Customer-Led Network
Revolution

CLNR Insight Report
Domestic solar PV customers with automatic balancing

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Contents

Executive Summary

With the increasing deployment of distributed energy generation from sources such as solar PV, significant net electricity export could challenge distribution networks in ways for which they were never designed. It is important to understand the potential impacts on the energy network and possible mechanisms to mitigate this. In the Customer Led Network Revolution project, households with PV installations and with different methods of maximising self-consumption were monitored to understand the potential to reduce PV export to the grid.

This report considers test cell (TC) 20 (Auto), comprising 93 customers with solar PV and an automatic balancing system designed to divert excess PV generation into a hot water store. This was intended to increase the proportion of PV generation used on site and reduce PV export at times of peak PV energy generation. TC20 (Auto) is compared against baseline group TC1a and TC20 (IHD), the latter comprising PV customers with an in-home display (IHD) notifying users when PV generation exceeded household demand so they can manually increase electricity consumption. This allows a comparison of the effectiveness of an automatic system for increasing load, against that of a manual one.

When making comparisons between the test cells, in general it is only possible to state the observed trends averaged across groups of customers. Trends which hold across a group may not relate to individual households as the spread of behaviour within customer groups can be large.

Compared to TC20 (IHD), households with solar PV and an automatic balancing system were found to show:

- **Higher self-consumption of electricity generated:** 87% of electricity generated was consumed on site for TC20 (Auto), compare to 79% for TC20 (IHD)
- **Lower peak PV export:** on the day of lowest demand, the peak export for TC20 (Auto) was 1kW, compared to 1.3kW for TC20 (IHD).
- **Higher consumption:** TC20 (Auto) had higher annual energy consumption that TC20 (IHD), and both were significantly higher than the reference test cell TC1a.

It was not possible to determine the extent to which these effects were due to demographic differences in TC groups, or to the automatic balancing system alone. However, the data does contain evidence that the automatic system contributes to improved self-consumption:

- Large changes in TC20 (Auto) consumption were observed to correlate with PV output: on sunny days self-consumption was observed to increase.
- In contrast to a “typical” diurnal consumption profile - which has a peak in the 4-8pm period, a very distinct morning/midday peak in consumption is seen in TC20 (Auto) in summer months (when PV output is high). However this mid-morning peak is absent from the TC20 (Auto) consumption data in the winter months (when PV output is significantly reduced).

Average higher daytime demand (and lower export) is seen for TC20 (Auto) during weekends compared to week days, suggesting that in addition to the automatic balancing system, household occupancy still plays a role in the utilisation of PV generation.

Regarding impact on the grid, no new peak was observed during the times of greatest network stress (4-8pm period in winter evenings when demand is highest). Peak export took place at times when demand of the PV households (and the homes around them) was low, which may pose new challenges to networks in the future in terms of increased voltage rise or exceeding the thermal capacity of the local network. However, the households with automatic balancing (TC20 (Auto)), despite having a higher PV generation on average, were found to have lower peak export. An automatic balancing system could therefore be of benefit to networks by mitigating the impacts of peak export.

1 Trial Overview

1.1 Description

This report presents the analysis of the domestic solar photovoltaic (PV) test cell TC20 (Auto), which comprised 93 domestic customers with PV installations and with an automatic load balancing system (as described in section 2.2) which automatically diverts some excess PV generation to hot water storage [1] . The system is designed to reduce peak power export to the grid.

Two other test cells in the CLNR project (TC5 and TC20 (IHD)) have also investigated domestic solar PV and are reported on in document CLNR-L090[1]

- **TC5** investigates households with solar PV generation and no additional interventions.
- **TC20 (IHD)** investigates households with solar PV and an In House Display (IHD) which notified customers when PV generation exceeded household consumption and therefore electricity was being exported to the grid. The objective was to encourage customers to manually adapt their energy consumption to in line with PV generation.

Where necessary, TC20 (IHD) and TC1a ("Basic profiling of domestic smart meter customers") are used in this report as the baseline groups against which the results of TC20 (Auto) are compared.

1.2 Purpose

This trial was designed to support Learning Outcomes 1 and 2. Specifically, it provides the data needed to understand:

- PV owners' patterns of electricity generation, in-home use and export to the grid;
- Whether automatic control of customers' appliances is an effective means to utilise a greater proportion the energy generated by domestic PV systems and prevent electricity export at times of high generation and low demand;
- The extent to which automatic control is more effective than visual prompts to the customers.

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[1] CLNR-L090 Insight Report: Domestic Solar PV Customers

2 Trial Design

2.1 Participation and recruitment

Test cell 20 (Auto) comprised 93 domestic customers, including non-British Gas customers. No out-of-region customers were included. Participants were offered a subsidy of £50-worth of vouchers on joining the trial, and a further £50-worth of vouchers at the end of the trial.

The existence of a solar PV installation was a pre-requisite for participation in test cell 20, which narrowed the potential target group for recruitment. However, the recruitment success rate for the PV test cells (TC5 and TC20) was very good (11%, compared to an industry average for direct-marketing in the region of 1.5%). This is in-line with reports from staff involved in customer recruitment who reported that customers showed interest in how they could make the most of their existing low carbon technologies [2].

Initially, a high number of households recruited were found to be part of “rent a roof” schemes[2], which then had to be excluded from the trial due to the added complexity involved in interacting with the scheme owners. Additionally, the EMMA unit (for controlling the demand) required additional space which was not always available [1]. A resulting shortfall in numbers was made up mainly by working with social housing providers who already had PV installations in place [2].

