based on monitored data" part of the Low Carbon Network Fund Tier 1 project "LV Network Solutions" run by Electricity North West Limited (ENWL).

The aim of the LV Network Solutions project is to provide ENWL with greater understanding of the characteristics, behaviour, and future needs of their low voltage networks. This will be based on the analysis of data gathered by appropriate monitoring schemes to be deployed on hundreds of LV feeders and substations, and the assessment of the corresponding computer-based network models in current and future scenarios.

In particular, this report explainsavailable methodologies and tools to model the corresponding consumption/generation profiles of electric heat pumps (EHPs), electric vehicles (EVs) and photovoltaic (PV) systems. These time-series models (with minute to half hourly resolutions) can then be used to assess the time-dependant behaviour of LV networks considering future penetration scenarios.

The main findings are:

- **Load Profiles.** The CREST tool is limited to domestic customers. Although assumptions can be made to model domestic un-restricted and two-tariff customers, commercial or other types cannot be modelled.

  Diversified ENWL load profiles when aggregated do show a very realistic behaviour. However, they cannot be used to model feeders with only a few customers (e.g., less than 50). In addition, due to their half-hourly resolution, effects on voltages might also be underestimated.

  Allocated profiles should not be considered individually but as a set of profiles that produce voltages and currents that match the corresponding monitoring points. These profiles are more realistic than ENWL load profiles and the CREST tool.

  The Smart Grids Forum WS3 load profiles produced corresponding to dwelling types, ages can be used to model with different heating systems especially EHPs. These profiles, however, might be inadequate due to half hourly resolution and lack of customer type.

- **PV Profiles**. CREST tool can also model PV electricity generation considering the corresponding irradiance, day of year as well as panel areas, size and orientation. This tool, however, might differ in cloud transients from actual measurements.

  The weather station-based PV profilescan be created considering real cloud transients from eleven weather stations. The main drawback, however, is that these profiles assume the same features for a given area and does not take into account the actual orientation of PV.

- **EHP Profiles**. EHP profiles developed in this report are based on real heat requirements of different houses of England considering the outside temperature and also the real characteristics of EHP. The methodology has the advantage of scale the profiles to model different insulation level and also allows the creation of ground source heat pump profiles. It is important to highlight that after diversity maximum demand (ADMD) increases from 0.8 kW without EHP to about 3.0 kW with EHP (for Air Source Heat Pump ASHP installed in modern houses).

- **EV Profiles**. EV profiles developed in this report are based on real EV data considering connection time and event. Although hundreds of individual profiles create for only one type of EV (Nissan Leaf), the model can be updated to incorporate different brands and different type of batteries. It is important to highlight that the ADMD increases bigger than 200% with EV (from 0.8 kW to 1.8 kW).

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1 Introduction

As part of the transition towards a low carbon economy, Electricity North West Limited (ENWL), the Distribution Network Operator of the North West of England, is involved in different projects funded by the Low Carbon Network Fund. The University of Manchester is part of the Tier 1 project "LV Network Solutions".

The objective of this project is to provide ENWL with greater understanding of the characteristics, behaviour, and future needs of their LV networks. This will be based on the analysis of data gathered by appropriate monitoring schemes to be deployed on hundreds of LV feeders and substations, and the assessment of the corresponding computer-based network models in current and future scenarios.

In order to understand future needs of LV networks, it is important to create realistic load profiles with or without new loads such as; electric heat pumps (EHPs), electric vehicles (EVs) and photovoltaic (PV) generation profiles. This report presents available methodologies and tools to model the corresponding consumption/generation profiles of EHPs, EVs and PV systems. These time-series profiles (with minute to half hourly resolutions) will be used to assess the time-dependant behaviour of LV networks considering future penetration scenarios.

Load Profiles. The creation of load profiles is a very challenging task due to the uncertainties involving the behaviour of customer electrical consumption. This in turn depends on the number of customers, customer behaviour, type of day, season, weather conditions, etc. To create customer load profiles, three methodologies are proposed here: using the CREST tool, diversified ENWL load profiles and allocated load profiles based on monitoring data. In addition, comments are provided re the potential use of profiles produced by the Smart Grids Forum WS3. In this context, the following remarks can be made:

- The CREST tool creates computational profiles for residential loads based on the domestic behaviour of British costumers. It takes into account the number of people at home, the type of day, the month, and the use of the appliances and provides one minute resolution profiles. The profiles are randomly created based on a pre-defined set of characteristics.

- The CREST tool is, however, limited to domestic customers. Although assumptions can be made to model domestic un-restricted and two-tariff customers, commercial or other types cannot be modelled.

- Diversified ENWL load profiles are derived from half-hourly Elexon profiles of electricity usage for each of the eight profile classes during the last fiscal year (1st April 2012 – 31st March 2013). Although these profiles when aggregated do show a very realistic behaviour, they cannot be used to model feeders with only a few customers (e.g., less than 50). In addition, due to their half-hourly resolution, effects on voltages might also be underestimated.

- Allocated load profiles are produced by the load allocation technique presented in Deliverable 3.1. These profiles can be produced for different profile classes and with the same resolution as the monitoring data. However, allocated profiles should not be considered individually but as a set of profiles that produce voltages and currents that match the corresponding monitoring points. These profiles are more realistic than ENWL load profiles and the CREST tool.

- The Smart Grids Forum WS3 adopted in their studies half-hourly load profiles for various dwellings considering 2012 and 2050 behaviours. Dwellings are classified according to their types and ages considering different seasons. Although these profiles are inadequate due to resolution and lack of customer type, they enable to model with different heating systems especially EHPs for future LV network solutions.

PV Profiles. PV electricity generation is related to the panel area, size, efficiency, orientation and geographical location (sun irradiance). However, sun irradiance is a critical input to actually model the corresponding generation profile. In addition, passing clouds (or cloud transients) can also cause rapid variations in PV output. Two approaches for the creation of PV profiles are presented: using the CREST tool and using real sun radiation data. One available PV profile data from the Smart Grids Forum WS3 is also presented. Unity power factor is adopted for both methodologies. The following remarks can be made:

- The CREST tool is also capable of modelling small-scale PV systems for areas in the UK. In this tool, synthetic irradiance data for any given geographic location is generated at one minute resolution. PV electricity generation is modelled considering the corresponding irradiance, cloud transients, day of year as well as panel areas, size and orientation. The CREST tool can model realistic PV electricity generation with calculated the total radiation on PV panel. This computer-based modelling, however, might differ in cloud transients from actual measurements

- PV profiles from real sun radiation data can be created considering size of PV and real cloud transients with available data from eleven weather stations (one at The University of Manchester and ten at ENWL substations part of the IFI PV array monitoring project). This data allows creating more accurate PV profiles by selecting the nearest geographic location of the weather station. The main drawback, however, is that the weather station-based PV profiles assume the same features for a given area and does not take into account the actual orientation of PV panels.

EHP Profiles. The demand profile of an EHP depends on a number of factors: the characteristics of the dwelling itself (e.g., size, age, insulation, etc.), the EHP technology (e.g., air source/ground source, size, performance, control modes, etc.), the dwelling’s heating demand behaviour, ambient temperature, etc. The dwelling’s heating demand behaviour, perhaps the most complex element to model, is particularly affected by the settings used for the heating system to number of occupants, type of day (e.g., weekday/weekend), etc. To create EHP profiles, one methodology is proposed here:

- The methodology developed in this report allows the creation of hundreds of individual profiles for electric heat pumps. These profiles are based on real heat requirements (space heating and domestic hot water) of different houses of England, taking into account the outside temperature and also the real characteristics of EHP (manufacture operational data). This methodology presents the advantage of scale the profiles to model different insulation level and also allow the creation of ground source heat pump.

EV Profiles. The demand profile of an EV depends on a number of factors, including: EV characteristics (electric range, size of battery, etc.), driving habits (or daily mileage) and state of charge when ‘returning home’, timing of the charging, charging characteristics of the battery and consequently, type of day (e.g., weekday, weekend, etc.). One methodology for the creation of EV profiles is presented here:

- The methodology developed in this report allows the creation of hundreds of individual profiles for EVs. These profiles are based on real EV data; the histograms for the connection time and for the energy required in each connection event are taken into account. For simplicity, only one type of EV is considered (Nissan leaf). However, the model can be updated to incorporate different brands and different type of batteries.

2 Typical Load Profiles

The creation of load profiles is a very challenging task due to the uncertainties involving the behaviour of customer electrical consumption. This in turn depends on the number of customers, customer behaviour, type of day, season, weather conditions, etc. To create customer load profiles, three methodologies are analysed here: using the CREST tool, diversified ENWL load profiles and allocated load profiles based on monitoring data. In addition, comments are provided re the potential use of profiles produced by the Smart Grids Forum WS3.

