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The Implications of Demand Response Measures and Electrification of Transport on UK Household Energy Demand and Consumption

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Abstract

This study has been undertaken to gain a better understanding on how the residential electricity demand and consumption values might evolve in the medium term in a future built environment benefiting from renewable energy systems and storage technologies. Analysis and modeling of winter and summer electricity demand and consumption data in four scenarios for 2030 was performed, after the establishment of a baseline scenario in 2015 (BS 2015). The scenarios in 2030 included the business as usual scenario (BAU 2030), a scenario assuming electrification of heating and energy efficiency measures (EE 2030), a scenario in which demand response measures are also considered (DR 2030) and a scenario in which one electric vehicle (EV) is assumed for each house as well (Te 2030). Electricity demand and consumption ranges for different scales at the distribution level for each scenario were derived. It was concluded that properties with currently low peak demand values are bound to experience a much higher peak in the early morning hours in winter under the Te 2030 scenario than properties with already high peak demand. This would signify a new peak at a new time. In terms of electricity consumption in 2030, the energy efficiency measures would counterbalance the increase of electricity consumption due to the inclusion of the EV in winter, so the consumption in Te 2030 is found to be similar to the consumption in BAU 2030. The analysis also demonstrated the need to explore the potential role of thermal storage versus electricity storage in buildings.

Keywords: electricity demand; electricity consumption; residential sector; scenario modeling; demand response; electric vehicles

1. Introduction

In the last two decades, sustainability and the irreversible depletion of natural resources has been the subject of

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constant debate in a global scale. The energy sector today is mainly responsible for the greenhouse gas emissions. Emissions coming from energy-related activities accounted for 68% of the global emissions in 2005 [1] and the building sector is found to be in charge of over 40% of the total energy consumption in Europe [2]. Identifying opportunities to reduce this consumption has become a priority in the global effort to deal with climate change. In addition, an ambitious target set by the EU entails reduction of greenhouse gas emissions by at least 40% by 2030 compared to 1990 levels [3]. An increasing demand in the electricity sector is anticipated in the upcoming years due to the extension of the electrification of different regions worldwide, the increase in energy consumption due to economic growth, the use of electrical energy for heating and cooling and the use of electricity in the transport sector [4]. Electricity is therefore likely to become a universal and versatile source of low carbon energy for the building sector, but at the same time this is debatable due to scenarios that favour an energy mix in the domestic energy consumption [5-7]. Therefore, the exploration of the evolution of electricity demand and consumption in buildings according to different scenarios would be central to identifying opportunities to reduce their carbon footprint. This exploration in electricity use could also serve as a basis to investigate the potential integration of renewable energy technologies and energy storage technologies in buildings, as such technologies are considered to be key components of a decarbonized future built environment [8, 9]. This study focused on the exploration of the evolution of the electrical energy use in the UK residential sector through scenario modelling, in order to identify possible impacts. In the UK, about 33% of total electricity consumption is by residential consumers [10], holding the biggest share among commercial, industrial, agriculture, public administration and transport sectors. In addition, due the cool temperate climate, space heating is the dominant energy demand in this sector [11].

2. Energy use scenarios in the UK residential sector

Several studies have explored the evolution of the peak demand and the electricity consumption of the UK residential sector based on scenario modeling, such as [12-14]. However, these studies were performed on a national scale and looked at the long-term impacts of the proposed scenarios, for example for a timescale to 2050. Eyre and Baruah [15] also explored four broad qualitative socio-technical scenarios regarding space heating demand and consumption. Although these scenarios were over simplistic, the intention was to map the space within which actual futures are likely to fall, and they also addressed a national scale. In addition, various top-down or bottom-up models have been proposed for residential energy demand projections [16-19]; yet these models represent the entire UK housing stock. Therefore, to the best of the authors' knowledge, the literature currently lacks recent studies on energy use through scenario modeling addressing smaller building scales and medium-term scenarios, which are of interest to architects, building physicists and relevant disciplines. The presented work could facilitate making informed design decisions for an energy supply or energy storage system in the medium term from the end-users' point of view.

3. Methodology

Analysis and modeling of residential electricity demand and consumption data in 4 scenarios in 2030 was performed, based on the data obtained for a baseline scenario in 2015, addressing different building scales, such as individual buildings and communities. Electricity demand and consumption ranges in winter and summer for the scales of interest were derived for each scenario considering gas heated and electrically heated properties. The electricity demand profiles for a typical weekday in winter and summer were drawn for each scenario for a single household based on the assumptions discussed below and on typical residential half-hourly profiles provided by ELEXON [20]. It should be noted though that as in the UK summer peaks are lower than winter peaks [21], the winter values are expected to inform the supply or storage system's design, which would be used all year round. The summer values are thus provided for a better understanding of electricity use throughout the year.

3.1. Scales of interest

The study focuses on the final level of distribution, which is the 400/230V electricity network. The average number of residential buildings that are supplied at this level was sought via Distribution Network Operators (DNOs). Western Power Distribution (WPD), Scottish and Southern Electric Power Distribution (SSEPD) and UK

Power Networks (UKPN) were the DNOs who were contacted for this study, in order to obtain information about the operation of the electric system at the distribution level. The number of households supplied at this level in the UK was found to be 400 in the case that gas heating is applied [22] or 75 in the case of electric heating [23]. These numbers of households (i.e. 400 or 75) were also used to set the upper boundary of the community scale in this study. Intermediate scales were also created for additional reliability on the results.

