Customer-Led Network Revolution

High Level Summary of Learning

Domestic Solar PV Customers

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AUTHORS
Harriet Bulkeley, Gavin Whitaker, Peter Matthews, Sandra Bell, Stephen Lyon Durham University
Gareth Powells, Newcastle University

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1. Executive Summary

This report by Durham and Newcastle Universities examines the nature and practice of energy use by domestic customers in the CLNR project who generated their own solar photovoltaic (PV) electricity. It brings together power monitoring data capable of providing insight into how electricity is generated and used at the household level with data concerning how households respond to these new forms of energy generation.

The report draws on the data for TC5 (Solar PV) and TC20 (IHD) (Solar PV with an In-Home Display showing consumption, export and import readings). Over the period 1st January 2013 – 31st December 2013, there were 143 customers in TC5 and 149 customers in TC20 (IHD). The TC5 and TC20 data is compared to the analysis of TC1a (a control set of customers with no interventions except smart meters and in-home displays of consumption) which contained a total of 8415 customers with data monitored over the period 1st October 2012 – 30th September 2013.

Social science research was conducted with households to investigate their current patterns and practices of electricity use and how this had changed along with the use of low carbon technologies and participation in the interventions developed under the CLNR project). In total, the analysis draws on 46 separate interviews with house tours.

Participants in TC5 and TC20 (IHD) were found to have higher overall levels of annual total electricity consumption than those in the control group (Figure Total Energy 1). The overall distribution of customer total energy consumption is also different, with TC5 and TC20 (IHD) having a larger number of customers with very high levels of total energy consumption than those in the control group (Figure Total Energy 1). Households with PV use a higher proportion of their total electricity consumption during the daytime period of 10 am – 4 pm than households in the control group.

There was no significant difference in the ratio of electricity used during the daytime period (the period of peak electricity generation) found between participants who had an export/import in-home display (TC20 (IHD)) and those who had not been provided with one of these devices on the trial (TC5). This finding should be tempered against the findings of the qualitative research which demonstrated that people without an in-home display found other means to monitor and assess the amounts of electricity they imported and exported. These methods included record keeping, collecting and interpreting monthly statistics and regularly checking meters. Participants with the in-home-display commonly became enthusiastic users of the illuminated green-red signalling system which prompted householders to change the timing of household practices, particularly those employing wet white-goods.

Although PV generation does not appear to pose a risk to network capacity at the individual customer level as the peak export observed lies within the network design tolerance and is comparable to peak demand, widespread deployment of PV may pose challenges to the network in the future.

Mean peak power demand was between 14 and 33 % higher in TC5 and between 22 and 41% higher in TC20 (IHD) than in the TC1a control group (at the 95% confidence level). The maximum peak power demand was also higher in TC5 (between 8-25% at the 95% confidence level) and TC20 (IHD) (of between 9 and 25% at the 95% confidence level) than in the TC1a control group; suggesting that customers with PV have higher loads than those without.

Our research also found that participants reported a shift in the time at which they undertook different activities, particularly those which were regarded as more flexible practices such as washing and drying clothes, using the dishwasher or other chores.

In TC20 (IHD), the presence of the in-home display is associated by participants with going further with changes that they had thought could be beneficial when they first adopted PV, but which had not been fully realized. For others the IHD identified new optimal alignments between PV and their practices.

We find that such interventions are creating new ideas of what ‘good’ and ‘valuable’ forms of solar generation and use might involve. This provides a potentially valuable resource for network operators. Even though the effects on overall power demand are likely to be low, developing ways in which consumers come to use their own electricity could provide network benefits by reducing the risks of voltage imbalance and steady state voltage rise (Wang et al., 2012) especially in areas where PV arrays are clustered on particular distribution networks.