The CREST tool produces profiles only for domestic customers (domestic un-restricted and two-tariff customers). Diversified ENWL load profiles are produced for eight different profile classes derived from half-hourly Elexon profiles for the last fiscal years. Allocated load profiles are produced from LV network monitoring data and considering network topology and customer type (adapting the diversified ENWL load profiles). The WS3 load profiles are half-hourly patterns particularly considering the dwelling type.

2.1.1 CREST Tool

The CREST tool is a freely available MS Excel VBA-based tool developed by Loughborough University CREST [1] . This tool creates computational profiles for residential loads based on the domestic behaviour of British electricity consumers [2]. It takes into account the number of people at home, the type of day, the month, and the use of the appliances. It provides one minute resolution profiles, indicating which appliance is on and how much power it is using. The profiles are randomly created based on a pre-defined set of characteristics.

Using the CREST tool, 250 load profiles were produced adopting a random number of people per household and random allocation of appliances (both options provided by the tool). Figure 1 shows four residential profiles (load1 to load4 – based on right axis) considering a weekday of April. The corresponding diversified demand (or average demand) of the 250 profiles is also shown in the figure – based on left axis. It can be seen that in average they behave as the typically expected domestic un-restricted customers.

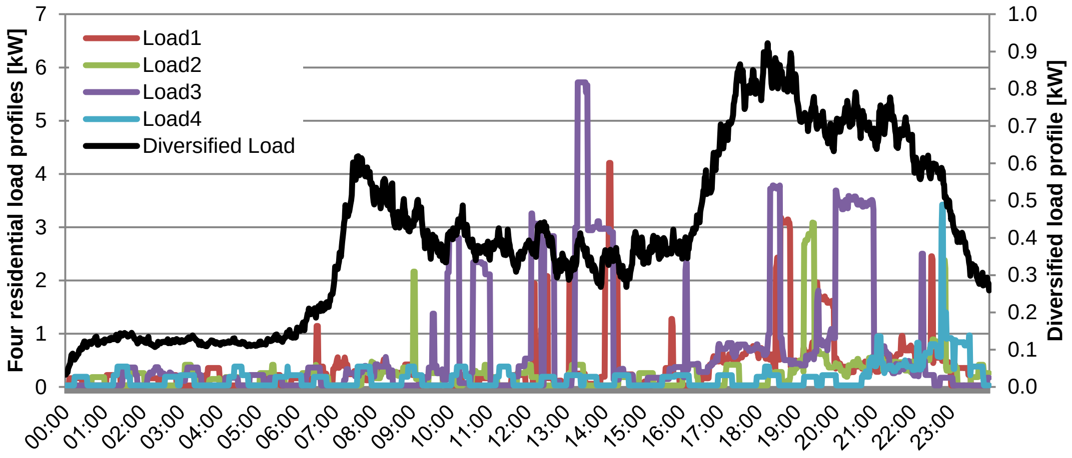

Figure 1: Daily load profiles by CREST tool

In order to validate the quality of the load profiles produced by the CREST Tool an LV feeder with 51 domestic un-restricted customers is considered (weekday, April). Figure 2 shows the active power per phase throughout the day for both simulation and the corresponding monitoring data (1st April, 2013).

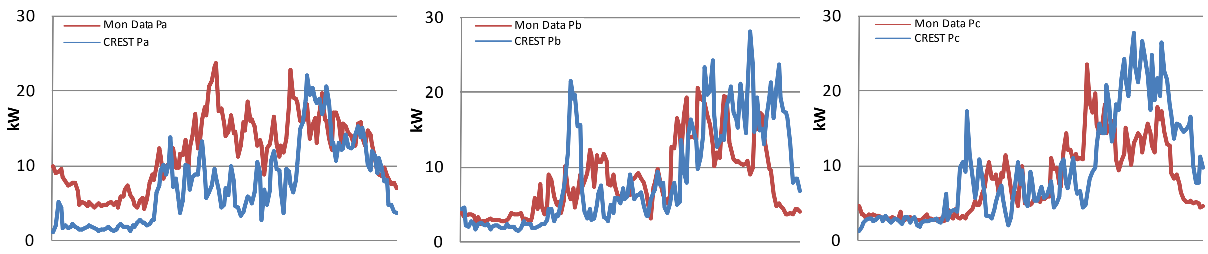

Figure 2: CREST Tool vs. Monitoring Data, LV feeder with 51 MPANs

It can clearly be seen that the CREST patterns of active power per phase are different from each other. This is mainly due to the random production of individual profiles but might also be due to the phase connection adopted in the network model. Although all patterns are different the corresponding behaviours show a good match during some periods (i.e., early morning, mid day), especially for phases B and C.

To quantify this match, the total energy consumption is calculated and compared. The CREST tool-based profiles consume 7.3% more energy than the real feeder – which can be said is a good match.

The CREST tool is, however, limited to domestic customers. Although assumptions can be made to model domestic un-restricted and two-tariff customers, commercial or other types cannot be modelled.

2.1.2 Diversified ENWL Load Profiles

Diversified ENWL load profiles are derived from half-hourly Elexon profiles of electricity usage for each of the eight profile classes. This is produced every year for the last fiscal year. Profile classes 1 and 2 are for domestic premises and 3 to 8 are for non-domestic premises. This is detailed below.

- Profile Class 1: Domestic Unrestricted Customers.
- Profile Class 2: Domestic Economy 7 (Two Rate and Off Peak) Customers.
- Profile Class 3: Non-Domestic Unrestricted Customers.
- Profile Class 4: Non-Domestic Economy 7 (Two Rate and Off Peak) Customers.
- Profile Class 5: Non-Domestic Maximum Demand (MD) Customers with a Peak Load Factor (LF) of less than 20%.
- Profile Class 6: Non-Domestic Maximum Demand Customers with a Peak Load Factor between 20% and 30%.
- Profile Class 7: Non-Domestic Maximum Demand Customers with a Peak Load Factor between 30% and 40%.
- Profile Class 8: Non-Domestic Maximum Demand Customers with a Peak Load Factor over 40%.

Figure 3 shows diversified ENWL load profiles for domestic premises on 1stApril 2012. Figure 4 shows diversified load profiles of non-domestic premises.

As an example of the comparison between the diversified ENWL load profiles and monitoring data, the previous LV feeder with 51 is considered. ENWL load profiles on 29th March 2013 are taken into account as the closest weekday to 1st April 2013 (monitoring data). Figure 5Figure 2 shows the active power per phase throughout the day for both simulation and the corresponding monitoring data.