3.2. Scenarios

3.2.1. Baseline scenario (BS 2015)

The peak demand ranges for the baseline scenario (BS 2015) for winter were sought through Intertek [24] for the gas heated properties and through Intertek [24] and WPD [25] for the electrically heated properties. Intertek's study was performed in 2012 and included a sample of 213 gas heated properties and 8 electrically heated ones. The latter is a small sample, but it was the only data available at the time that this research was undertaken and the values give an idea of the spread of possible peak power demands in UK households. The data were found to compare well against published values from other sources, such as Kreutzer and Knight [26], ELEXON [20] and the Department of Energy and Climate Change (DECC) [27] or obtained data from the UK Power Networks [23]. Intertek's data are inclusive of distinctive spikes in power demand fluctuation, as measurements were obtained in shorter time intervals. This enhanced the reliability and validity of the results. For reliability reasons, a confidence interval of 95% was applied to Intertek's sample consisting of 213 gas heated households, regarding the peak demand values. Regarding the summer peak demand range, it was not possible to source non-averaged data with relatively small time intervals and, as Zheng [28] claims, such high time resolution data are largely unavailable. However, according to Drysdale et al. [19] the peak electricity demand in winter in 2012 was 21% higher than in summer in the UK domestic sector. This is consistent with Knight and Ribberink's findings for 2007 [29], so this assumption was considered in order to compute the peak demand range in summer based on the peak demand range in winter. Depending on the year of publication of the data, an adjustment was made for 2015 based on increasing or decreasing trends published by DECC [27]. DECC's projections were the most recent ones at the time of this study and addressed the medium-term. Regarding the range of the peak demand for each scale, it was calculated based on the number of households considered in this study and by using the diversity of the electrical load for the residential sector, explained in section 2.2.

The electricity consumption profile in half-hourly intervals for a typical gas heated residential building in the UK based on the different seasonal characteristics was also obtained through ELEXON [20], who administers the wholesale electricity balancing and settlement arrangements for Great Britain. Based on the curves depicted in the profiles and as the range of domestic demand on weekdays and weekends according to Hesmondhalgh [30] is found to be very similar in the UK, the peak demand range, which, occurs at 6-7pm, is assumed to be the same for summer weekdays and weekend, as well as for winter weekdays and weekend. Daily electricity consumption ranges (kWh/day) for a single household, including the social sector, for winter and summer, as well as for weekdays and weekends, were also collated and synthesized from recent journal publications, conference proceedings and reports, such as Kreutzer and Knight [26], Cambell and Cambell [31], Hesmondhalgh [30] and SP Energy Networks [32]. Depending on the year of publication, an adjustment was made for 2015 based on increasing or decreasing trends published by the Department for Business Enterprise and Regulatory Reform [33] and DECC [27, 34]. These ranges were used for the estimation of the daily electricity consumption in 2015 for the different building scales.

3.2.2. Business as usual scenario (BAU 2030)

In this scenario there are no major changes in the way electricity is used. This scenario builds on the baseline scenario and includes also the impact from population and economic growth, as well as the historic trend towards increase in natural energy efficiency. As no data regarding peak demand trends in the domestic sector was found in the literature, an assumption is made that the proportional increase in peak demand is equal to the electricity consumption increase over the years, based on [35-38]. An increase of 10.4% in electricity consumption is, therefore, assumed [27], under the current trends.

3.2.3. Energy efficiency and electrification of heating scenario (EE 2030)

Electricity efficiency measures are assumed to take place in the EE 2030, DR 2030 and Te 2030 scenarios, i.e.

improved insulation levels, more efficient appliances and more efficient lighting. According to DECC [27], there is an electricity demand reduction potential of about 45% or 63 TWh in the residential sector from 2010 to 2030. The greatest potential is in switching to efficient appliances and electronics and accounts for about 42% of this potential, followed by building shell improvements with a share of 31%. Moreover, about 20% of this potential reduction is attributed to the shift from incandescent to compact fluorescent lamps [27]. As the above reduction of 45% is assumed for a 20-year period, this study assumes an accelerated reduction in the range of about 15% from 2010-2015, which is consistent with the data published by the Department for Business, Energy and Industrial Strategy [39]. Thus a potential of 30% in energy demand reduction through efficiency measures is assumed both for winter and summer for a period of 15 years.

3.2.4. Demand response scenario through peak shifting (DR 2030)

This scenario addresses only electrically heated households as these present higher potential to influencing the electricity demand and thus for demand response measures. The domestic sector is expected to offer most shiftable demand at the evening peak all year round [27]. Hence this study only assessed the scope for demand shifting at the evening peak in winter and summer. According to DECC's assumptions [27], it is estimated that about 34% of total domestic, commercial and industrial electricity load in a winter evening could be technically shiftable in 2025 and this load accounts mainly for on-peak space heating. Similarly, for a summer evening, 29% of the total peak load is likely to be shiftable and it would potentially come from cold appliances, cooling and ventilation. According to DECC [27], it is assumed that approximately 50% of the total shiftable load can be attributed to the residential sector, both for winter and summer. So considering the aforementioned proportions of 34% and 29% for all sectors, the potentially shiftable load for the residential sector in 2025 is estimated to be 17% in a winter evening and about 15% in a summer evening. DECC assumes the above shiftable load for a period of 15 years (2010-2025), so in this study the same assumptions were used for 2030, as the exploration includes a 15-year period as well (i.e. 2015-2030). The optimal period for peak shifting was identified to be from 8-11pm in summer, and 5.30-8.30pm in winter. During these two periods the highest load during a day is expected to occur according to the demand profiles obtained from ELEXON [20]. An even distribution of the shifted load is thus assumed over the rest of the winter day. It should be noted that, as the peak electricity demand reduction mainly comes from on-peak electric space heating in winter, a small shiftable load in the range of 3% [27] is assumed for the gas heated properties (instead of the 17% assumed for the electrically heated ones) in winter due to non-space heating related activities. Therefore, the gas heated properties remain only slightly affected during the winter period from the demand side measures in that period. For the summer period the same reduction of 15% is assumed. In this scenario the electricity consumption was not assessed, as no change in the total daily consumption is incurred by the shifting of the load.

