Effect of COVID-19 lockdown on residential grid electricity and decentralised solar energy consumption in the UK Homes

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Abstract
The lockdowns induced by the COVID-19 pandemic has been forcing people to work and school from home. This study aimed to investigate the impact of COVID-19 lockdown on residential grid electricity and decentralised solar energy consumption in 100 houses from southwestern UK homes with Battery Energy Storage Systems (BESS). We analysed highly granular (1-minutely) grid electricity and decentralised solar energy consumption data for April-August 2020 compared to the same months in 2019 for the same houses for the study. Our study showed statistically significant differences during and after the lockdown period in energy demand, where minutely average electricity demand was 1.4-10% lower during April-August 2020 than in 2019. Our analysis showed that the grid electricity consumption in homes reduced 24-25%, whereas the self-consumption from solar PVs increased 7-8% during the lockdown (April and May 2020) as compared to 2019, predominantly in the morning and afternoon, which might be due to working and schooling from homes during the lockdown.

Keywords: COVID-19 lockdown, Residential electricity consumption, Solar PV, Seasonal-Trend Decomposition, UK

1 Introduction

Extreme disruptive events such as pandemic-induced lockdowns tend to be of high impact for the public and, when sustained, can drive significant changes in behaviour and encourage alternative practices, such as extended periods of working, schooling, or living from home for a significant portion of the population, which is likely to have a clear impact on electricity consumption. In addition, studies and policy reports have already shown that current building stock in parts of the UK is susceptible to overheating (EAC, 2018; Kovats & Osborn, 2016). Therefore, regular and prolonged indoor occupancy during lockdown may make the residential housing stock and the occupants significantly vulnerable to overheating during summer. Furthermore, the literature suggests that considerable uncertainties still exist on the long-term impact of the COVID-19 on the UK's energy demand (CREDS, 2020).

In this study, we intend to understand initial changes in practices during the lockdown, relaxation of those changes as the lockdown was removed, and then reset back to more normal practices as we emerge out of lockdown, to investigate whether some of these changes may be pervasive. We focus on the first COVID-19 pandemic lockdown (started on 23 March 2020 and slowly relaxed from mid-May in the UK) for this study's scope. We analysed the 1-minutely residential grid electricity and decentralised solar energy generation and consumption data for April-August 2020 (summer and autumn) in 100 homes in the South-West of the UK. The objective of analysing decentralised solar energy generation and consumption and total electricity demand of the houses was to examine the self-consumption of PV as residential occupancy (and therefore demand) might become a better match for solar PV generation.

The study will analyse "adapted" residential sector energy consumption during lockdown at an aggregated level for 100 houses. Firstly, aggregated residential demand (from 100 houses) will be studied to examine electricity consumption changes during the lockdown. Secondly, the solar PV generation and consumption from Battery Energy Storage Systems (BESS) were analysed to investigate the lockdown's decentralised electricity consumption pattern. During the lockdown, the electricity consumption was compared with the same temporal duration in 2019, considered the pre lockdown demand. The residential grid and decentralised solar electricity consumption pre and during lockdown were investigated to explore the impact of COVID-19 pandemic induced lockdown on the aggregated demand.

2 Methodology

In the study, we used the Local Energy Market (LEM) Residential data from the Cornwall LEM (Centrica PLC) project, which was part-funded by the European Regional Development Fund under European Structural and Investment Funds Programme 2014-2020 (Nichols & Kane, 2021). The database had 1-minutely electricity demand and generation data from 100 houses in the South-West of the UK for April 2018- September 2020. The project's remit was to develop a LEM trading platform for houses with Solar PV and behind-the-meter Battery Energy Storage Systems (BESS) (Figure 1). Measurements at each site included (all energy values were in Wh per minute):

- Energy consumption on the site.
- Energy from the Solar PV system.
- Energy charge/discharge to and from the BESS.
- Energy exported and imported to and from the grid, respectively.
- Energy from the Solar PV system that:
    - was used to charge the BESS directly.
    - Fed instantaneously consumption.
    - Spilt instantaneously to Grid Export.
- Energy from the BESS that:
    - Fed consumption instantaneously.
    - Exported to the grid to feed the community.
- PV & BESS standby loads.
- BESS state of charge (in %).
- Grid/BESS/PV active power (V).
- Grid voltage (mV), frequency (Hz), and Power Factor (%).