Households with PV have higher overall levels of annual total electricity consumption than those without PV. PV households also tend to use more electricity during daylight hours. Householders with PV are more engaged in monitoring, assessing and manipulating their electricity consumption than those without PV. Importantly PV generation does not appear to present a risk to network capacity, at least at the level of individual customers even though customers with PV have higher peak loads than those without. PV households have a strong tendency to shift chores such as washing and drying clothes or using dishwashers according to levels of PV generation. In home-display units are a welcome adjunct to PV households enabling even greater degrees of flexibility. The greatest benefit to network operators emerges from circumstances where PV arrays are clustered.

2. Introduction

The Customer-Led Revolution (CLNR) Project is a £54 million collaboration funded by Ofgem under the Low Carbon Networks Fund (LCNF). Led by Northern Powergrid, in partnership with British Gas, Durham University, Newcastle University, and EA Technology Ltd, this collaborative enterprise is investigating current business and domestic electricity usage, and trialling a series of electricity customer and network interventions to investigate end-use customer and technological flexibility. The aim of this research is to study how smart grid interventions might be designed and implemented and to understand social responses to such interventions.

This report by Durham and Newcastle Universities examines the nature and practice of energy use by domestic customers in the CLNR project who generated their own solar photovoltaic (PV) electricity. It provides analysis of the largest socio-technical integrated study of PV use conducted in the UK. While much of the research conducted in the UK to date on micro-generation technologies has sought to understand their technical performance, some recent studies have sought to understand the ways in which the impacts of micro-generation technologies are shaped by the ways in which households adjust their everyday practices (Kierstead 2007). However, there is limited research that has sought to bring together power monitoring data capable of providing insight into how electricity is generated and used at the household level with data concerning how households respond to these new forms of energy generation. This report contributes to addressing this gap in our understanding about the potential impact of solar PV on power networks and on how households are engaging with these new forms of electricity provision.

3. Methodology

The report draws on the data for TC5 (Solar PV) and TC20 (IHD) (Solar PV with an In-Home Display showing consumption, export and import readings). Over the period 1st January 2013 – 31st December 2013, there were 143 customers in TC5 and 149 customers in TC20 (IHD). Customers were recruited from among owner-occupiers and from social housing landlords.

The TC5 and TC20 data is compared to the analysis of TC1a (a control set of customers with no interventions except smart meters and in-home displays of consumption) which contained of 8415 customers with data monitored over the period 1st October 2012 – 30th September 2013.

The social science team conducted research with households to investigate their current patterns and practices of electricity use and how this changed along with the use of low carbon technologies and participation in the interventions developed under the CLNR project. Qualitative research consisted of:

- a semi-structured interview focused on current forms of electricity use;
- a tour of the participant's premises in order that they could 'walk through' the ways in which different technologies, devices and spaces were used in relation to energy consumption;
- a further interview session reflecting on the flexibility of everyday electricity use in relation to specific practices.

Audio-recorders and cameras were used to collect voice recordings, photos, basic categorical information about the participants (e.g. their heating and lighting technologies), as well as diagrams drawn by participants sketches of the property's floor plans and estimated load profiles).

In TC5, 20 visits were conducted with 13 households (7 households agreed to repeat visits). In TC20, 26 visits were conducted with a total of 18 households on the manual and automatic trials (8 households agreed to repeat interviews). In total, the analysis draws on 46 separate interviews/house tours (Figure 1). The data were analysed using the software package NVivo that supports qualitative and mixed method research, which also acts as a database. NVivo enables researchers to collect both the text-based material (transcripts of interview, sheets used to record technology ownership and household details, notes and reflections) and multimedia information (audio files, photographs, drawings).