The factors above are likely to have an impact on the demographic make-up of test cell 20. However, no demographic data is available for this test cell, which should be noted when comparing results against the control test cell TC1a.

2.2 Equipment and tariff

TC20 (Auto) customers had pre-existing solar PV installations, varying in capacity and date of installation. Where not already present, the following equipment was installed:

- **Mains isolation switch** to allow isolation of mains power and safe installation of the secondary meter;
- **Metering:** a secondary meter on the mains electrical supply to monitor energy import and export, and an in-line meter to monitor the energy generation of the PV system;
- **Communications:** a hub was installed to collect the metering data.
- **Cool Power “EMMA” system:** based on 10-minute monitoring of generation and import/export, this system is designed to divert excess PV generation into hot water storage.

No change was made to customers’ existing tariffs, although the installation of a smart meter may have had an effect on the calculation of remuneration under the Feed-in Tariff.

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[2] In this type of scheme, companies lease roof space form homeowners for the installation of solar PV panels. Customers can typically make use of the electricity generated by the panels and thus reduce energy bills, although the scheme operator receives the Feed-in Tariff subsidy related to the generation of renewable energy.

3 Trial Results

3.1 Data available

Table 1 below shows the number of customers and date ranges for which metered data is available for the solar PV test cells 20 (Auto) and (IHD) and the baseline test cell 1a. Although the months of October to December are not directly comparable between the solar PV test cells and the baseline test cell, there is a good overlap during and around the summer months, which are key when investigating the effects of PV generation. Table A1 in the appendix shows the number of days with "good" customer data for each month for TC20 (Auto).

Test Cell	Number of customers	Date range
TC1a	8415	October 2012 – September 2013
TC20 (Auto)	93	January – December 2013
T20 (IHD)	149	January – December 2013

Table 1: Data available in each test cell

Note that during QC procedures on TC20 (Auto), we observed that household consumption was significantly greater than in the reference test cell (TC1a). The difference is ca. 200W average and is quite consistent during the day and overnight. As this is difference is significant, a number of tests were undertaken on TC20A consumption data but we found no evidence to prove this was an erroneous recording. Possible valid explanations for this enhanced consumption include

- Dwellings in TC20Auto were larger (on average) than those in TC1a
- Occupants increase consumption after PV is installed

Although there is insufficient information to prove the above points, they are supported by the observation that both TC5 and TC20 (IHD) (houses with PV) also showed significantly higher consumption than TC1a.

Nevertheless the difference in consumption between TC20 (Auto) and TC1a means that some caution is advised when interpreting the results of this trial.

3.2 Load and generation profiles

The diurnal profiles for gross daily consumption in test cell 20 (Auto) are shown in Figure 1 below. Gross consumption excludes PV generation. The graph also includes profiles for TC1a, TC5 and TC20 (IHD) for reference.

Although the shape of all profiles is broadly similar, the baseline test cell 1a plateaus around 9am whereas the solar PV test cells show consumption continuing to increase after this point. This could suggest an attempt to match energy demand to solar PV generation, and this is explored further in section 3.4.

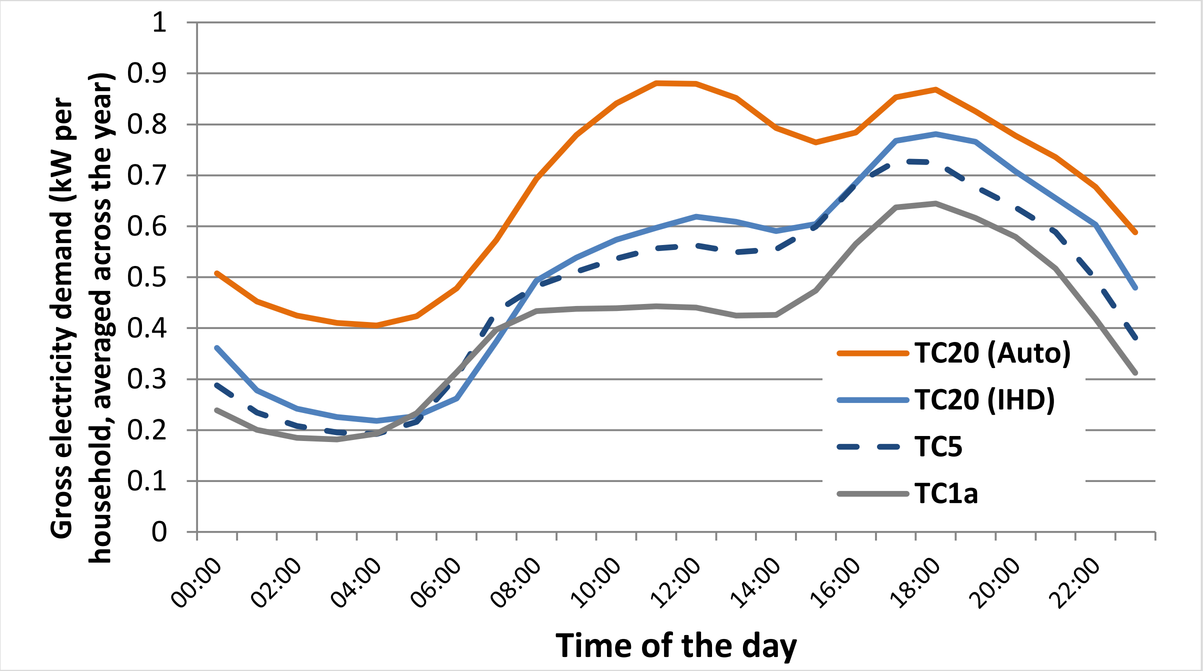

Figure 1: Daily load profiles for all three test cells, averaged across the year. This excludes any PV generation

As expected, PV generation varied across the year, with the summer months showing more power generated and longer generation hours. Figure 2 shows the daily generation profiles for each month for test cell 20 (Auto). The seasonal effect is particularly clear, with average peak generation in June more than four times that of January. Most months show some form of energy generation during the 4-8pm period, which in general corresponds with the times of greatest domestic electricity use.