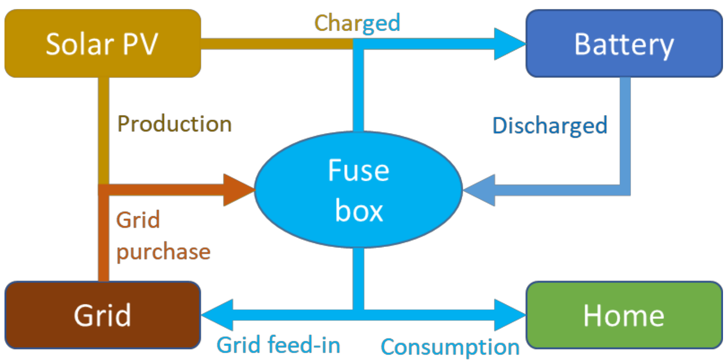


Figure 1: Energy systems and flow in the monitored houses

Although the primary dataset composition was explicitly recorded for LEM trading trials, the consumption data alone were of principal interest in this work. The PV and BESS performance was intentionally omitted to direct attention to COVID-19 related impacts on the general population. Additional site-by-site MetaData also accompanied the primary time-series dataset, describing dwelling and household composition; this was also used in the present work.

We analysed energy consumption data from the Cornwall LEM database (via the MySonnenBatterie (MSB) portal) during COVID-19 lockdown to investigate residential electricity consumption under extreme disruptive scenarios in the South-West of the UK. First, we analysed the aggregated consumption in the studied months for both years. We also conducted dependent t-tests to examine if the difference in the mean demand in the two-period were statistically significant or not. Second, the aggregated 1-minutely electricity consumption (Grid and BESS) data were analysed to examine the impact of lockdown on the energy system variables mentioned in Figure 1. Then the grid and solar PV electricity consumption was analysed in different parts of the day to study lockdown on the user demand. Third, the grid and solar PV electricity was examined with the Seasonal-Trend Decomposition (STL) based approach (Cleveland, et al., 1990) from 100 houses to investigate the changes in seasonal trends of total residential demand over disruptive periods April-August 2020 and compared with the same period in 2019. For the analysis, we used the R code from (Patidar, et al., 2021).

3 Household, appliances, solar PV, and storage capacity analysis

Among the 100 houses, 67 houses had a floor area between 41-191 square meters (sqm) (Figure 2A). There were 56 detached (30 houses and 26 bungalows), 12 semi-detached, three mid-terrace and six end-terrace houses. In the monitored 100 homes, 213 occupants (34 houses had no data) were 40 children, 138 were adults aged 16+ and 35 were aged over 65 (Figure 2B).