Figure 1: Number of households

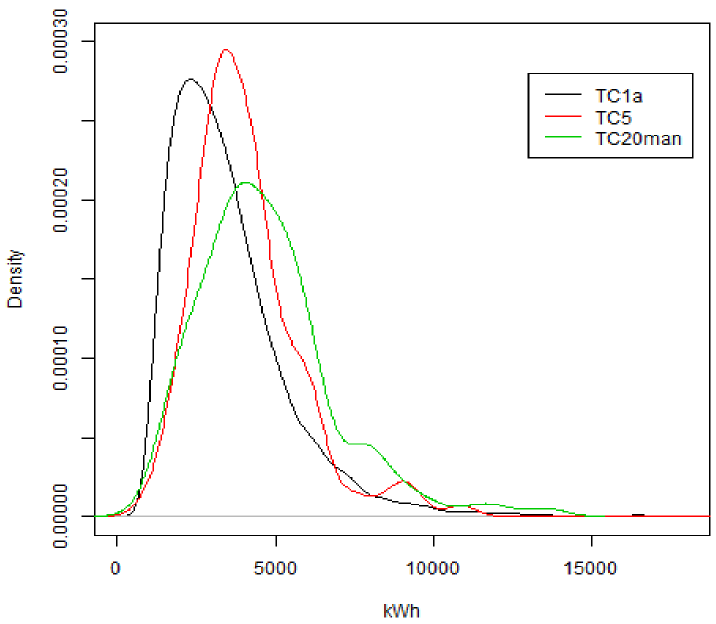
	Number of households taking part in the trial and submitting consumption data	Number of individual households interviewed as part of qualitative research
TC5 – PV and Consumption Display Device	150	13
TC20(IHD) – PV and Generation Consumption Display Devices	107	13
TC20auto – PV, automated Hot water heating and Consumption Display Device	66	5
TOTAL	**323**	**31 (plus 15 follow up visits)**

4. Analysing energy consumption in PV households

4.1 Total Energy Consumption

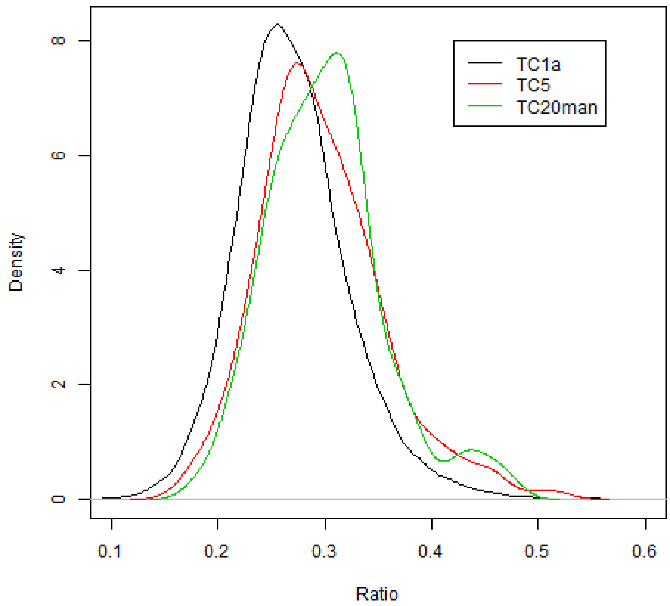
Participants in TC5 and TC20(IHD) were found to have higher overall levels of annual total energy consumption than those in the control group (Figure Total Energy 1). Analysis reveals that total energy consumption was between 10-30% more than TC1a in TC5 and between 24% and 43% more in TC20(IHD) (from the 95% confidence intervals associated with a two-tailed t-test). The overall distribution of customer total electricity consumption is also different, with TC5 and 20(IHD) having a larger number of customers with very high levels of total electric consumption (Figure Total Energy 1). The CLNR project did not include monitoring of total electric consumption before the installation of Solar PV so it is not possible to definitively state whether these customers were already high users of electricity or whether their use of electricity has increased as a result of the installation of solar PV.