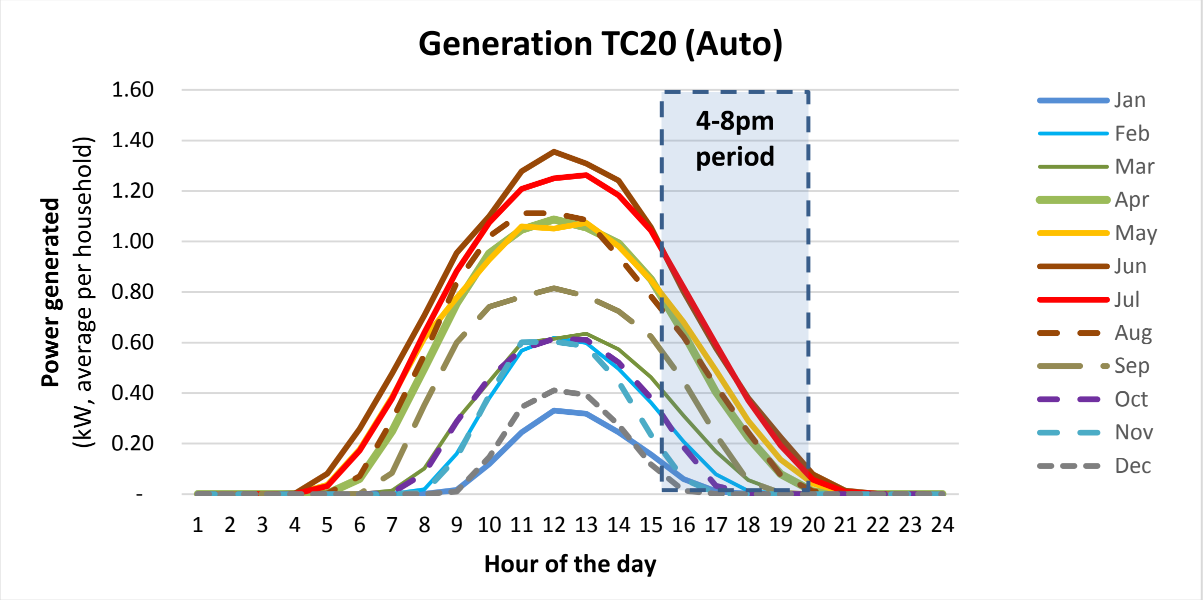

Figure 2: Daily PV generation profiles for test cell 20 (Auto), averaged across each month

3.3 Annual electricity consumption

As mentioned above, the average annual electricity consumed by TC20 (Auto) households was found to be significantly higher than in TC20 (IHD) and TC1a households, as shown in Table 2 below.

Table 2: Annual consumption, generation and export values

	TC20 (Auto)	TC20 (IHD)	TC1a
Annual consumption (kWh)	5,352	4,675	3,498
Annual PV generation (kWh)	2,019	1,925	
Annual net export (kWh)	267	414	

Figure 3 shows the average overall annual consumption for each of the three test cells alongside the energy generated by the solar PV test cells. The electricity generation of TC20 (IHD) households is equivalent to 41% of their annual electricity consumption, and 38% in the case of TC20 (Auto) households.

Therefore, although TCs20 (Auto) and (IHD) show higher gross electricity use than TC1a, the PV generation more than outweighs this. The result is a net annual electricity demand of the solar PV households which is 5 – 20% lower than the baseline test cell.