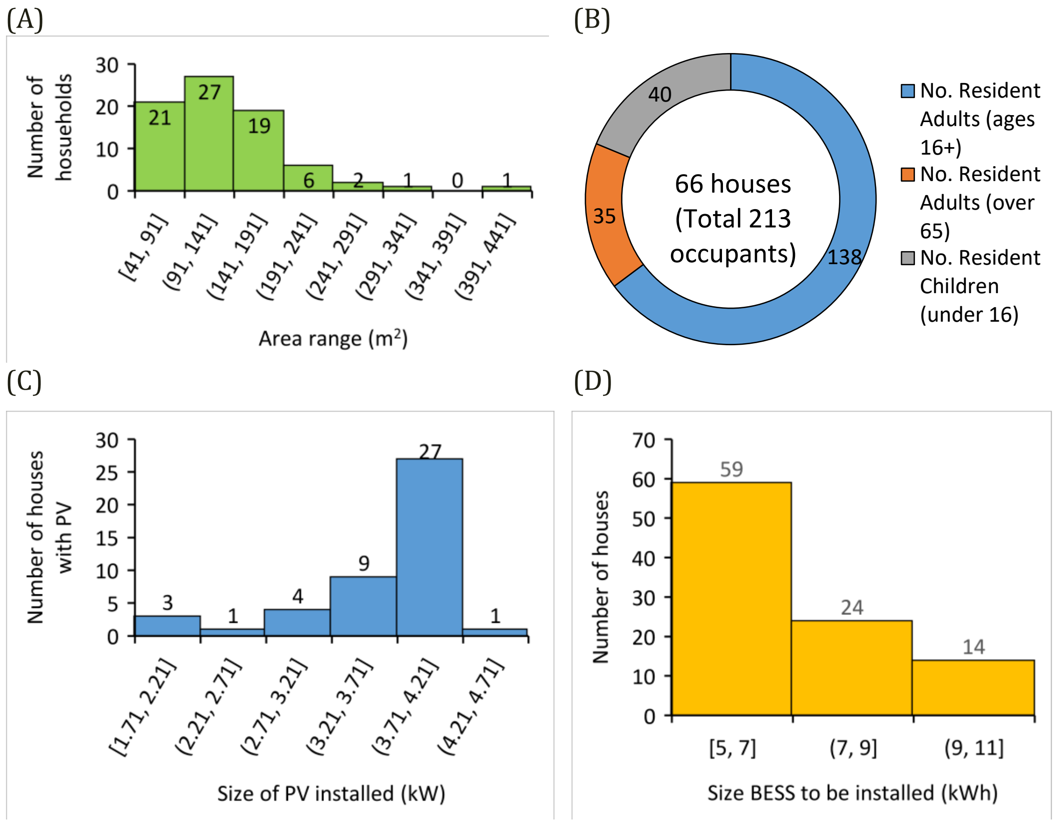


Figure 2: (A) Floor area distribution among 77 houses (23 no data); (B) Number of occupants in 66 Houses (No data for 34 houses); (C) Number of houses with PV distribution among 45 houses (55 no data), (D) Number of houses with different size Battery Energy Storage Systems (BESS).

In terms of the Solar photovoltaic (PV) installation, 45 houses reported they had installed PVs with a capacity ranging from 1.71-4.71 kW. A maximum of 27 houses with solar PVs of 3.71-4.21 kW (Figure 2C). All the monitored houses had Battery Energy Storage Systems (BESS). Among the ten houses, there were three Sub-fleets: 5kWh (59 houses), 7.5kWh (24 houses) and 10kWh (14 houses) (Figure 2D).