3.2.5. Electrification of transport scenario (Te 2030)

One medium EV with a Li-ion or NiMH battery, thus requiring 5 hours of charging at a level value of 7kW [40] over the charging period, is considered for each gas or electrically heated typical household. Charging of the vehicle is assumed to be taking place at home in 2030. There are two time periods that customers can choose to charge their electric vehicle; one is right after they come back from work, i.e. at peak consumption time, and the other is during the night, when household consumption is typically low. Overnight charging would help to smoothen the load curve without adding extra load during the periods of high demand already. This is also supported by the observations by the Committee on Climate Change [41] and Element Energy [42], who claim that the majority of EV charging is expected to occur overnight and that access of overnight charging is a pre-requisite to a BEV purchase. This work examined the implications of both on-peak and off-peak/overnight EV charging to study the expected effects alongside the other scenarios used. The scenario is indicated as Te 2030 on-peak or Te 2030 off-peak when charging is taking place on on-peak and off-peak times respectively.

The inclusion of an EV per household would affect at a great extent the daily electricity consumption of a single household, since it would be charged at home. Based on findings published by the UK National Travel Survey of the Department for Transport [43] and Element Energy [42], a consumption value of 6 kWh is assumed per car (i.e. per household). In the Te 2030 off-peak scenario, EV charging takes place from 1.30-6.30am in winter and summer weekdays and from 2-7am on weekends. These hours were drawn from the half-hourly data for domestic unrestricted customers from ELEXON [20] and were identified as the overnight hours with the lowest load. All the assumptions discussed above along with their references are presented in Table 1.

Table 1: Assumptions for the scenario modeling (N/A: not applicable)

	Peak demand	Electricity consumption	Timing	References
BAU 2030	+ 10.4%	+10.4%	N/A	[27]
EE 2030	- 30%	-30%	N/A	[27]
DR 2030	- 17% (winter evening) - 3% for gas heated [44]	N/A	5.30-8.30pm (winter)	[20, 27]
	- 15% (summer evening)	N/A	8-11pm (summer)	[20, 27]
Te 2030 on-peak	+ 7kW	+ 6kWh	5.30-10.30pm	
Te 2030 off-peak	+ 7kW	+ 6kWh	1.30-6.30am weekdays 2-7am on weekends	[20, 40, 42, 43]

3.3. Diversity of the electrical load

In the case that the same distribution transformer supplies more than one property, diversity of the electrical load occurs. This means that in the case of a group of properties, it is unlikely that all properties would have their peak demand at the same time. Hence, they would have their maximum demand at different intervals of time. The diversified load is the expected electrical load to be drawn per connection, according to the number of houses specified in the left column, during a peak period in a group of buildings. Table 2 presents typical practice diversity values for domestic connections (properties) with gas central heating or electric heating, provided by WPD [25], as well as the diversified load per house in winter and the overall peak demand of the system in BS 2015, which were calculated based on the diversity values. In this example the BS 2015 ranges of 3-13.9kW and 4.8-16.3kW per property for gas and electrically heated households respectively have been used.

Table 2: Diversity [25] and diversified load for gas heated properties according to the number of connections

No. of properties	Gas heated properties					Electrically heated properties				
	Diversity	Diversified Load (kW) per property Winter		Overall peak demand of the system (kW)		Diversity	Diversified Load (kW) per property Winter		Overall peak demand of the system (kW)	
		min	max	min	max		min	max	min	max
1	1	3.0	13.9	3	13.9	1	4.8	16.3	4.8	16.3
2	0.5	1.5	7.0	4.5	20.9	0.9	4.3	14.7	9.1	31.0
3	0.33	1.0	4.6	5.5	25.4	0.775	3.7	12.6	12.8	43.7
4	0.2	0.6	2.8	6.1	28.2	0.68	3.3	11.1	16.1	54.8
5	0.18	0.5	2.5	6.6	30.7	0.665	3.2	10.9	19.3	65.6
10	0.144	0.4	2.0	9.2	42.7	0.639	3.1	10.4	35.1	119.4
25	0.131	0.4	1.8	15.7	72.6	0.629	3.0	10.3	80.9	275.7
50	0.125	0.4	1.7	25.5	118.0	0.625	3.0	10.2	156.2	532.3
75	0.125	0.4	1.7	34.8	161.4	0.625	3.0	10.2	231.1	787.3

4. Results

4.1. Peak demand for single properties

Considering the assumptions above, the peak demand in winter is shown in Figure 1 and in summer in Figure 2.