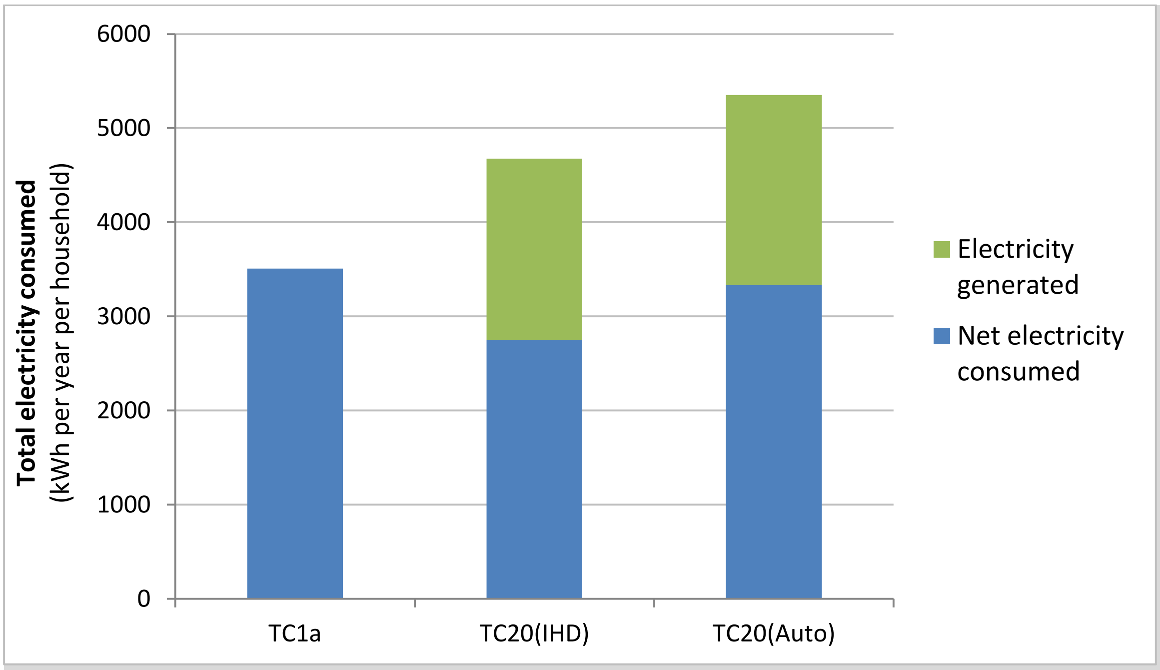

Figure 3: Total net and gross annual electricity consumption

3.4 Load balancing

3.4.1 Proportion of electricity used on site

On average across the year the majority of electricity generated by the PV panels in TC20 (Auto) and (IHD) is used on site (87 and 79% respectively), as shown in Figure 4.

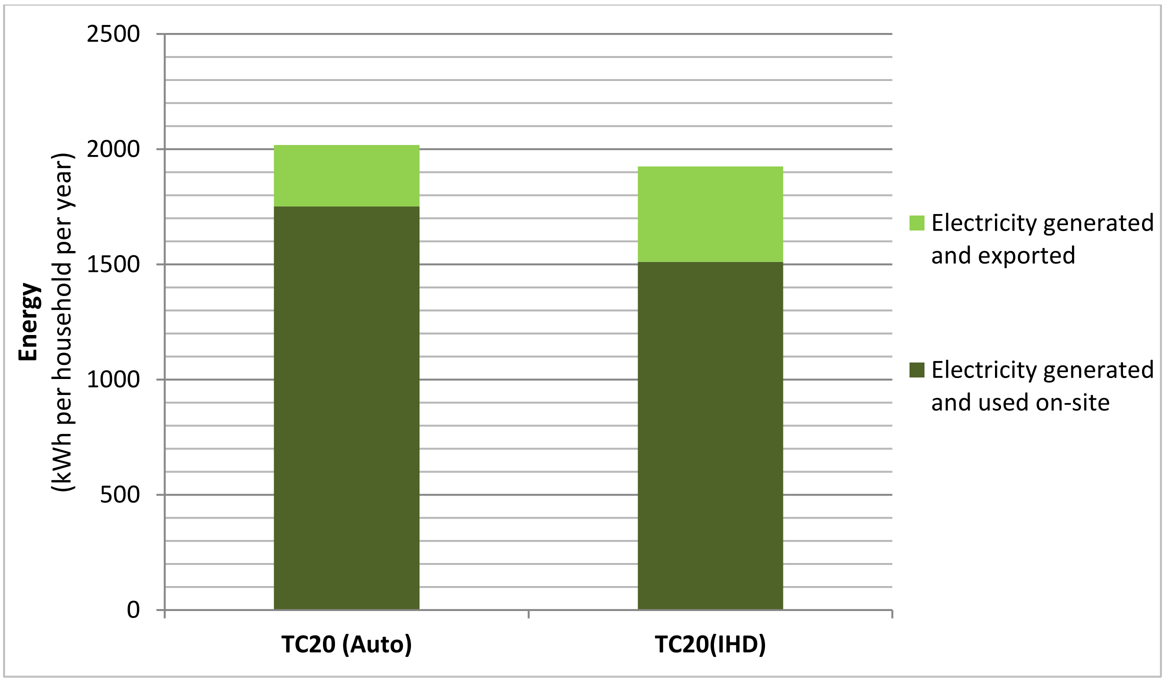

Figure 4: Proportion of generation used on site and exported. Average per household across the year.

The households with automatic appliance control show a higher on-site use of their electricity generation, which suggests that the automatic control is effective at increasing self-consumption. However, overall electricity consumption in TC20 (Auto) is 14% higher than in TC20 (IHD), which would itself increase the proportion of PV generation used on-site.

3.4.2 Peak export

One concern with the mass deployment of PV generation is the onset of a new "time of greatest network stress" due to high levels of electricity exported at the domestic level when low electricity consumption coincides with high generation. To understand the scale of this issue, the day of minimum demand was analysed. Using TC1a as a basis, this was found to be Tuesday 4th June 2013.

Figure 5 shows the average TC1a load profile for this day alongside the gross and net consumption profiles for TC20 (Auto) and (IHD).

On the day of minimum demand, both the PV test cells show a considerable peak export period around midday. around midday. Whereas the TC1a demand in this period is less than 0.5kW, the PV test cells show a peak export of over peak export of over 1kW at midday. TC20 (Auto) peak export which is lower (23% less) than TC20 (IHD), suggesting that (IHD), suggesting that automatic control of appliances is more effective than the presence of an in-house display in house display in terms of mitigating this peak. This can be seen by comparing the gross demand profiles (dotted lines on

profiles (dotted lines on

Figure 5): in TC20 (Auto) the greater demand during daytime hours, partly due to the EMMA system, reduces the excess PV generation exported into the grid.