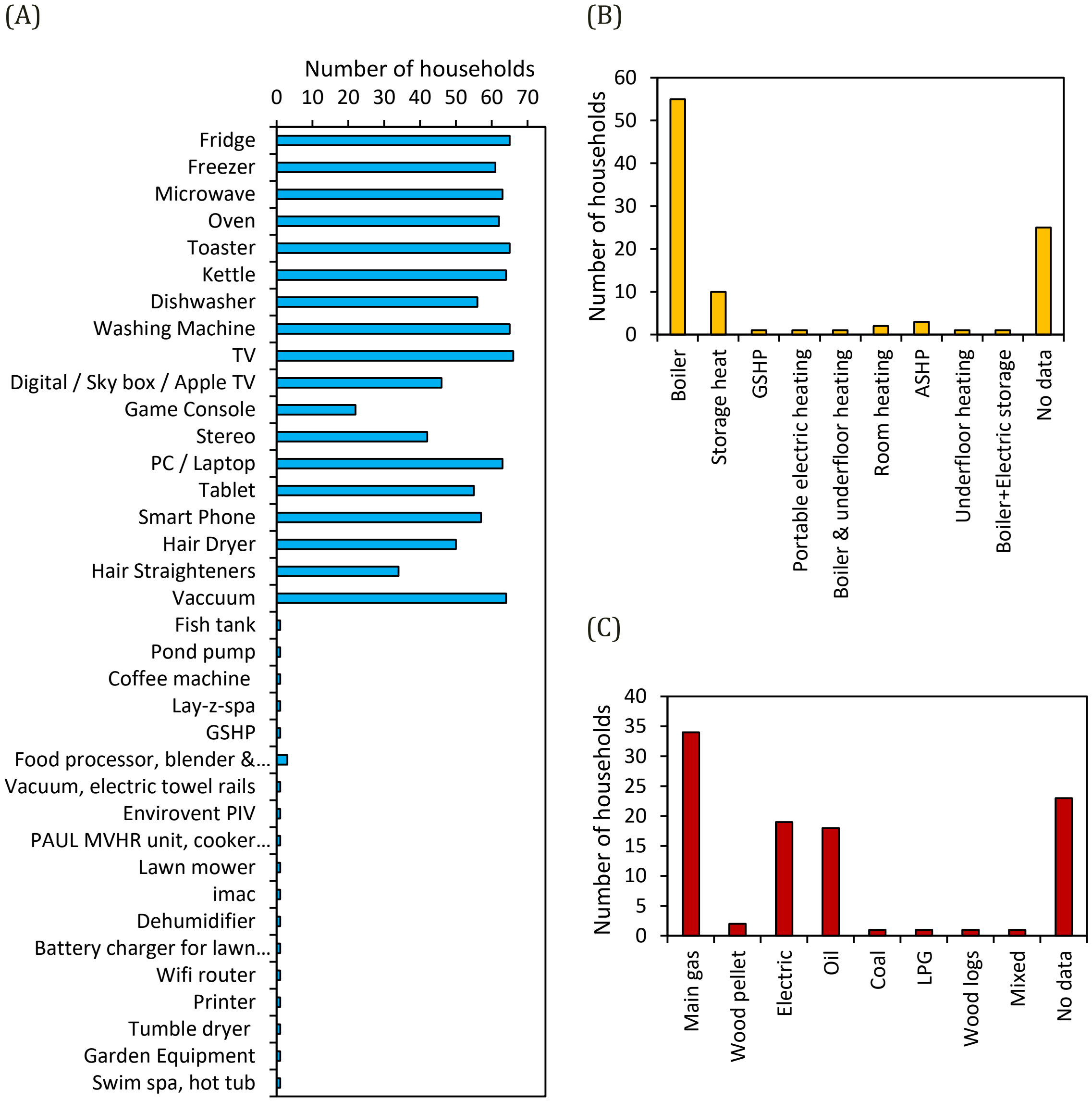


Figure 3: (A) Cumulative number of appliances in 66 houses (there were no data for 34 houses); (B) Heating types in 100 households; (C) Heating fuel used in 100 houses.

In terms of the houses' appliances (No data for 34 houses), more than 90% of houses (out of 66 houses) had fridges, freezers, microwaves, oven, toaster, kettle, washing machines, TV, PC/laptops, vacuum cleaners (Figure 3A). Most of the houses had dishwashers, tablets, smartphones, hairdryers, hair straighteners, digital/skybox/Apple TV, and game console. In terms of heating, 55 houses used boilers (Figure 3B), of which 34 were gas and 18 were oil-fueled (Figure 3C). There were also electric heating systems in 19 houses, such as underfloor heating, portable heating, heat storage, Air source heat pumps and ground source heat pumps (Figure 3B). Four houses were using coal, wood logs, and wood pellets for heating.

4 Result

First, we analysed the electricity consumption, Solar PV based electricity generation, self-consumption (by the users), battery charge, discharge, grid electricity export and grid electricity consumption to see which component of the BESS showed the impact lockdown through any change. Then for STL analysis, we focused on the ones with significant change due to COVID-19 lockdown.

4.1 Total electricity consumption

As shown in Figure 4, the mean of minutely aggregated electricity consumption reduced 1.4-10% in April-August 2020 than in 2019. During the first lockdown period, the total electricity consumption decreased 6.5% and 1.4% in April and May 2020 than in 2019. Also, the distribution of monthly electricity demand changed from unimodal to bimodal, denoting a shift in consumption in 2020. During April and May 2020, the electricity consumption shifted to lower and higher bins, whereas the demand shifted towards lower bins in June-August 2020 than in 2019. A dependent t-test was conducted on the minutely aggregated electricity consumption where the null hypothesis was 'there is no statistically significant difference in mean consumption in 2019 than in 2020'. The p-value less than 0.05 suggested rejecting the null hypothesis at a 95% confidence interval, denoting a statistically significant difference in average consumption in 2019 to 2020 for each analysed month.