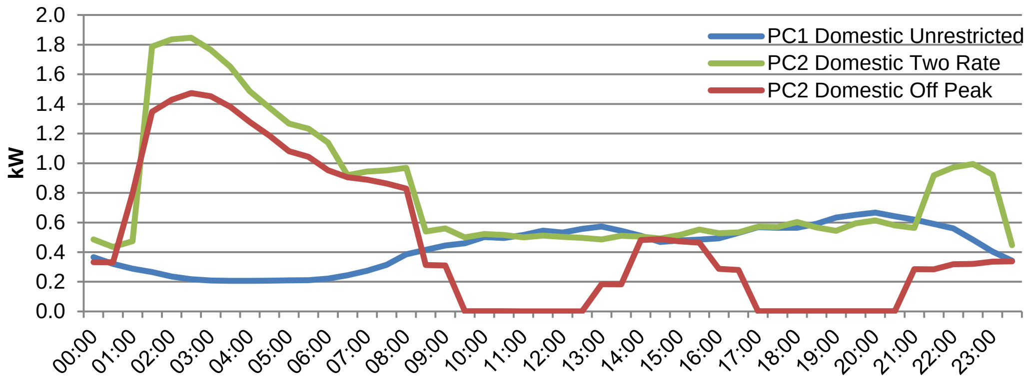

Figure 3: Daily load profiles for domestic premises by ENWL Elexon

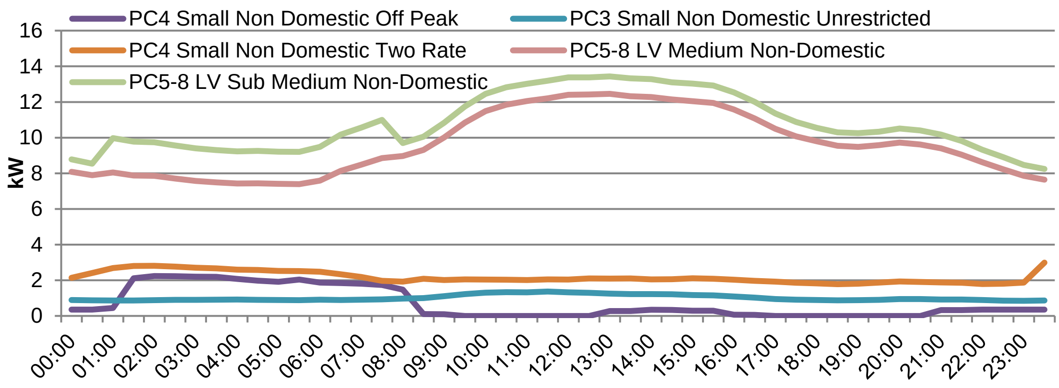

Figure 4: Daily load profiles for non-domestic premises by ENWL Elexon

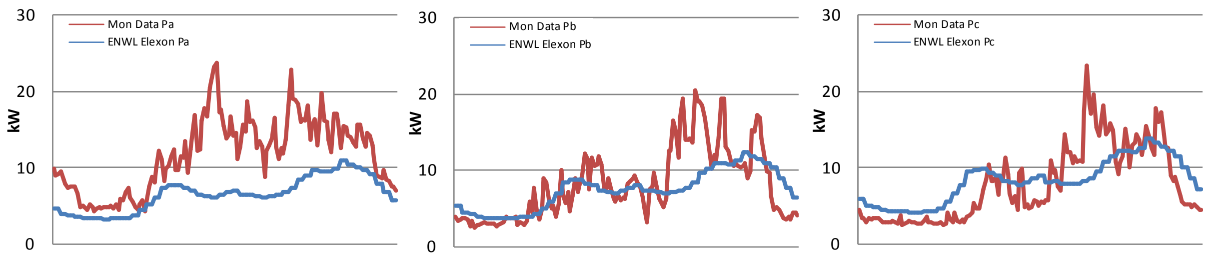

Figure 5: ENWL Profiles vs. Monitoring Data, LV feeder with 51 MPANs

The diversified ENWL-based patterns of active power per phase are very similar given that only PC1 customers were modelled. The match per phase is however not very good, with a significant discrepancy in phase A. Indeed, the Elexon-based total energy consumption is 20.52% less than that monitored. In this particular case the diversified ENWL load profiles failed to provide a close match. Although the phase connection of the network model might be playing an important role, clearly the CREST tool was more successful.

Although these profiles when aggregated do show a very realistic behaviour, they cannot be used to model feeders with only a few customers (e.g., less than 50) [3]. In addition, due to their half-hourly resolution, effects on voltages might also be underestimated [4].

2.1.3 Allocated Load Profiles

As described in Deliverable 3.1, by using a load allocation technique it is possible to 'disaggregate' monitored data for each moment in time (according to the sampling rate) in a way that customers (i.e., MPANs) are allocated loads that, as a whole, produce the same voltages and currents recorded by the monitors [5].

The load allocation technique is capable of estimating the unknown individual demands (kW and kVAr) of customers based on limited monitored points. This technique requires three sets of data: network data, currents, voltages at the head of the feeder (and other monitoring points if available), and approximate values of demand for each customer. Here, these approximate demand values are obtained from Elexon's half-hourly demand profiles. Average consumptions per profile class is used on the same time and date (albeit from a previous year) as the monitored data.

Figure 6 shows some of the allocated load profiles of Greenside Lane Five Ways on 14th January 2013. The load allocation technique is able to produce (per phase) a high granularity profile class for each of the adopted diversified ENWL load profiles.

It is important to highlight that allocated profiles should not be considered individually but as a set of profiles that produce voltages and currents that match the corresponding monitoring points. These profiles are more realistic than ENWL load profiles and the CREST tool.

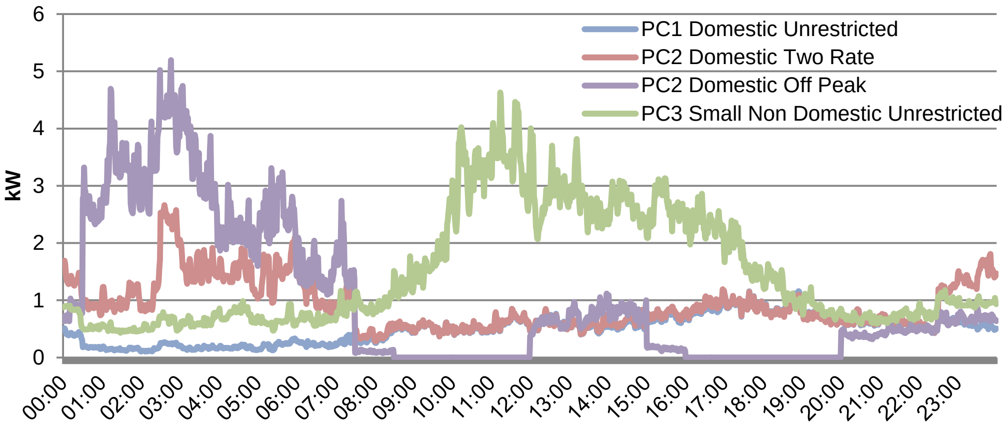

Figure 6: Daily load profiles from LV network monitoring data

2.1.4 WS3 Load Profiles

The Smart Grids Forum WS3 adopted in their studies half-hourly diversified load profiles for various dwellings considering 2012 and 2050 behaviours. Dwellings are classified according to their types such as detached, semi-detached, terraced and flat corresponding to their ages; very old, old and modern (Figure 7). Two different seasons are considered: summer and winter (Figure 8).

From Figure 8, it can be seen that load profiles are different due to dwelling type and age. For example, the peak demand of a very old detached dwelling is 1.62kW in the summer of 2012 whereas for a modern flat is less than a third (0.51kW). In terms of seasonality, it can also be seen that the peak demand of a very old detached dwelling adds to 1.98kW in the winter of 2012. However, the peak demand of a modern flat reaches only 0.58kW (11% increase).

It is important to highlight that WS3 diversified load profiles are the only available profiles produced considering dwelling types. Even though these profiles are limited due to resolution (i.e., half-hourly only) and lack of customer type specification (i.e., profile class), they are useful for modelling heating needs (e.g., for EHPs).

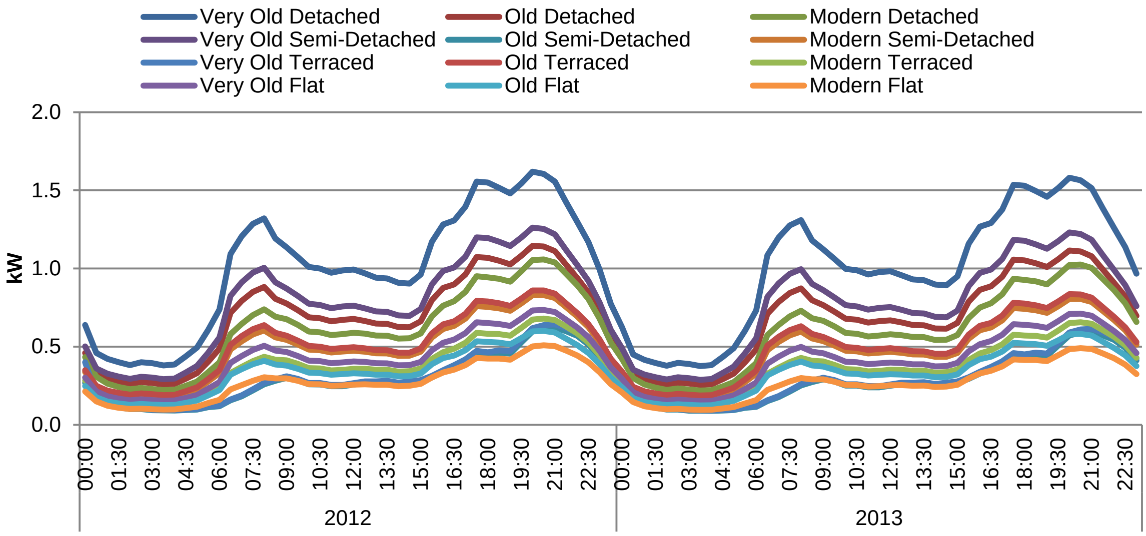

Figure 7: Smart Grids Forum load profiles of dwelling types for summer

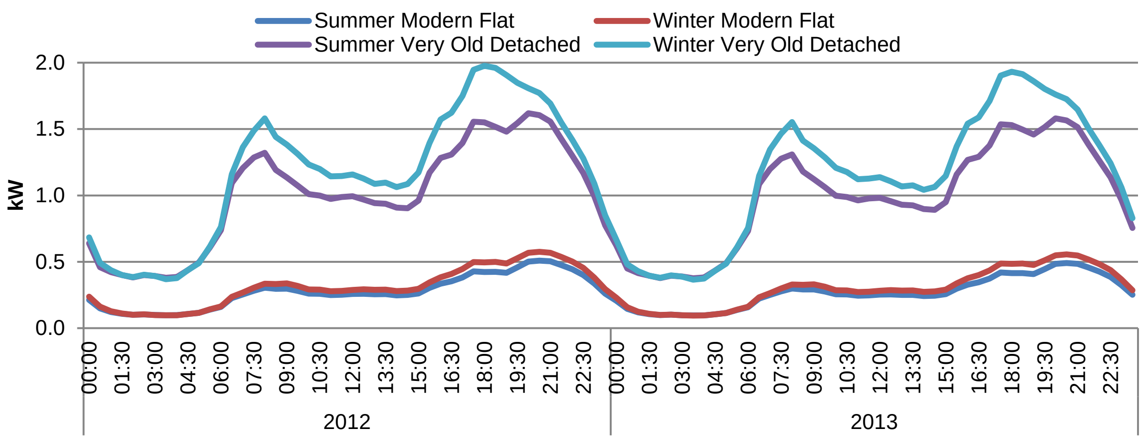

Figure 8: Smart Grids Forum load profiles of dwelling types for summer and winter