Figure 2: Figure Total Energy 1: Distribution of the annual absolute energy consumption for all periods in kWh for TC1a, TC5 and TC20(IHD) (solar generation is excluded for solar test cells)



Households with PV use a higher proportion of their total electricity consumption during the daytime period of 10 am – 4 pm than households in the control group. In short, the 'daytime ratio' of their electricity use is higher than in those households without PV (Figure Ratio 1). This ratio was found to be from 6% to 13% higher than TC1a in TC5 and between 8 to 15% higher in TC20(IHD) (at the 95% confidence level). This pattern of higher ratios of daytime electricity use persisted across almost all months of the trial. As no analysis was undertaken with participants as to the level and pattern of their electricity use before the trial we cannot evaluate whether these higher levels of daytime electricity use pre-date the installation of PV – and may even have provided an incentive for their installation – or whether it reflects a shift in the timing of household practices to take advantage of the production of electricity at this time of the day.

Figure 3: Figure Ratio 1: Distribution of the annual absolute energy consumption between 10am and 4pm divided by the annual absolute energy consumption for all periods for TC1a, TC5 and TC20(IHD) (solar generation is excluded for solar test cells)



Importantly, there was no significant difference in the ratio of electricity used during the daytime period (the period of peak electricity generation) found between participants who had an export/import in-home display (TC20(IHD)) and those who had not been provided with one of these devices on the trial (TC5). Such a finding could lead to the conclusion that the presence of in-home displays or other devices that calculate the generation and use of electricity makes little difference to household energy using practices.

However, our qualitative research suggests the opposite conclusion may be more valid – that the calculation of electricity generation and use is *so important* that households without devices specifically designed for this task undertake their own forms of measurement. We find that PV ownership leads to more active ways of relating to energy, where individuals engage in the calculation of their own energy use and production, as well as in monitoring and managing their use to a greater extent than in other households interviewed during the course of the CLNR project:

> *We keep a record of what we generate, [husband] normally does it, now we've got that thing, he'll [record] how much we sent back and how much we've used. He likes things like that! … That's how much we use in the day, that's how much we used yesterday – we only used 3 but we exported 11. (DL14)*

> *I check it every day. I've got all the stats since we got it, the monthly stats. ... When the number goes round, that's how many units we've brought in, and shoved out to the grid. (DL20)*

Our work with participants found that the green/red signal provided by the in-home display unit as to whether the household was producing or importing electricity was widely welcomed as an easy way to identify when it was appropriate to use electricity and in enabling participants to take a more active role in managing energy systems:

> *[When asked about leaving items on standby] Not after the solar panel, which went in … we were generating, we didn't really think about it. It was after we got that box, that identified to us green and the red, that literally next day changed our habits. (HS01)*

> *I'm in green which means I'm generating more than I'm using. … So whenever it's on green we stick a big appliance on and you are more or less getting that electricity free cause we're generating it. Then obviously at night … it's all red because we're not generating any power. When I went to bed I was putting a wash on and dishwasher on and then obviously realised that that wasn't generating any power at that point. (DL13)*

These findings suggest that the in-home display may replace the improvised and bespoke means through which individuals with solar PV manage their electricity use and was widely welcomed by participants. It further suggests that such devices are readily embedded in the practices of everyday life and may play a role in shifting electricity use into daytime hours. However, others with existing systems in place or high levels of expertise felt that the IHD offered little additional information:

> *I think the reason I don't use it is that I know how much a kettle uses, how much a TV uses. I'm quite knowledgeable about what I actually use. …I've got a meter which measures total power generated, which is in the garage not from the inverter. So that's good information. (DL1502)*

5. Power demand and network planning

The greatest measured average export of PV occurred in TC20(IHD), on 4 June 2013 (day of lowest network demand) at about 1.3kW. This load is comparable to the greatest import demand found in TC1a during January 2013 at 0.9kW and the current design standard of 2kW. This suggests that at current levels of installation, PV generation does not pose a risk to network capacity at the individual customer level.