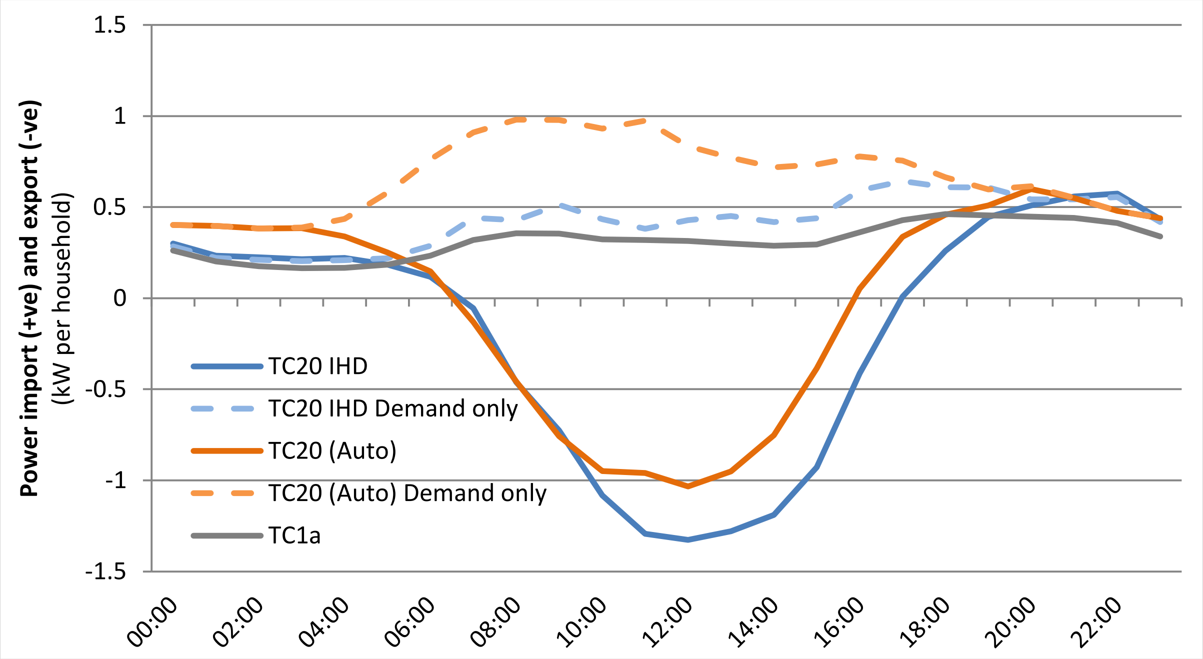

Figure 5: Load profile for Tuesday 4th June 2013, all three test cells.
Positive values indicate consumption, negative values indicate export.

The effect of the automatic control in TC20 (Auto) can be seen more generally by comparing Figure 6 with Figure 7 below. While the TC20 (Auto) winter time consumption profile is similar in shape to TC1a (with a peak in the evening), the summer time consumption profiles are very different. For the reference case with no solar PV or automatic control (Figure 6), electrical demand in the summer months is lower than in the winter months for both daytime and evening periods. However in the case of TC20 (Auto) (Figure 7), in summer the daytime electrical demand is sometimes equivalent to the winter demand in this test cell. This extra demand can be attributed to the automatic control which switches on an electric water heater during times of excess PV generation.

As a further illustration, Figure 8 and Figure 9 compare demand and PV generation for TC20 (Auto) on two consecutive weekdays. During daytime hours, gross demand and PV generation are higher on the 4th of June than on the following day, which is consistent with what would be expected with an EMMA system creating additional daytime demand in hours of excess PV generation.