2.2 Summary

Three methodologies for the creation of customer load profiles were analysed here: using the CREST (Centre for Renewable Energy Systems Technology) tool, diversified ENWL load profiles and allocated load profiles based on monitoring data. In addition, the potential use of profiles produced by the Smart Grids Forum WS3 was discussed. The following remarks can be made:

The CREST tool creates computational profiles for residential loads based on the domestic behaviour of British costumers. It takes into account the number of people at home, the type of day, the month, and the use of the appliances and provides one minute resolution profiles. The profiles are randomly created based on a pre-defined set of characteristics. The CREST tool is, however, limited to domestic customers. Although assumptions can be made to model domestic un-restricted and two-tariff customers, commercial or other types cannot be modelled.

Diversified ENWL load profiles are derived from half-hourly Elexon profiles of electricity usage for each of the eight profile classes during the last fiscal year. Although these profiles when aggregated do show a very realistic behaviour, they cannot be used to model feeders with only a few customers (e.g., less than 50). In addition, due to their half-hourly resolution, effects on voltages might also be underestimated [4].

Allocated load profiles are produced by the load allocation technique presented in Deliverable 3.1. These profiles can be produced for different profile classes and with the same resolution as the monitoring data. However, allocated profiles should not be considered individually but as a set of profiles that produce voltages and currents that match the corresponding monitoring points. These profiles are more realistic than ENWL load profiles and the CREST tool.

The Smart Grids Forum WS3 adopted in their studies half-hourly diversified load profiles for various dwellings considering 2012 and 2050 behaviours. Dwellings are classified according to their types and ages considering seasonality. Although these profiles are inadequate due to their resolution and lack of customer type specification, they enable the modelling of heating needs for EHPs in future LV networks.

3 Creation of PV Profiles

The PV electricity generation is related to the panel area, size, efficiency, orientation and geographical location (sun irradiance). However, sun irradiance is a critical input to actually model the corresponding generation profile. In addition, passing clouds (or cloud transients) can also cause rapid variations in PV output.

Two approaches for the creation of PV profiles are presented: using the CREST tool and using real sun radiation data. One available PV profile data from the Smart Grids Forum WS3 is also presented. Unity power factor is adopted for both methodologies.

3.1.1 CREST Tool

The CREST tool is also capable of modelling small-scale PV systems for areas in the UK. In this tool, synthetic irradiance data for any given geographic location is generated at one minute resolution. PV electricity generation is modelled considering the corresponding irradiance, day of year as well as panel areas, size and orientation. This tool also considers cloud transients (but based on the Loughborough University geographic area).

Using the CREST tool, the estimated PV generation profile for 1kWp PV system located in Sackville Street, Manchester on 11th January was produced and is shown in Figure 9. The clear sky beam radiation (red line) and the total radiation on the panel (green line) are calculated by the tool adopting a panel area of 7.28m^2 and a slope of 40°, south facing. The PV generation profile (blue line) was calculated considering 10% system efficiency and a random clearness index.

The CREST tool can model realistic PV electricity generation considering a calculated total radiation. This computer-based modelling, however, might differ in terms of cloud transients from actual measurements.

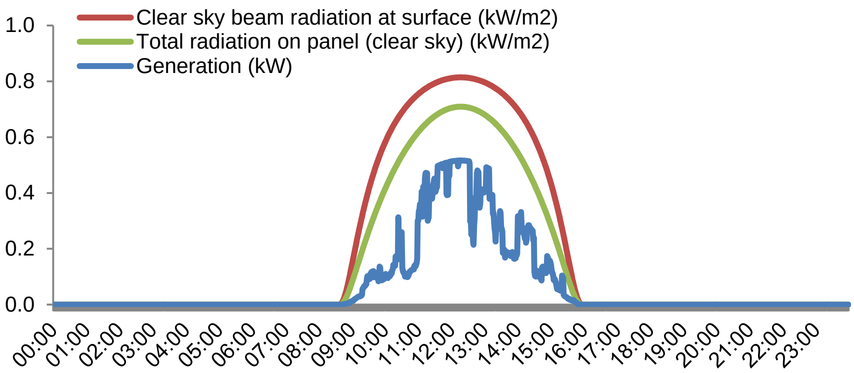

Figure 9: Daily PV profile by the CREST tool

3.1.2 The weather station-based PV Profiles

The University has access to two databases containing real sun radiation data. One is from the Whitworth Meteorological Observatory at The University of Manchester which has one weather station on top of Sackville Street Building, Manchester. The other database aggregates measurements from 10weather stations located at 10 ENWL substations (all also monitored by the IFI PV array monitoring project).

The PV generation profile is determined considering global sun radiation data and parameters related to efficiency. The PV output at time *t* is calculated (approximately) by equation (1).

$$PV(t) = SunRad(t)*PkW*7*0.1*0.95 \qquad (1)$$

Where, SunRad(*t*) is the global sun radiation data (kW/m^2) at *t* time, PkW is the installed capacity (kW), 7 corresponds to the area for a 1kW PV installation (m^2/kW), 0.1 is the adopted PV efficiency, and 0.95 is the adopted inverter efficiency.

A weather station-based PV profile for 1kWp is shown in Figure 10. This profile was produced using data from The University of Manchester for 11th January 2013 and equation (1). The PV generation profile (green line) is calculated from the global sun radiation (red line) without considering the total radiation on panel.

The main drawback, however, is that the weather station-based PV profiles assume the same features for a given area and does not take into account the actual orientation of the PV array, neither the corresponding locational effects of diffuse and reflected radiation.

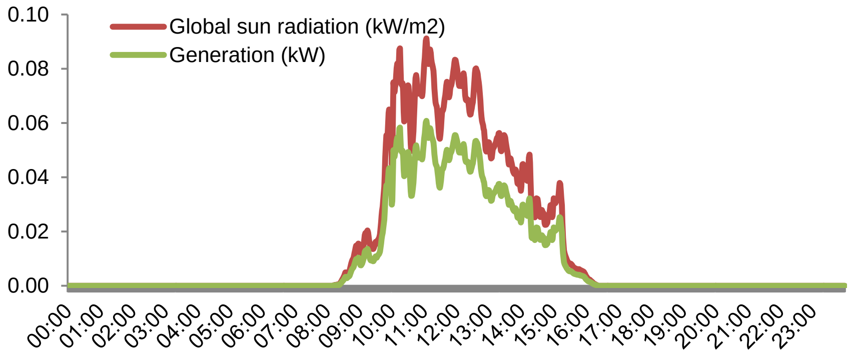

Figure 10: Daily PV profile by real sun radiation

3.1.3 WS3 PV Profiles

Smart Grids Forum PV profiles are half hourly estimated patterns between 2012 and 2050. These load profiles are given for winter peak, average of summer and winter without considering location, cloud transients.

Figure 11 shows WS3 diversified PV profiles for different seasons between 2012 and 2013. The peak generation is 0.72kW in the summer of 2012 and also 2013. This decreases to 0.17kW and 0.03kW in the winter and the winter peak, respectively. These profiles are for clear sky and same for all years.

WS3 PV diversified profiles are only for clear sky and are limited to the best and worst PV output. However, cloud transients should be catered for to some extent. Consequently, the use of these profiles in realistic LV network models is very limited.

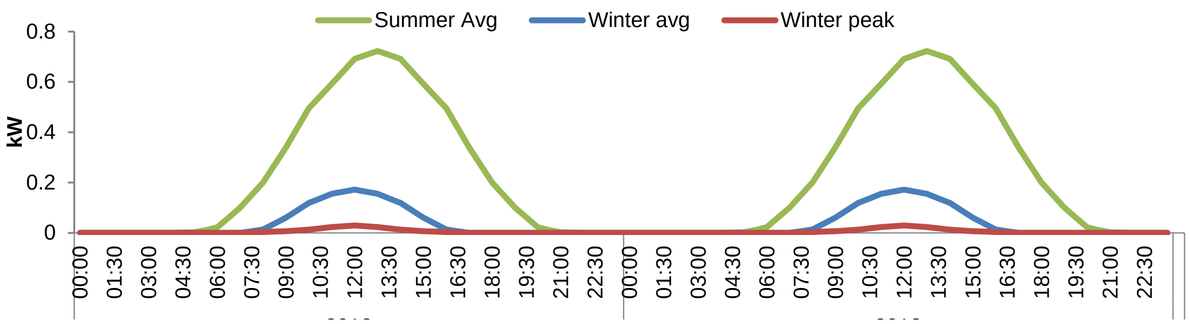

Figure 11: PV profiles from Smart Grids Forum

3.2 Summary

Two approaches for the creation of PV profiles were presented: using the CREST tool and using real sun radiation data. One available PV profile data from the Smart Grids Forum WS3 was also presented. Unity power factor is adopted for both methodologies.