Figure 4: Figure Peak 1: Distribution of the annual mean 4-8pm peak in kW for TC1a, TC5 and TC20(IHD) (solar generation is excluded for solar test cells)

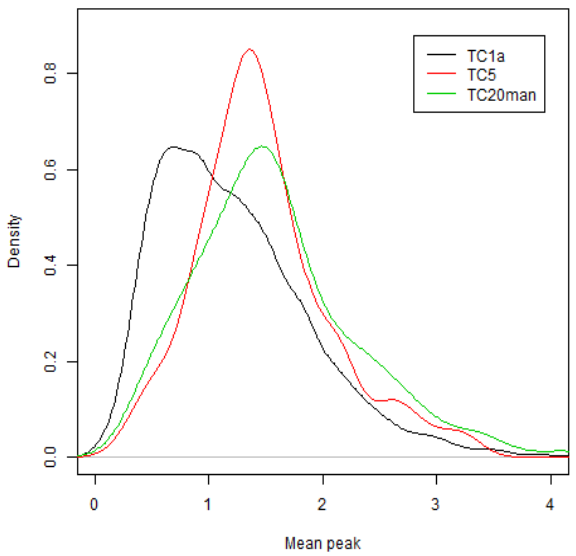
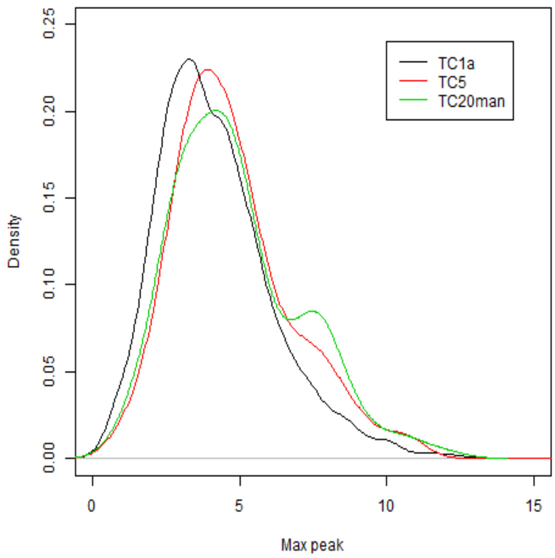


Figure 5: Figure Peak 2: Distribution of the annual max 4-8pm peak in kW for TC1a, TC5 and TC20(IHD) (solar generation is excluded for solar test cells)



Nonetheless, the results do suggest that there are significant differences in overall power demand between households that have PV installed and those that do not. Mean peak power demand was between 14 and 33 % higher in TC5 and between 22 and 41% higher in TC20(IHD) than in the TC1a control group (at the 95% confidence level). The maximum peak power demand was also higher in TC5 (between 8-25% at the 95% confidence level) and TC20(IHD) (of between 9 and 25% at the 95% confidence level) than in the TC1a control group. This suggests that customers with PV have higher loads than those without.

In the absence of data on customer loads before the installation of PV, it is not possible to discern whether they are more likely than the control group to have high loads before they adopt the technology or because their demand changes in relation to the PV installation. We do note however that in the control group, it is those with the highest incomes who have the highest total energy consumption, mean peak power demand and maximum peak demand. Other studies suggest that the biggest factor shaping the take up of PV is the availability of capital to invest (Balcombe et al.

2013), which in turn suggests that it is those with higher incomes who install PV and that it may be the income levels in this group that explain their high levels of energy consumption and load. Nonetheless, any such link should be treated with caution as participants in the trial were not only owner-occupiers but also those who lived in social housing where income levels are traditionally lower than in the owner-occupier group.