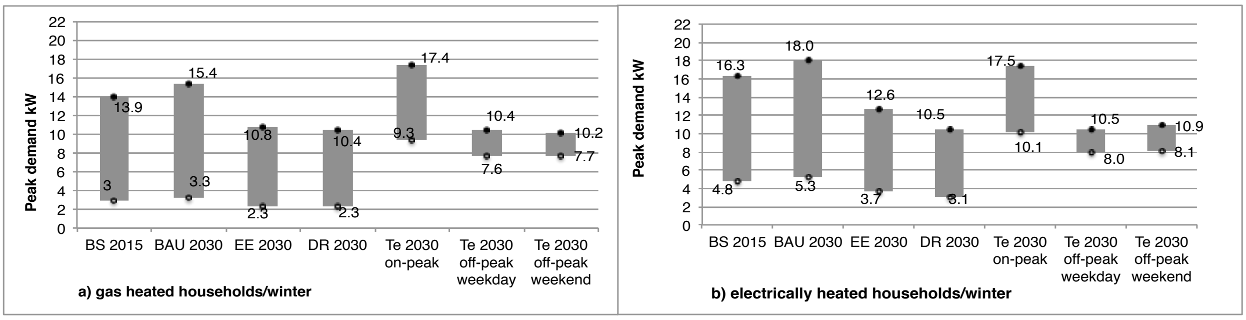

Figure 1: Winter electricity peak demand range for a) gas heated and b) electrically heated households in all scenarios

It is apparent in Figure 1 how big a difference the time of the EV charging makes for either gas or electrically heated households. In the case of off-peak EV charging, the maximum peak demand is the same as in the DR 2030 scenario, at 10.4kW, while the peak night one occurring at 6.30am is 9.9 kW. As for the summer period in 2030, the assumptions are the same for the gas and the electrically heated households, as no heating is assumed to take place in summer. Thus, there is only one graph for summer that is presented in Figure 2. As the peak demand in summer is a lower value than winter, the values for the different scenarios are affected at a smaller extent by the increase or decrease of demand due to the measures taking place. The biggest impact is from the electrification of transport and the subsequent inclusion of one EV per household. This caused the demand to peak at about 14.6kW in the case of on-peak vehicle charging, while the demand decreases to 10.6kW if off-peak charging is applied.

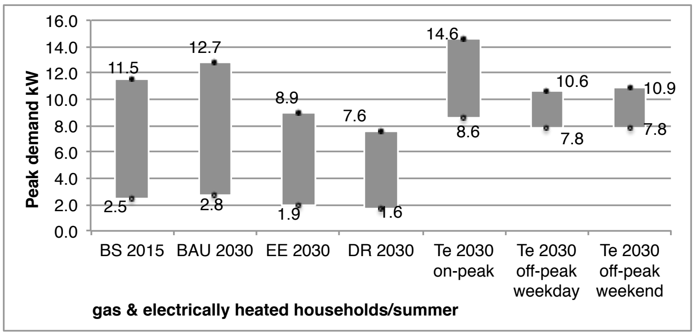

Figure 2: Summer electricity peak demand range for gas and electrically heated households in all scenarios

4.2. Load profiles for single properties

The impact of all measures discussed above on the daily load profile of a domestic property on a winter and a summer weekday in 2030 is presented in Figure 3, drawn by the authors. The figure presents the range of daily load profiles in each scenario. These load profiles could be used to facilitate making informed design decisions for energy storage requirements in sub-daily autonomy periods. For the gas heated households the analysis was based on the daily load profiles obtained by ELEXON [20] for winter and summer, which were used for BAU 2030, and the assumptions regarding peak demand in each scenario. The profile in BAU 2030 was therefore used as a base case and the rest of the profiles are depicted as a percentage of the peak demand found in the BAU scenario. Thus, the electricity demand profiles for a typical weekday and weekend day in winter and summer were drawn for each scenario for a single household. The peak demand values calculated above are not displayed in the half-hourly profiles, as they represent a spike during a 2-minute interval that is not reflected on the half-hour profiles. In Figure 3, by using the range of the load profiles for BAU 2030 for winter as a base (in grey), the amended range of the load profiles for the rest of the scenarios are superimposed in transparent shades.

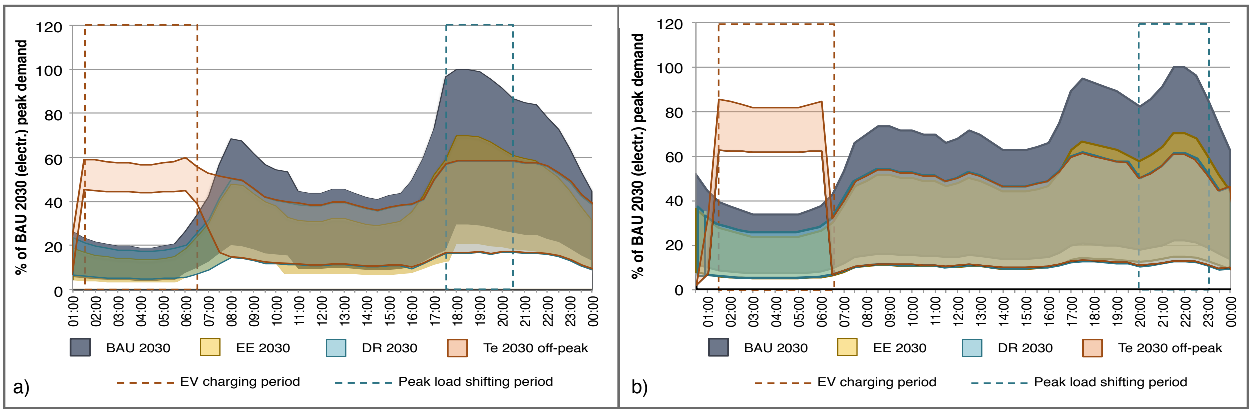

Figure 3: Evolution of load profiles in all scenarios for a single household on a a) winter and b) summer weekday in 2030 (presented in ranges)