The CREST tool is also capable of modelling small-scale PV systems for areas in the UK. In this tool, synthetic irradiance data for any given geographic location is generated at one minute resolution. PV electricity generation is modelled considering the corresponding irradiance, cloud transients, day of year as well as panel areas, size and orientation. This computer-based modelling, however, might in some cases differ significantly from actual measurements.

PV profiles from real sun radiation data can be created considering real cloud transients, size and efficiency of PV with available data from eleven weather stations (one at The University of Manchester and ten at ENWL substations part of the LV Network Solutions project). This data allows creating more accurate PV profiles by selecting the nearest geographic location of the weather station. The main drawback, however, is that the weather station-based PV profiles assume the same features for a given area and does not take into account the actual orientation of PV, neither the locational effects of diffuse and reflected radiation.

The Smart Grids Forum WS3 PV profiles are half-hourly estimated patterns between 2012 and 2050. These load profiles are given for winter peak, average of summer and winter without considering location and cloud transients. These profiles are only given as best and worst case scenarios. Consequently, their use in realistic LV network models is very limited.

4 Creation of Electric Heat Pump Profiles

The Electric Heat Pump (EHP) is a machine able to extract heat from a low temperature source (i.e., outside home) and move it to a high temperature place (i.e., inside home), providing the central heating and the hot water demand required for one building. These requirements for a single house can be totally or partially satisfied by an EHP. In the case of very cold days the EHP is supported by either an electric auxiliary heater or a gas boiler. The profiles created in this section were developed with the co-supervision of Dr. Pierluigi Mancarella and they belong to a paper recently submitted [6].

4.1 Input: Heat Profile Data

Real load data for both electricity and heat consumption taken from a Carbon Trust Report (database) for micro-cogeneration systems [7] have been considered in this section, this data provides the consumption for different types of houses with 5-minute resolution. The electricity data in this data base is only used to validate the heat profiles. From the complete set of data, specific information has been selected for "cold" (and "very cold") winter days and sixteen houses in central England areas so as to properly take into account the coincidence factor and therefore diversity of the thermal load in a given area under harsh conditions. In order to create further diversity, a larger set of electricity and heat profiles has been generated by randomly shifting the original profiles by 5 to 30 minutes backward and forward.

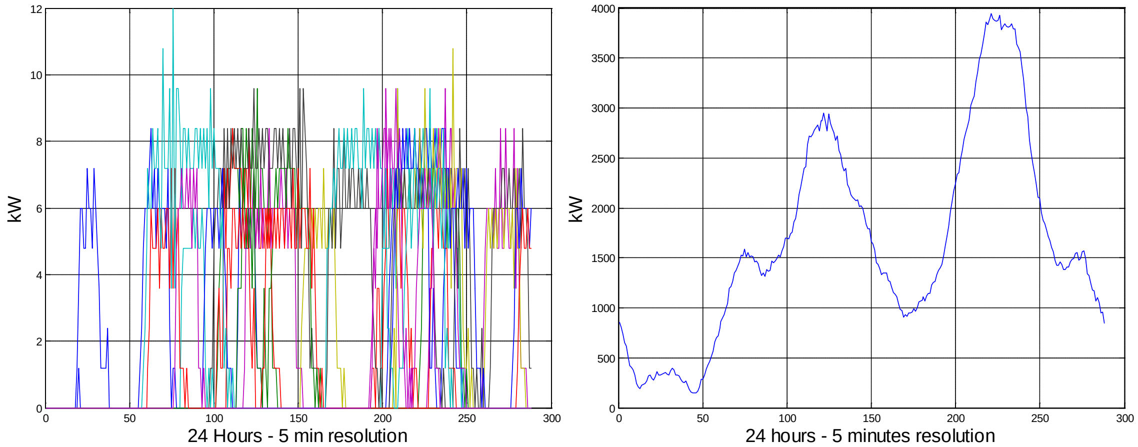

Figure 12: Individual (left) and aggregated (right) thermal load profiles

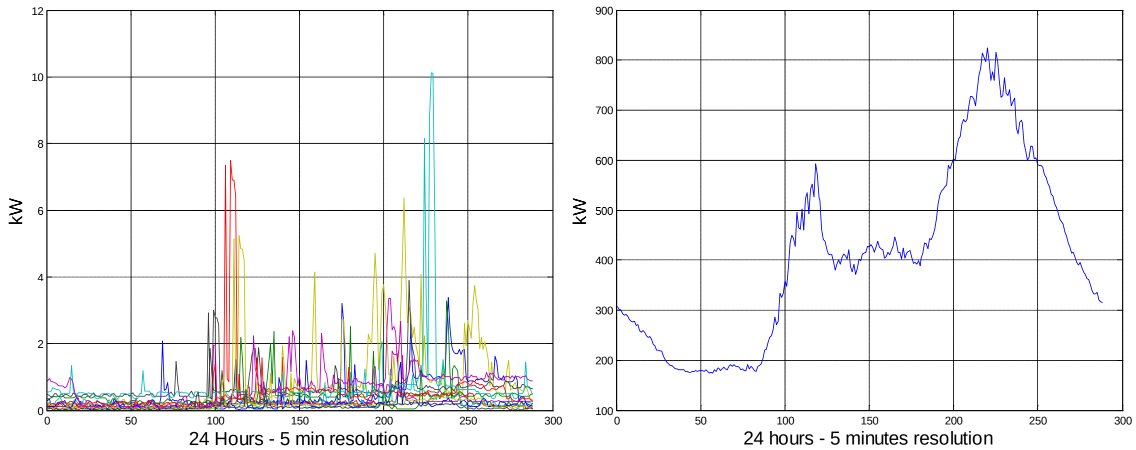

Figure 13: Individual (left) and aggregated (right) electricity load profiles

Examples of individual heating profiles and diversified heating profiles for 1000 customers are shown in Figure 12, while examples of 'typical' individual electricity profiles and diversified profiles for 1000 customers are shown in Figure 13. The diversified profiles obtained with this approach is consistent with typical electricity profiles [8], and the after diversity heat profiles are consistent with the ones available from other studies [9].

4.2 Creation of EHP profiles

The heat capacity and the relevant electricity consumption curves are taken from manufacturers' catalogues, i.e., [10] and [11], and fitted through linear models to represent their dependence on the source temperature and of the delivery temperature (typically air or water at different temperatures, depending on the house distribution system). Moreover, an auxiliary heater is assumed to be available with the EHP in order to increase the thermal capacity under harsh conditions. In this report, the EHP has been designed to cover 80% of the peak thermal load on the coldest day, as indicated by manufacturer's recommendations [11]. The final EHP size is chosen among the three feasible units considered in the analysis (Table 1) for air source heat pumps. The remaining capacity for space heating and DHW (domestic hot water) is covered by the auxiliary heater (AH) if this is needed.

Table 1: Main characteristics of the EHP/AH used

	EHP		
Nominal thermal capacity at 55˚C output [kW] and 0˚C outdoor ambient temperature	2.97	5.63	7.86
Nominal electrical consumption at 55 ˚C output and 0˚C outdoor ambient temperature	1.54	2.93	3.98
Auxiliary heaters capacity [kW]	2x3		

The traditional operation of EHP is an on-off process, where the length of each period depends on the heat requirements and the temperature conditions (outside and inside). In [12], a minimum cycling period of 6 minutes per hour is recommended. In the same report, different cycling periods are observed for different ambient temperatures. For instance, a cycling period of 11 minutes is observed at 5˚C and a cycling period of 42 minutes is measured at -4˚C. To be consistent with the real EHP operation, the on-off operation is simulated in this report by introducing different cycling period according to different heat requirements.

The steps to create individual electric heat pump profiles from each heat profile are:

1. Identification of the heating periods: the number of periods, the length of each of them, and the relevant energy are identified. For instance, in Figure 14, it is possible to observe two well defined heating periods.