6. PV use, everyday practice and flexibility

Previous research suggests that those who adopt PV report a shift in the time at which they undertake common household practices. For example, in Kierstead's (2007) study of 63 households, "43% of respondents reported some form of load-shifting activity primarily in response to the generation profile of their PV system; this occurred mainly in households where technology or the occupants' lifestyle facilitated the load-shift." (p.4135). Our research also found that participants reported that they had shifted the time at which they undertook different activities, particularly those which were regarded as more flexible practices such as washing and drying clothes, using the dishwasher or other chores:

> *I try and I'll even cook things when the sun shines or get a shower when the sun's shining if I can … I just try and make full use of the solar panels. … I'll fill the washer up tonight and in the morning …put it on a timer [on the washing machine] … and it'll be timed to come on later in the day when the sun shines. … If the forecast is for a bright day that's what I'll do. (DL06)*

> *Now that we're producing our own electricity, if it's a sunny day my wife will set the washing machine during the day. (DL12).*

Our qualitative research with households found a difference between those in TC5 and those in TC20(IHD) in terms of the key reasons for the uptake of PV and the consequent ways in which PV electricity was integrated into household routines. In TC5, we find that the uptake and use of PV is being shaped by a particular set of new conventions organised around logics of investment and returns:

> *At the time it was after the crash of '08 and I came out of the health service. I was looking for somewhere to put my lump sum on retirement and instead of putting it in stocks and shares I put it on the roof! And I got the maximum tariff. (DL19)*

> *I don't know 'now about the technology, but it's nice to get that amount for your electricity. Every pensioner should have it as standard. (DL21)*

> *I got an income of £1600 and an outlay of around £1000 so I was getting £600 more than I was using. In terms of what I paid and what I'm getting back from it there's nowhere I would get the same income with security. For 25 years … and I think 25 years will probably see me out! (DL15)*

The UK's feed-in tariff, particularly in the presence of low interest rates and insecurity about housing and financial markets, led to PV being regarded as one of the most secure and profitable forms of investment during 2010 – 2011. PV began to make an appearance in financial advice media primarily as an investment technology than an energy technology (Which 2013; Louth 2013) and has given rise to a logic of investing in PV and focusing on the export of power rather than any engagement with how using the electricity generated by PV could also lead to financial (and environmental) benefits.

Whereas in TC20(IHD), the presence of the in-home display is associated by participants with going further with changes that they had thought could be beneficial when they first adopted PV, but which had not been fully realized. For others the IHD identified new optimal alignments between PV and their practices:

> *We don't want to export. We want to use. ... We are better off using it. That's why we then changed that habit because we're using what we generate. We could change our habits more really, if we thought about it. Probably … We were generating and not really thinking about it - It was after we got that box [the IHD] that identified green, amber, and red that literally the next day our habits changed. It was quite drastic … That's only been recently that I thought about that one but it was just changing the habit from putting them on at night to putting them on through the day. Changing the habit of putting it on at night. (DL13)*

We find that such interventions are creating new ideas of what 'good' and 'valuable' forms of solar generation and use might involve which focus on putting the electricity produced to good use inside the home. In some cases, households report that this leads them to change their everyday rhythms so that practices are removed from the evening peak (e.g. washing clothes, dishwashers) and undertaken during the day. This provides a potentially valuable resource for network operators. Even though the effects on overall power demand are likely to be low, developing ways in which consumers come to use their own electricity could provide network benefits by reducing the risks of voltage imbalance and steady state voltage rise (Wang et al., 2012) especially in areas where PV arrays are clustered on particular distribution networks.

7. Conclusions

Households with PV have higher overall levels of annual total electricity consumption than those without PV. PV households also tend to use more electricity during daylight hours. Householders with PV are more engaged in monitoring, assessing and manipulating their electricity consumption than those without PV. Importantly PV generation does not appear to present a risk to network capacity, at least at the level of individual customers even though customers with PV have higher peak loads than those without. PV households have a strong tendency to shift chores such as washing and drying clothes or using dishwashers according to levels of PV generation. In home-display units are a welcome adjunct to PV households enabling even greater degrees of flexibility. The greatest benefit to network operators emerges from circumstances where PV arrays are clustered.

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For enquires about the project
contact info@networkrevolution.co.uk
www.networkrevolution.co.uk