The graphs of BAU 2030, EE 2030, DR 2030 and Te 2030 off-peak are superimposed in this order. The reduction of the upper bound of the peak load is apparent at 6pm, which is due to energy efficiency and peak load shifting. In addition, by including an EV, which is charged from 1.30-6.30am, the demand at 1.30am equals the peak at 6pm signifying a double peak with the same value. As for the lower bound of the peak demand range, which represents properties with low peak demand values, the night-time EV charging creates a new peak at a new time, i.e. 1.30am.

4.3. Peak demand for communities

The winter peak demand ranges for gas heated and electrically heated communities in BAU 2030, EE 2030, DR 2030 and Te 2030 off-peak scenarios are presented in Figures 4 and 5.

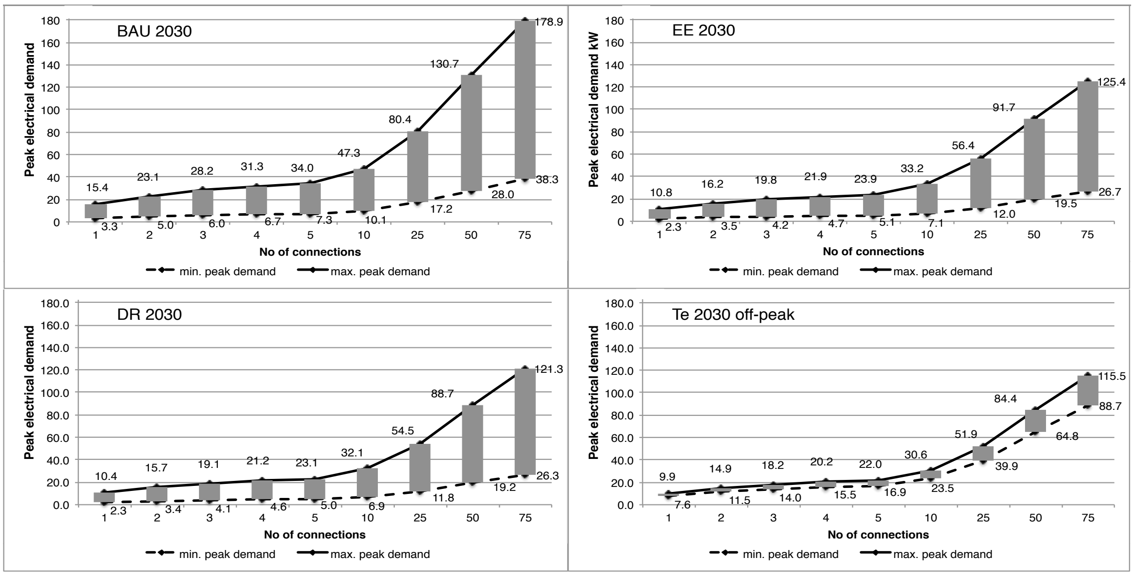

Figure 4: Winter peak demand range for gas heated communities in all scenarios

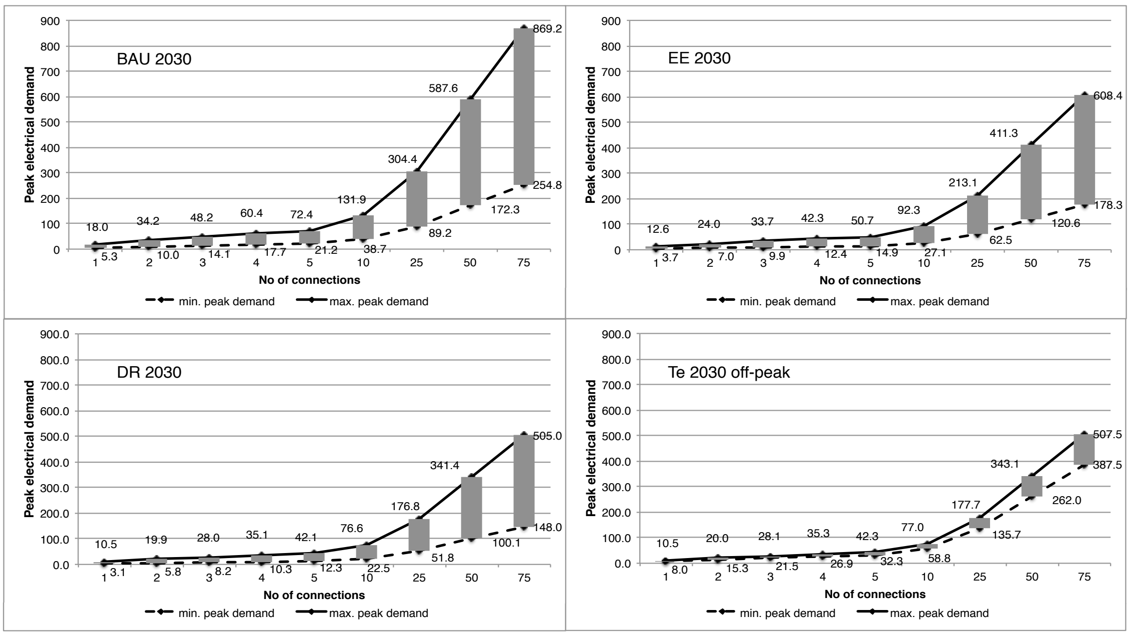

Figure 5: Winter peak demand range for electrically heated communities in all scenarios

It is observed that due to the diversity of the electric load, there is an inverse relationship between the number of the properties and the per-property peak demand. In other words, the greater the number of properties, the lower the per-property peak demand, which is translated to more efficient use of the generated electricity. This was anticipated and is of interest regarding the provision for electricity storage, as economies of scale arise.