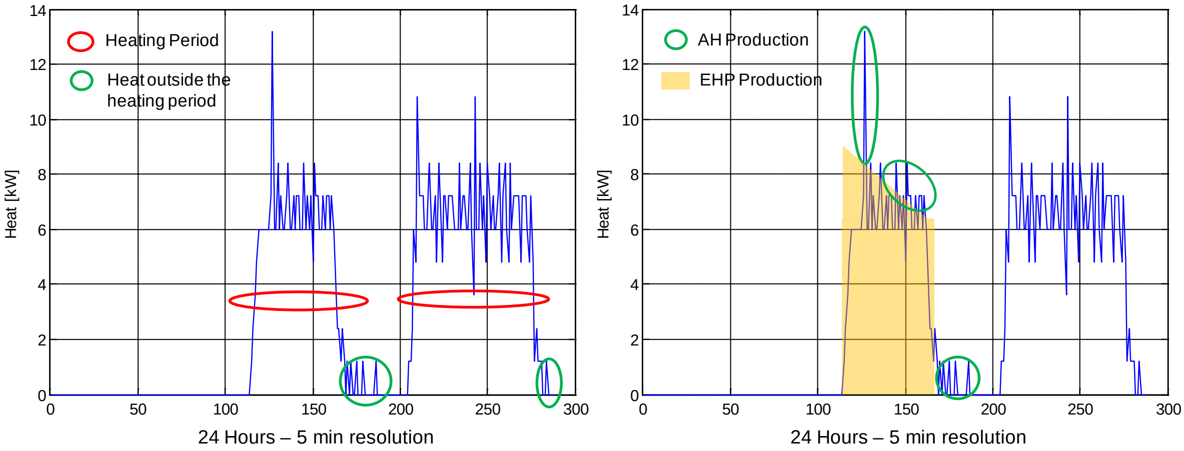

Figure 14: Example of Heating periods and auxiliary heater operation for heating period 1

2. Identification of the auxiliary heater operation (AH):

    a. Coverage of small heat requirement outside the main heating periods: these relatively small energy requirements will be supplied by the auxiliary heater since they represent a sporadic and small amount of energy consumption (likely related to maintain the required temperature for the domestic water supply). This type of consumption is highlighted in Figure 14.

    b. AH operation inside the main heating periods: to capture the operation of auxiliary heater either for harsh ambient conditions or for large unexpected heat consumption (e.g., large domestic hot water drawn-off) the auxiliary heater production should be extracted before modelling the EHP cycling operation (step 3). In this way, it is possible to avoid the elimination of the unexpected AH operation by increasing the EHP cycling period. Hence, for each time step (5 minutes) the plausible EHP production (e.g., yellow region in Figure 14 – right side) is compared with the thermal demand (e.g., blue line in Figure 14), and if the EHP production is lower, the AH makes up for the remaining heat requirement. Therefore, the heat to be supplied by the EHP cycling operation in each heating period is the difference between the heat demand and the AH production.

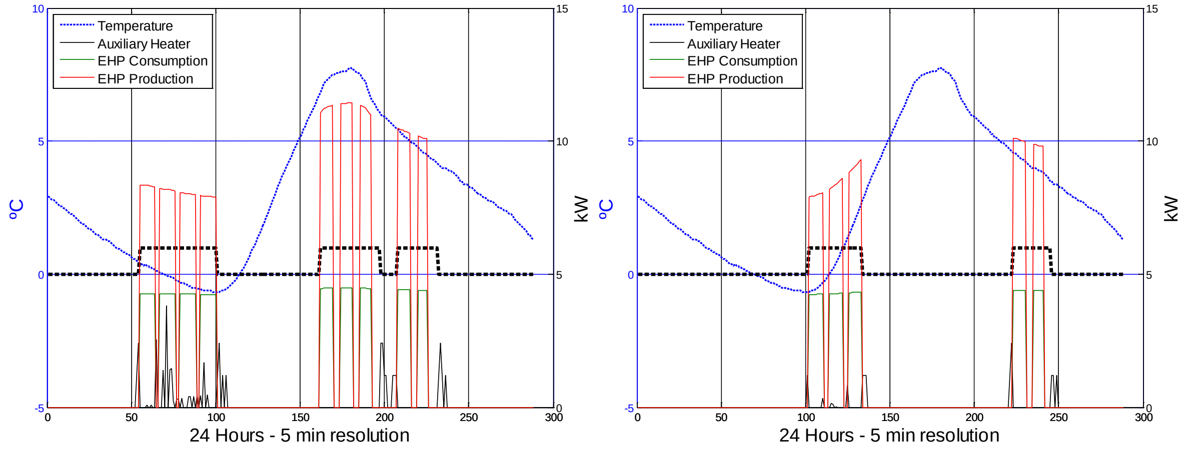

Figure 15: Example of EHP and auxiliary heater profiles for two different houses

3. EHP cycling: the total amount of heat is determined for each heating period (dotted black line in Figure 15). Starting with a minimum EHP cycling period of 10 minutes per hour (consistent with the suggested minimum cycle duration of 6 minutes and considering the 5 minutes resolution data) and taking into account the outside temperature (changing every 5 minutes), the EHP heat production and consumption is determined for each EHP cycle. If the heat production is lower than the energy requirement in the heating period the EHP cycling period is increasing by 5 minutes. This process is repeated until the EHP production is matched with the heat requirement for each particular heating period. Hence, the cycling period will be shorter for lower heat requirements and longer for higher heat requirements (Figure 15).

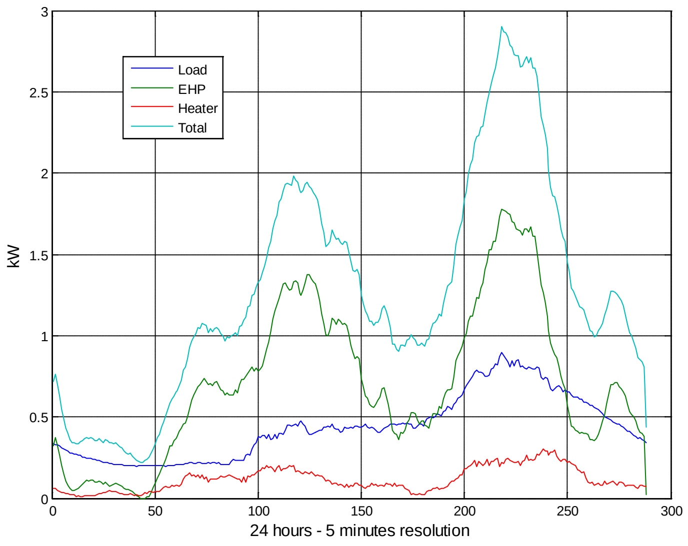

Figure 16: Diversified profiles for 1000 houses

An example of the operational load patterns is shown in Figure 15 for two different houses, while the diversified aggregated load pattern for 1000 houses equipped with EHP and auxiliary heaters is shown in Figure 16. The variation on the heat production output levels in Figure 15 is determined by the dependence of the heat output on the ambient temperature as from manufacturers' performance maps. Hence, it is possible to see how the EHP production increases as the temperature increases. Also, it is possible to observe that EHP on-period is longer for the lower temperatures.

4.3 WS3 EHP profiles

The Smart Grids Forum Work Stream 3 also provides half-hourly diversified profiles for the period 2012 and 2050. However, the profiles are exactly the same for all the years forecasted. The only difference is presented between the classification "winter average" and "winter peak" as can be observed in Figure 17. Both cases present a similar after diversity maximum demand equal to 3kW. However, the "winter case" (which resembles an economy-7 customer) has the peak demand during the night time and the "winter peak" profile has the peak around 7 AM and also a significant afternoon peak around 18:00 PM. As expected, the energy consumed in the winter peak profile is bigger than the winter average profile. The firs one consumes 43.9 kWh/day and second one 34.6 kWh/day.

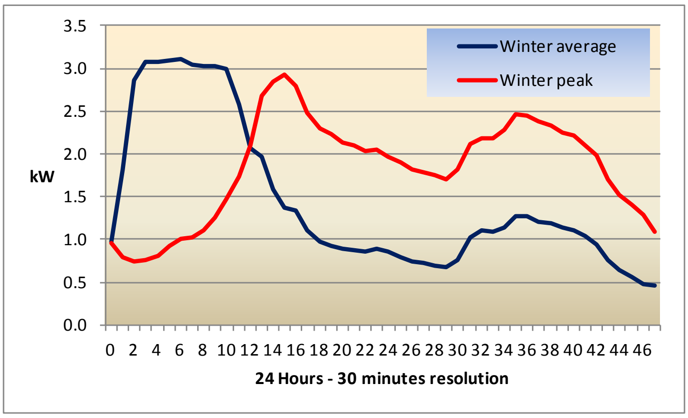

Figure 17: WS3 - EHP profiles

By comparing the WS3 profiles with the profiles generated in section 4.2, it is possible to appreciate that the winter peak profile is closer to the diversified heat profile produced from the real data (Figure 12) and therefore closer to the profiles generated in this report. The main difference is the peak demand, which is smaller in our model 2 kW (1.7 kW EHP + 0.3 Auxiliary Heater - Figure 16) against 3 kW. However, the data collected from the trial corresponds to well insulated home, hence, the individual profiles generated can be scaled in order to represents a broader spectrum of home insulation. Moreover, the data collected in [7] and used in this report shows a maximum heat peak demand located in the afternoon.