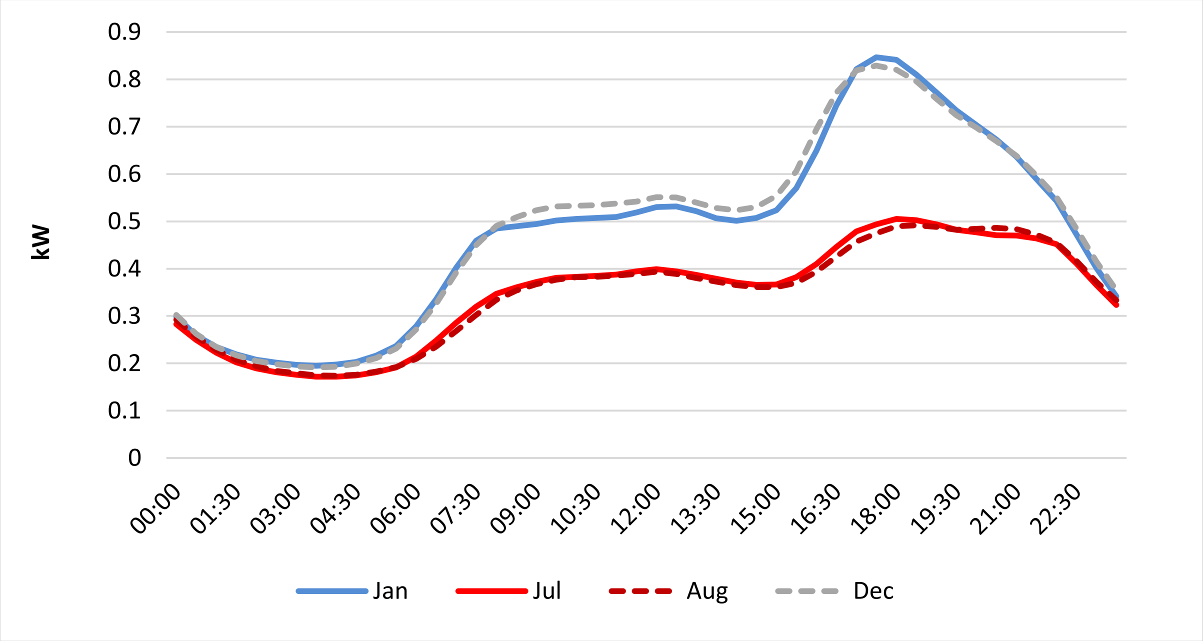

Figure 6: Monthly average demand profiles for TC1a in four selected months

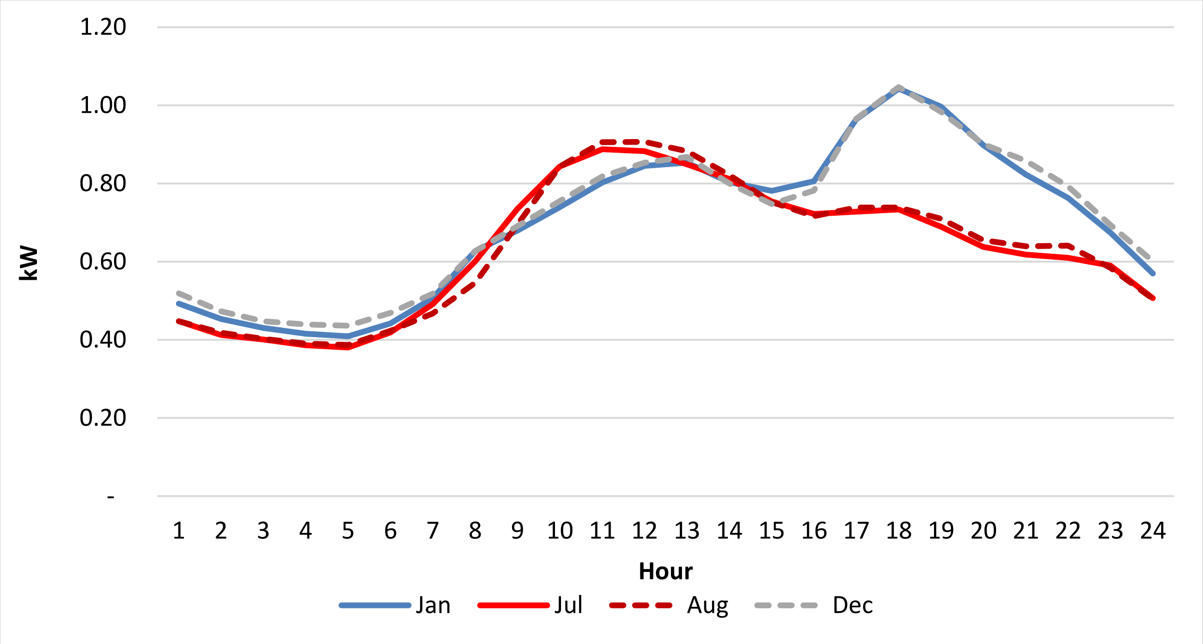

Figure 7: Monthly average gross demand profiles for TC20 (Auto) in four selected months

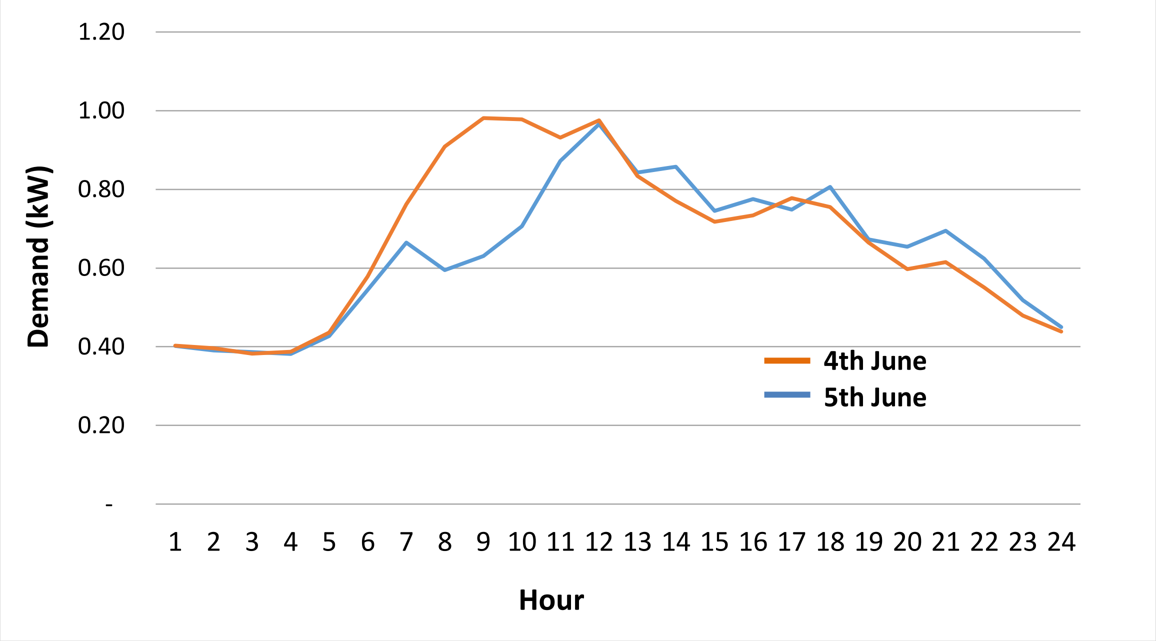

Figure 8: Average gross demand on two consecutive days for TC20 (Auto)