4.4. Daily electricity consumption for single properties and communities

The daily electricity consumption for communities would depend on the amount of electricity consumed on a day in a single household and the number of households. The BS 2015 scenario and the three scenarios in 2030 are considered in this analysis. The consumption in the Te scenario is not affected by the timing of the EV charging, i.e. whether charging is on on-peak or off-peak hours. The electricity consumption range for different scales and for all scenarios is provided in Figure 6. As consumption is slightly higher on weekends than on weekdays, Figure 6 provides weekend values. This would allow for a more effective provision for daily electricity storage, as the effective capacity of the storage system would need to be informed by the highest occurring daily consumption values. As observed, in Te 2030 there is a considerable load added due to the inclusion of one EV in each household and in this scenario the upper bound of the electricity consumption for winter is either about equal (for gas heating) or lower (for electric heating) than the consumption in BAU 2030. In summer, due to the lower overall household consumption, the added electrical load due to EVs is considerably high.

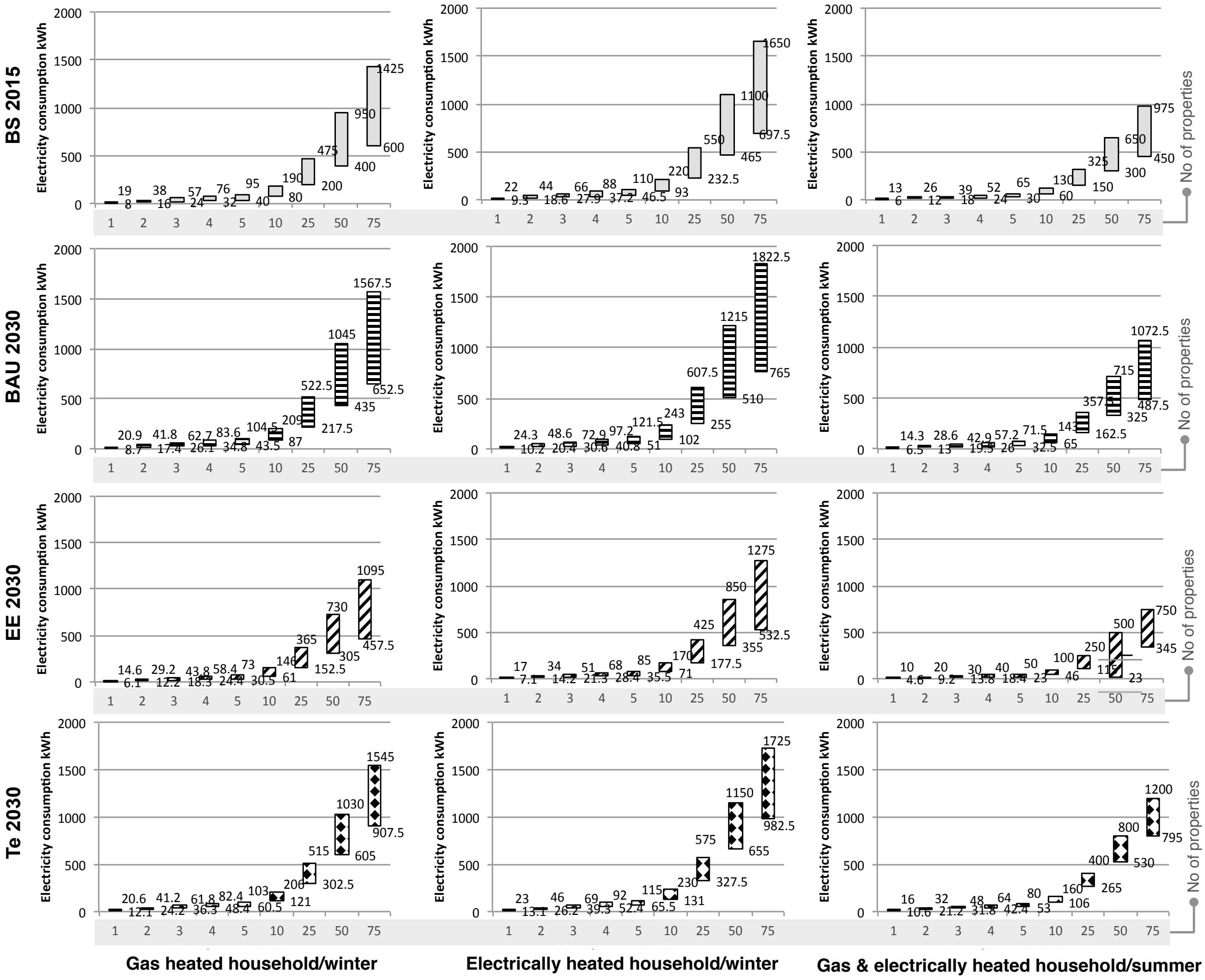

Figure 6: Electricity consumption range on weekends for different building scales in all scenarios