4.4 Summary

The methodology developed in this section allows the creation of hundreds of individual profiles for electric heat pumps. These profiles are based on real heat requirements (space heating and domestic hot water) of different houses, taking into account the outside temperature and also the real characteristics of EHP (manufacture operational data). This methodology presents the advantage of scale the profiles to model different insulation level and also allow the creation of ground source heat pump (more likely to be installed in larger houses). From the simulation, it is possible to observe that the diversified average peak increase from 0.8 kW (assuming only unrestricted residential customers) without EHP to about 3.0 kW with EHP, which means an increase bigger than 300%.

5 Creation of Electric Vehicle Profiles

An electrical vehicle (EV) is a vehicle that employs electrical energy as mean of propulsion. In order to have autonomy, the electrical vehicles store the energy in batteries. These batteries need to be charged from the electrical grid. As many of these vehicles will be used with private purposes (i.e., commuting trips), it highly likely that these vehicles will be charged at home, therefore the LV distribution networks will be stressed with this technology.

The main considerations to understand the possible impacts are: the state of charge, this is the amount of energy still available in the battery at the charging moment and the power of the battery, which determines the maximum requirement of power (capacity) from the distribution network. These two characteristics determine how long the battery needs to be connected to the energy source; longer periods can increase the probability of coincidence with other charging points.

In this work, the approach implemented in [13] is developed for creating the EV profiles, but using as input data a closer study to the UK reality. In particular, [13] uses transportation data from the U.S. Department of Transportation. From this data, they built the histogram of vehicles versus daily miles driven and the histogram of vehicles versus their final arriving time. The main assumptions are:

a) All the vehicles start the charging process immediately once they have arrived at home.
b) All the vehicles start the day fully charged and therefore the state of charge just depends on the number of miles driven in one particular day.

Unfortunately, this process cannot be replicated by using the information from the UK National Travel Survey because the arriving time is not available in that report [14]. For that reason, in this work, a different source, [15], with similar information is used. In [15], the results for a one year field trial of EV in Dublin, Ireland are presented. The main results used for the creation of profiles are presented in Figure 18 and Figure 19. The first one indicates the distribution (based on the real data) of connection times, this is when the EVs are connected to the charging point and the second one indicates the energy required for each vehicle during the connection period.

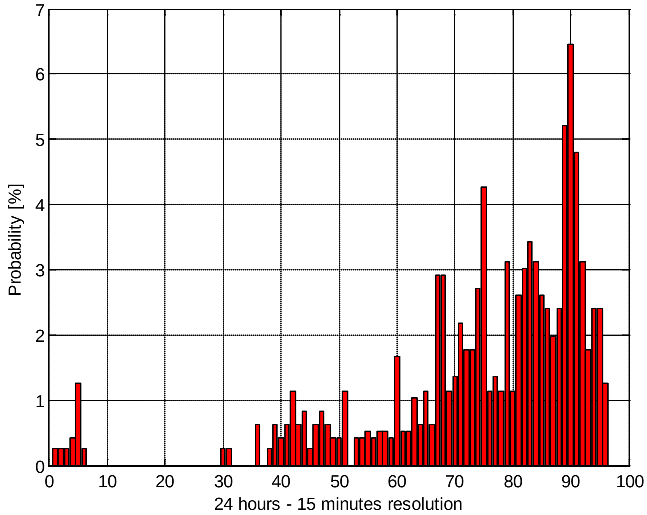

Figure 18: Probability distribution function of EV connection times

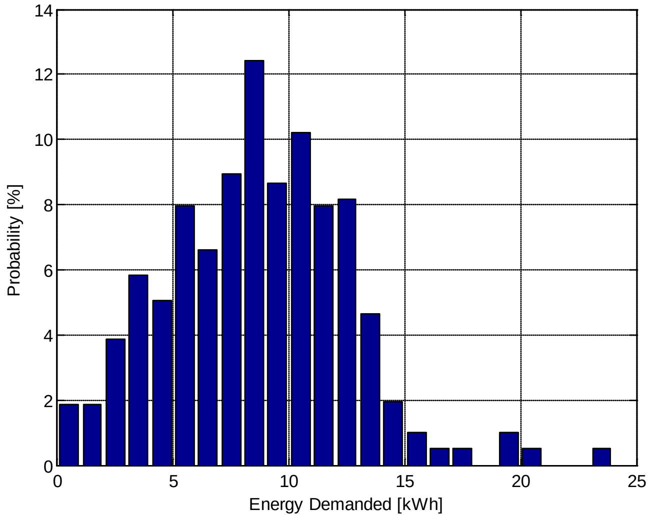

Figure 19: Probability distribution function for the daily EV energy requirement

5.1.1 Methodology

From the previous probability distributions, it is possible to know when an EV is connected to the network and how much energy required. The latter will determine for how long the EV needs to be connected to LV network taking into account the charging capacity (a normal single phase connection is limited by 16 Amps). Indeed, the EV used in this simulation is based on real EV, the Nissan Leaf, with a battery of 3kW and 24 kWh. Thus, if the energy required is 18 kWh, the EV must be connected for 6 hours (18kWh/3kW). With this framework, it is possible to create a pool of EV profiles to be used in our impact studies. The following process was implemented for the elaboration of each electric vehicle profile:

1. Random selection of the connection time following the distribution presented in Figure 18.
2. Since the original data has a 15 min resolution, to create a 5 min profile (resolution used along this report), the final connection period is randomly located in one of the three periods inside of the 15 min period.
3. The amount of energy required by this car is randomly selected by following the probability distribution presented in Figure 19.
4. This energy is divided by the battery capacity (3kW/24kWh – Nissan Leaf) to calculate the number of periods required.
5. The charging time is between the connection time and the total time required (connection time + the periods required).

5.1.2 Results

With the procedure stated above, it is possible to create thousands of different EV profiles. Some examples are presented in Figure 20. These profiles show different lengths since the different energy requirements of each car and they also present different starting points due to the variety in arriving time at home.

The creation of several individual profiles allows the creation of diversified profiles. These are useful to understand the peak coincidence demand of the EV in one particular feeder and/or secondary substation. As an example, Figure 21 presents the diversified profile for 100 EV (this might represent a very loaded feeder) and Figure 22 shows the same results for 1000 EV (this could represent a couple of secondary substations). Hence, the after diversity maximum demand is around 1.5 kW and 1.2 kW for the 100 loads and 1000 loads, respectively.