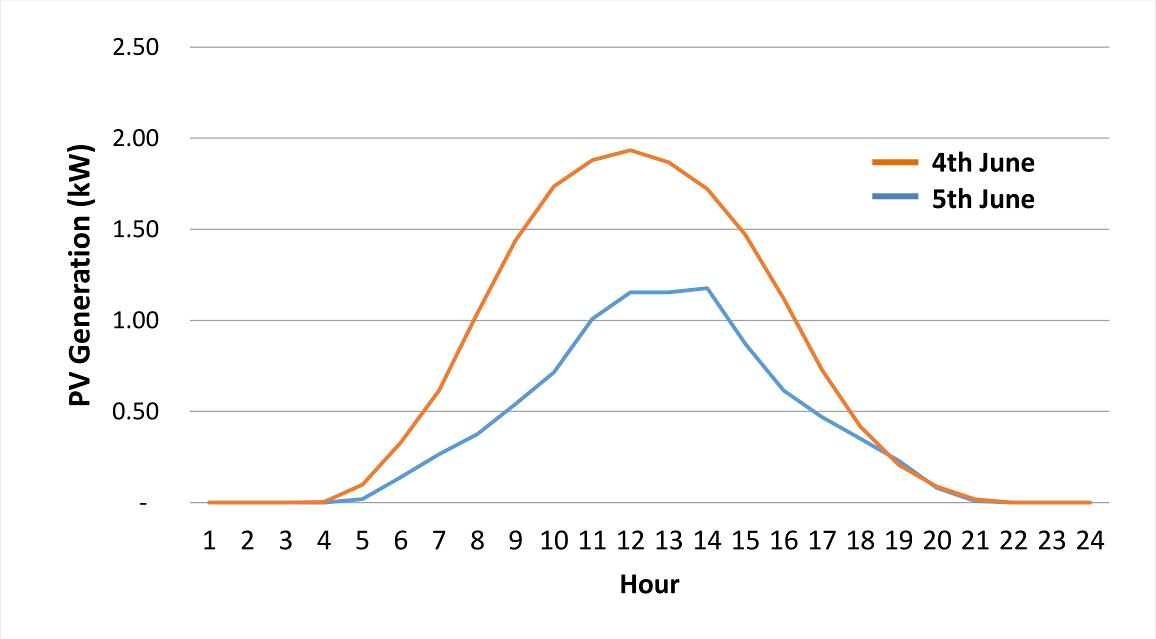

Figure 9: Average PV generation on two consecutive days for TC20 (Auto)

3.4.3 Day of the week

Figure 10 below compares the consumption profiles for TC20 (Auto) on weekends and weekdays. Around midday, when PV generation is likely to be the greatest, electricity demand is seen to be greater on weekends than weekdays. This indicates that in addition to the automatic EMMA power control system, household occupancy still plays a role in maximising the self-consumption of PV generation.

This can be seen more clearly on Figure 11, where export during weekends is reduced compared to weekdays.

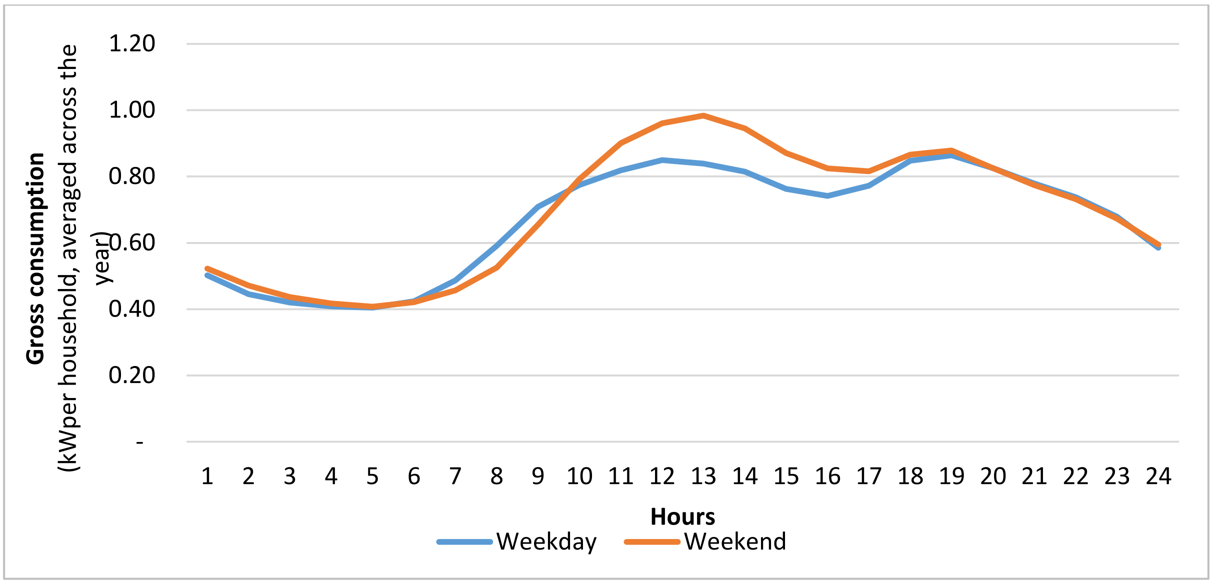

Figure 10: Weekend and weekday consumption for TC20 (Auto)