5. Discussion

The analysis shows the different impacts from energy efficiency and demand response measures, as well as from the likely electrification of heating and transport on the UK residential electricity demand and consumption. More specifically, regarding the peak demand for single properties, it is observed that smaller energy savings in the order of 4kW are achieved from off-peak charging in summer, while in winter, savings of about 7kW for gas or electrically heated properties could be achieved, as shown in Figure 1. From an electricity storage requirement perspective, the lower the peak demand the smaller the size of the inverter and thus the smaller the size and cost of the overall storage system. Therefore, there is great potential for reduced size and costs of the overall storage system in the Te 2030 off-peak scenario. Furthermore, the BAU 2030 and Te 2030 models foresee a considerable additional electrical load added to each household, which may have an impact on existing wiring regulations and legacy electrical infrastructure. In terms of the load profiles, as the nighttime EV charging in the Te 2030 off-peak model creates a new peak at a new time, i.e. 1.30am (Figure 3), properties with currently low peak demand values are bound to experience a much higher peak in the early morning hours in winter under the Te 2030 off-peak scenario.

As regards the peak demand at the community level, economies of scale may reduce the overall footprint and the spatial requirements of the storage system per property, as well as the cost of the system per property. Moreover, the difference in the respective values for each scenario between the gas heated and the electrically heated properties in Figures 4 and 5 signify that there is a considerable load added to the electrically heated properties due to the effect of electric heating. This demonstrates the need to explore the potential role of thermal storage alongside electricity storage in buildings, as heating is the dominant residential energy demand. This exploration, which could be part of a future study, could help illustrate the net benefits of either, which in turn would give returns on investment, market advantages through operation within ancillary services and for example, electricity infrastructure investment deferral savings. In addition, as observed in Figure 6, the winter electricity consumption in Te 2030 is either about equal (for gas heating) or lower (for electric heating) than BAU 2030. This means that the energy efficiency measures would counterbalance the increase of electricity consumption due to the electrification of transport.

In terms of the limitations of this study, it is appreciated that there might be barriers hindering the full abatement potential of the energy efficiency measures, such as transaction costs, agency issues for rented accommodation or little behavioural change of the occupants; however any substantial obstacles to realisation of the measures are assumed to be tackled through appropriate policies. Another limitation is that the underlying assumptions regarding EV ownership projections might be optimistic for 2030. For example, there might not be one EV per house by then and the charging regime for an EV will be dependent on the average daily usage and therefore possibly not requiring a full charge every night. Further scenarios relevant to this and also the potential of the EV to impact the residential power profile by providing dynamic electricity storage to level or shift the existing peaks could be investigated in future work. Finally, it should be noted that the Te 2030 scenario is based on the current level of battery technology, inverters and equipment in current EVs, which may be expected to have changed by 2030.

6. Conclusions

This study focused on the energy demand side providing estimates on the evolution of the residential electricity demand and consumption in the medium term due to current trends, energy efficiency and demand response measures, as well as a higher uptake of electric vehicles. In future research, the presented work could be used to explore options and scenarios regarding the energy supply and energy storage sides at the end user's level. Regarding peak demand, this work showed that properties with currently low peak demand values are bound to experience a much higher peak in the early morning hours in winter under the electrification of transport with off-peak EV charging scenario (Te 2030 off-peak) than properties with already high peak demand. This would signify a new peak at a new time. In terms of electricity consumption in 2030, the energy efficiency measures would counterbalance the increase of electricity consumption due to the electrification of transport in winter for all scales of interest, so the electricity consumption in the Te 2030 model is found to be similar to the consumption in the business as usual scenario (BAU 2030). Furthermore, the BAU 2030 and Te 2030 models foresee a considerable additional electrical load added to each household which may have an impact on existing wiring regulations and legacy electrical infrastructure. The analysis also demonstrated the need to explore the potential role of thermal storage versus electricity storage in buildings, as heating is the dominant residential energy demand.

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Response to the Reviewers' Comments

The Implications of Demand Response Measures and Electrification of Transport on UK Household Energy Demand and Consumption

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We would like to thank the reviewers for their helpful comments. We have addressed the reviewers' comments and questions in the revised manuscript, complementing the paper with additional information. In the following, a reply to each of the comments is provided. Throughout this document, our replies are given in blue colour.

Reviewer #1:
We are pleased that Reviewer 1 accepted our paper and provided some minor comments to improve the manuscript.

> In abstract business as usual scenario "(BAU 2030) shall be added to be consistent with the description of other scenarios.

"BAU 2030" was added in the abstract.

> Is it possible to provide more specific information in conclusion section about the results of the study.

More specific information has been added in the conclusion regarding the results of the study. More specifically, the following additions were made in the conclusions: "[…] under the electrification of transport with off-peak EV charging scenario (Te 2030 off-peak) […] so the electricity consumption in the Te 2030 model is found to be similar to the consumption in the business as usual scenario (BAU 2030). […] Furthermore, the BAU 2030 and Te 2030 models foresee a considerable additional electrical load added to each household which may have an impact on existing wiring regulations and legacy electrical infrastructure."