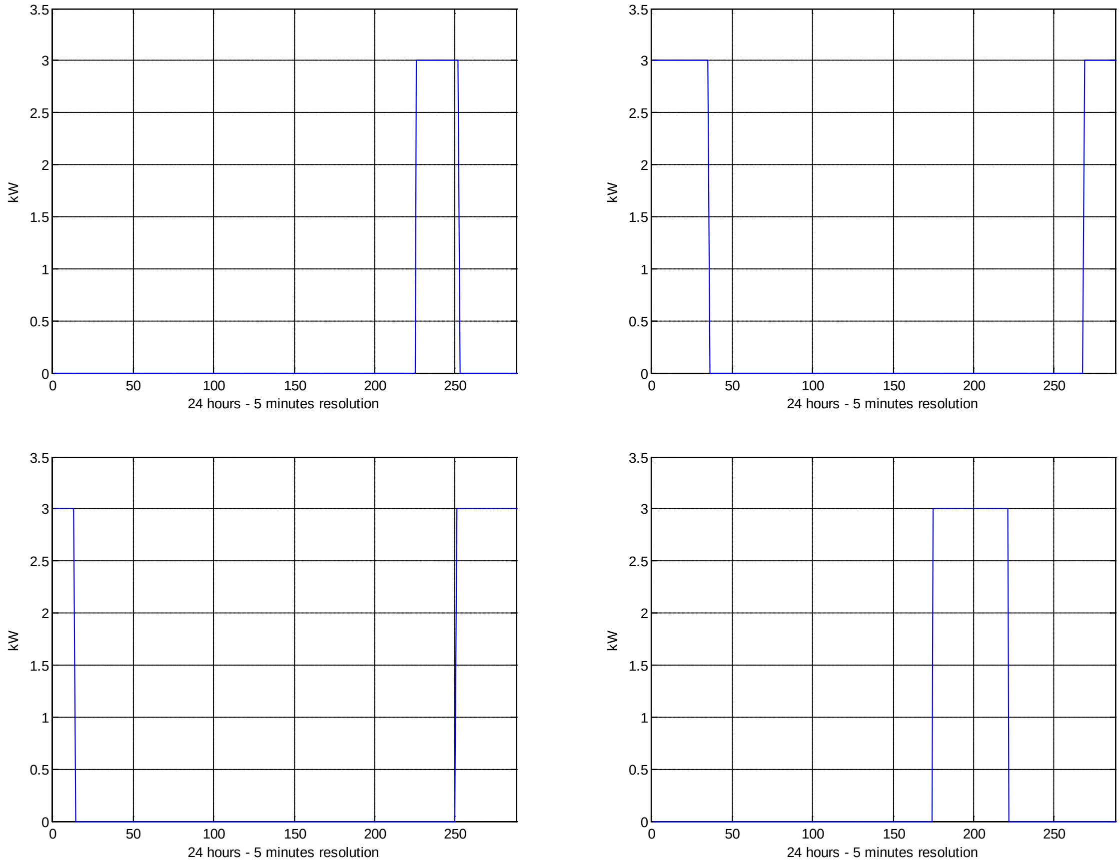

Figure 20: Example of individual EV profiles

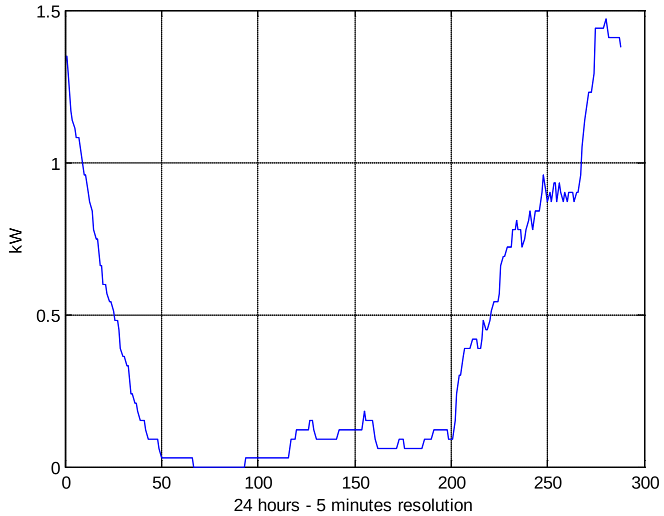

Figure 21: Diversified profile after aggregating 100 EV profiles

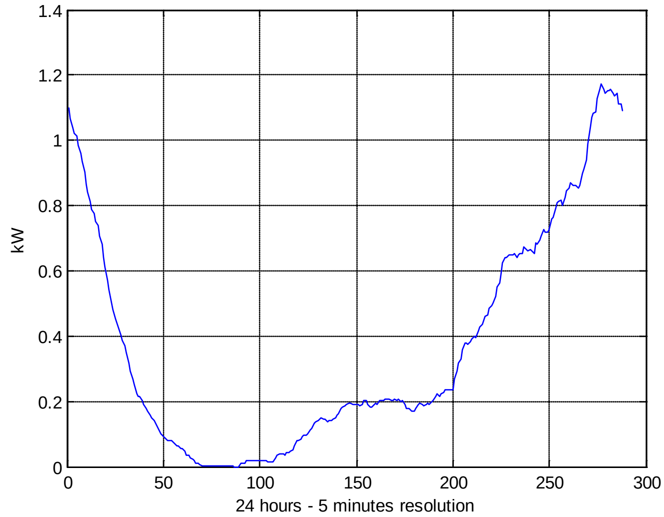

Figure 22: Diversified profile after aggregating 1000 EV profiles

5.2 WS3 EV profiles

The Smart Grids Forum Work Stream 3 includes half-hourly diversified profiles for EVs for the period 2012 and 2050. Again, the profiles are exactly the same for all the years forecasted. Additionally, there is no difference between summer, winter average and winter peak profiles. The profile is shown in Figure 23.

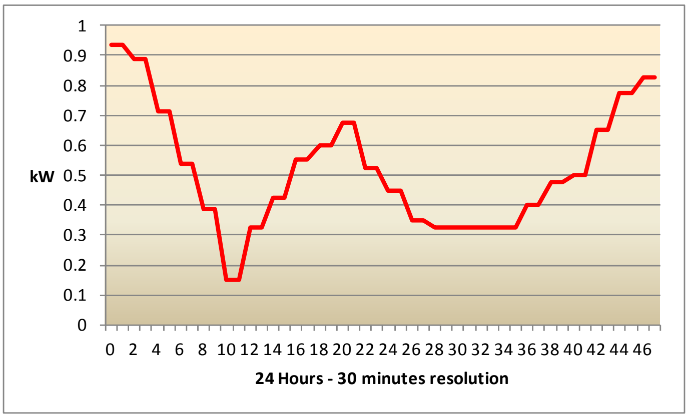

Figure 23: WS3 - Diversified EV profile

The EV profile presented has an after diversity maximum demand about 1 kW during the night time, which is very close to the profile developed in this report (about 1.2 kW). Furthermore, the shape of both profiles is very similar with most of the energy consumption concentrated at the end of the day and at the very beginning of the day.

5.3 Summary

The methodology developed in this section allows the creation of hundreds of individual profiles for electric vehicles. These profiles are based on real EV data; the histograms for the connection time and for the energy required in each connection event are taken into account. For simplicity, only one type of EV is considered (Nissan leaf). However, the model can be updated to incorporate different brands and different type of batteries. From the simulation, it is possible to observe that the diversified average peak increases from 0.8 kW (assuming only unrestricted residential customers) without EV to about 1.8 kW with EV, which means an increase bigger than 200%. This effect is depicted in Figure 24.

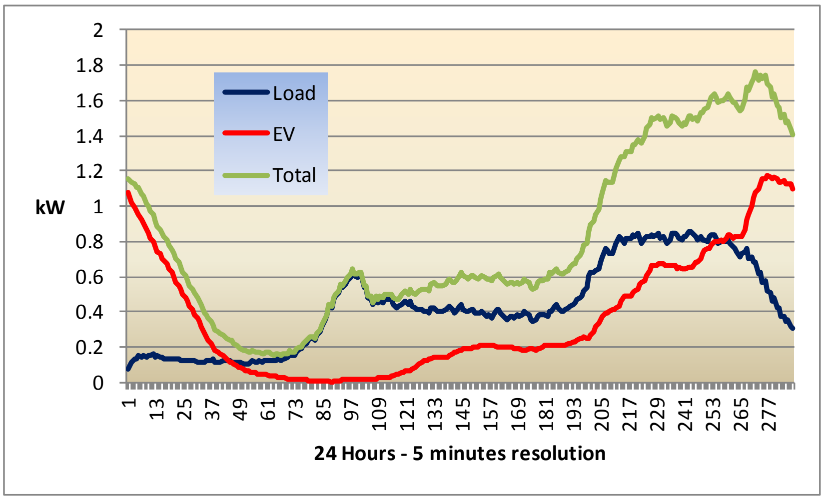

Figure 24: Total diversified profile: normal load + EV

6 Conclusions

This report presented somemethodologies for electrical behaviours of customer consumption, EHP and EV profiles and PV generation profiles to assess future LV networks. These time-series profiles (with minute to half hourly resolutions) will be used to assess the time-dependant behaviour of LV networks considering future penetration scenarios.

The main findings are:

- **Load Profiles.** The CREST tool is limited to domestic customers. Although assumptions can be made to model domestic un-restricted and two-tariff customers, commercial or other types cannot be modelled.

  Diversified ENWL load profiles when aggregated do show a very realistic behaviour. However, they cannot be used to model feeders with only a few customers (e.g., less than 50). In addition, due to their half-hourly resolution, effects on voltages might also be underestimated.

  Allocated profiles should not be considered individually but as a set of profiles that produce voltages and currents that match the corresponding monitoring points. These profiles are more realistic than ENWL load profiles and the CREST tool.

  The Smart Grids Forum WS3 load profiles produced corresponding to dwelling types, ages can be used to model with different heating systems especially EHPs. These profiles, however, might be inadequate due to half hourly resolution and lack of customer type.

- **PV Profiles**. CREST tool can also model PV electricity generation considering the corresponding irradiance, day of year as well as panel areas, size and orientation. This tool, however, might differ in cloud transients from actual measurements.

  The weather station-based PV profiles can be created considering real cloud transients from eleven weather stations. The main drawback, however, is that these profiles assume the same features for a given area and does not take into account the actual orientation of PV.

- **EHP Profiles**. EHP profiles developed in this report are based on real heat requirements of different houses of England considering the outside temperature and also the real characteristics of EHP. The methodology has the advantage of scale the profiles to model different insulation level and also allows the creation of ground source heat pump profiles. It is important to highlight that after diversity maximum demand (ADMD) increases from 0.8 kW without EHP to about 3.0 kW with EHP (for Air Source Heat Pump ASHP installed in modern houses).

- **EV Profiles**. EV profiles developed in this report are based on real EV data considering connection time and event. Although hundreds of individual profiles create for only one type of EV (Nissan Leaf), the model can be updated to incorporate different brands and different type of batteries. It is important to highlight that the ADMD increases bigger than 200% with EV (from 0.8 kW to 1.8 kW).

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