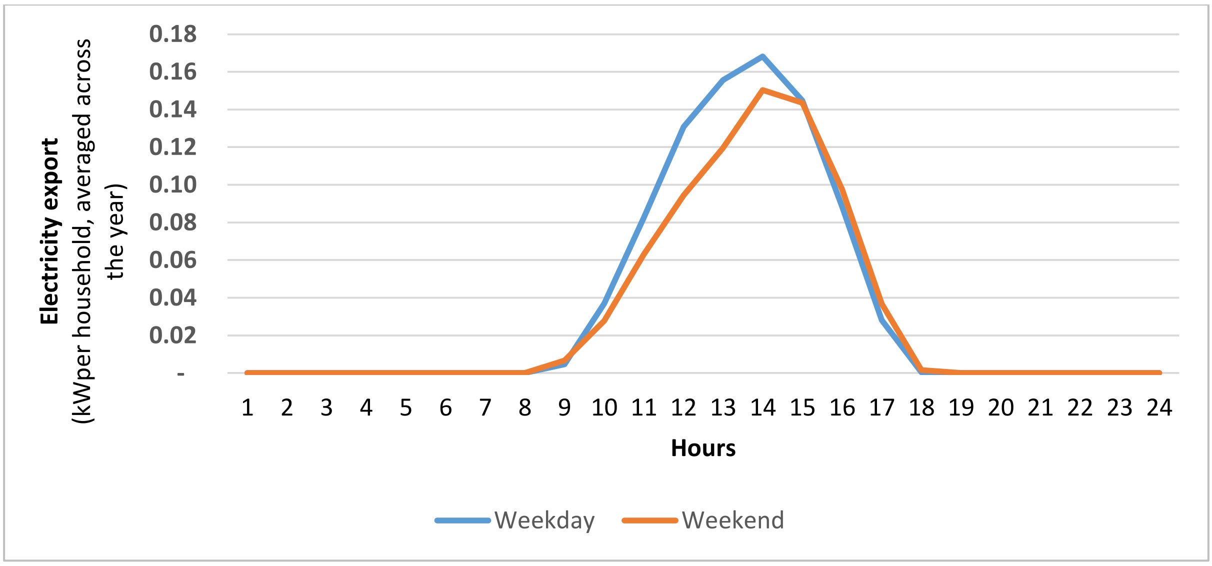

Figure 11: Weekend and weekday export for TC20 (Auto)

4 Conclusions

4.1 Learning Outcome 1

In order to support **Learning Outcome 1**, this report has analysed the electricity demand and generation characteristics of households with solar PV installations and automated water heating to utilise excess generation (test cell 20 (Auto)).

Averaged across the year, customers with PV panels and automated water heating were found to generate an amount of electricity equivalent to around 37% of their annual energy consumption, although as expected this varied considerably between the winter and summer months due to differences in number of daily hours of sunshine, cloud cover and elevation angle of the sun.

During the day, PV generation brought down net demand of these customers, often to negative values (i.e. net export), particularly outside the winter months. At the height of summer, the combination of low electricity demand and high generation leads to peak export of the order of 1.3kW per household for TC20 (IHD) and 1kW per household for TC20 (Auto). These new peaks due to PV export will have to be managed by the network operators as the penetration of solar PV increased. Peak export is observed to be lower in the TC20 (Auto) test cell relative to TC20 (IHD).

On the opposite end of the scale, peak net demand still occurs in the evenings, especially in the winter months.

4.2 Learning Outcome 2

Comparisons between test cells are able to support **Learning Outcome 2**: Comparing TC20 (Auto) against the baseline TC1a allows to investigate whether customers might adapt their electricity use to maximise savings by matching consumption to PV generation, and comparing against TC20 (IHD) allows to look into whether automated water heating can further improve this.

The TC20 (Auto) customers showed a higher gross annual electricity use than both those in TC1a and in TC20 (IHD). This may be down to the additional water heating demand triggered by the EMMA system, but may also indicate some form of “rebound” effect whereby customers who generate some of their own electricity feel able to consume more, which diminishes the net gain of installing any given amount of on-site generation. This could also be due to a different demographic make-up of the customers in TC20 (Auto) compared to TC20 (IHD) and TC1a, although there is not enough demographic information to confirm this.

Comparing TC20 (Auto) to TC20 (IHD) suggests that automated water heating is more effective than customers’ manual intervention at maximising utilisation of PV generation. Investigation of consumption and generation patterns supports the observation that the EMMA system increased self-consumption and reduced PV export. Additionally, electricity export for TC20 (Auto) customers was lower on weekends than weekdays, suggesting that occupancy further increases demand and therefore on-site utilisation of PV generation.

5 References

[1] **CLNR-L262** “Lessons Learnt Report: Customer Trial Equipment Installations”, Clare Dudeney et al, February 2015

[2] **CLNR-L036** “Project Lessons Learned from Trial Recruitment”, Rebekah Phillips et al, July 2013

[3] **CLNR Residential Propositions,** British Gas, February 2013

[4] **TC1a Insight Report,** December 2014

[5] **DEI-CLNR-DC027** “Technical Note: Test Cell 20 Trial Design Note”, Pádraig Lyons, September 2011

[6] **Test Cell 20 dataset**

6 Appendix: Data tables

Table A1: Data availability for TC20 (Auto)

Month	Days with good consumer data	Weekdays with good consumer data	Weekend days with good consumer data
Jan 2013	27	19	8
Feb 2013	26	20	6
Mar 2013	24	16	8
Apr 2013	30	22	8
May 2013	31	22	9
Jun 2013	16	11	5
Jul 2013	31	23	8
Aug 2013	31	21	10
Sep 2013	23	17	6
Oct 2013	30	23	7
Nov 2013	30	20	10
Dec 2013	30	22	8