Reviewer #2:
We are pleased to read that Reviewer 2 considered the proposed models beneficial in highlighting for policy makers and stakeholders involved in power generation and distribution the significant disruption that the proposed scenario could have. In

particular with the business as usual scenario where EV charging is likely to further contribute to the evening peak. We are also pleased that Reviewer 2 found that this research poses interesting questions for the changes that will be needed in behaviour, technology, storage and/or grid management.

> A number of the underlying assumptions contributing to the baseline and models are not sufficiently considered, for example, even the most optimistic projections of EV ownership do not run to one EV per house by 2030, the charging regime for an EV is dependent on the average daily usage and therefore not likely to require a full charge every night, and whether the charging profile of a fully-discharged EV is a level value over the charging period or tapers down as the EV charges. These factors could have been weighted into the models or described under further work.

The following addition was made in the discussion section: "One of the limitations of this study is that the underlying assumptions regarding EV ownership projections might be optimistic for 2030. For example, there might not be one EV per house by then and the charging regime for an EV will be dependent on the average daily usage and therefore possibly not requiring a full charge every night. Further scenarios […] could be investigated in future work." Moreover, the charging profile of a fully-discharged EV is a level value indeed considering it uses a Li-ion or NiMH battery, as seen in reference [36]. Therefore, in order to avoid any misunderstanding, the first sentence in section 3.2.5 was rephrased as follows: "[…] requiring 5 hours of charging at a level value of 7kW [36] over the charging period […]".

> The potential of the EV to impact the residential power profile by providing dynamic electricity storage (particular at weekends) and levelling or shifting the existing peaks should have been considered within the scenario. The paper should caution that the Te2030 scenario is based on the current level of battery technology, inverters and equipment in current 2015 EVs which may be expected to have changed by 2030.

The following addition was made in the discussion section: "Further scenarios relevant to this and also the potential of the EV to impact the residential power profile by providing dynamic electricity storage to level or shift the existing peaks could be investigated in future work. In addition, the Te2030 scenario is based on the current level of battery technology, inverters and equipment in current EVs which may be expected to have changed by 2030."

> The EE projection DECC [23] of electricity demand reduction potential is about 45% in the residential sector from 2010 to 2030. The justification to select 30% for the proposed EE model is not sufficiently justified. No additional criteria were given to select this value. The pro-rata value for 2015-2030 would be 33.75%? In addition, the author should investigate whether there are additional data sets for the first six years of the DECC projection to

qualify the progress toward that target in some of the areas, equipment, insulation, etc.
Data published by the Department for Business, Energy and Industrial Strategy were found which suggest an electricity reduction in the range of 13-15%, so the sentence relating to this was rephrased as follows: "[…] this study assumes an accelerated reduction in the range of about 15% from 2010-2015, which is consistent with the data published by the Department for Business, Energy and Industrial Strategy [39]. Thus a potential of 30% in energy demand reduction through efficiency measures is assumed both for winter and summer for a period of 15 years." A further reference was also added.

It is notable that the TE2030 model foresees a considerable additional electrical load added to each household which may have impact on existing wiring regulations and legacy electrical infrastructure.
Thank you for bringing this up. This was added in the first drafts of the paper, but was removed due to lack of space. The authors added it back in the discussion section: "Furthermore, the BAU 2030 and Te 2030 models foresees a considerable additional electrical load added to each household which may have an impact on existing wiring regulations and legacy electrical infrastructure." This was also included in the conclusions.

In the conclusions, the author states that the "analysis also demonstrated the need to explore the potential role of thermal storage versus electricity storage in buildings, as heating is the dominant residential energy demand" It is not clear from the references, data or models where this assertion is derived and there does not appear to be any basis for this conclusion.

This conclusion is drawn from current section 4.3, where it is stated that "[…] This demonstrates the need to explore the potential role of thermal storage alongside electricity storage in buildings, as heating is the dominant residential energy demand". For further clarification, the following addition was made in section: "In addition, due the cool temperate climate, space heating is the dominant energy demand in this sector [11]" and a further reference was added.

Page 2: CO2 should have the 2 as a subscript.
CO2 was replaced by "emissions".

Consider rewording the sentence on page 3 that starts with - The selected sources were considered as most reliable,
Intertek's data are inclusive of distinctive spikes in power demand fluctuation, as

measurements were obtained in shorter time intervals. This enhanced the reliability and validity of the results.

> The references for the EU targets in 2050 area based on references from 2010 and 2011. Following the agreement of COP21, more recent references to the revised EU2050 targets should be sourced.

A more recent reference was added and the sentence changed to "an ambitious target set by the EU entails reduction of greenhouse gas emissions by at least 40% by 2030 compared to 1990 levels".
https://ec.europa.eu/clima/policies/strategies/2030_en

> On page 6, the text states "the demand decreases to 10.3kW if off-peak charging is applied". However, Figure 2 shows both TE2030 off-peak values as in the range 7.8-10.6kW and 7.8-10.9kW.

The value in text was changed to 10.6kW, as shown in Figure 2.

Session chair:
We would like to thank the session chair for his valuable comments. Below we confirm that his comments were addressed in the revised manuscript.

> In addition, please also note that your paper should include a literature review section between the Introduction section and the Methodology section (some of the discussion in the Introduction section should be in the literature review section) and also your paper also needs to separate the Results and Discussion section into two sections.

All the suggested sections were added.

> Finally, your list of references are in the incorrect font size.

Thank you for spotting this – it has now been corrected.