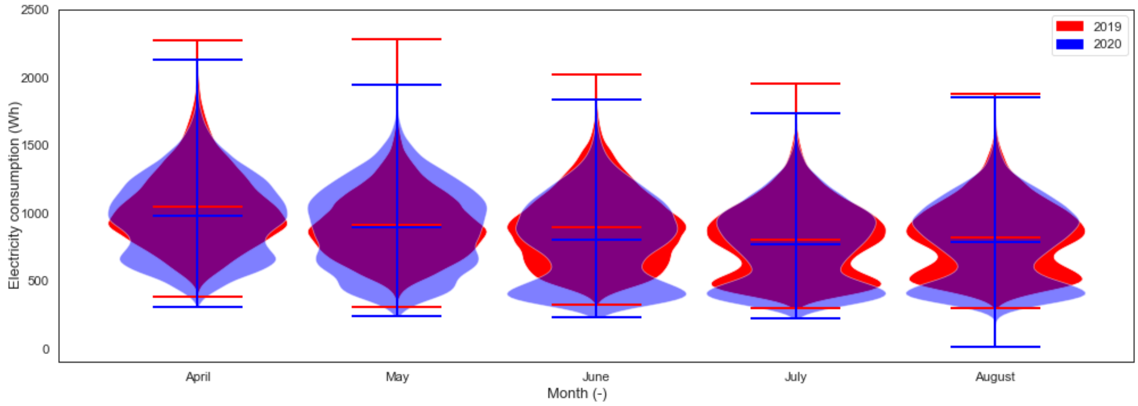
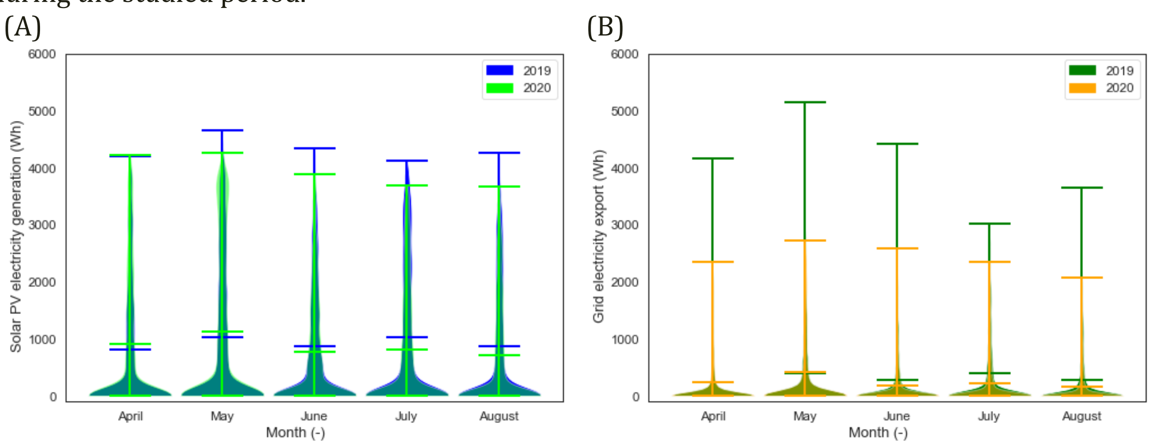


Figure 4: Minutely aggregated electricity consumption comparison between 2019 and 2020

4.2 Total solar PV generation, battery charge, discharge, and grid export

In the total Solar PV generation, during April and May 2020, the average increased 11.3% and 9.6% than 2019 (Figure 5). But the solar PV generation decreased 12-20% in June-August 2020. However, the mean battery charge, discharge, and grid export in April-August 2020 showed a minimal change than in 2019. Solar PV electricity generation highly depends on the weather during the studied period.



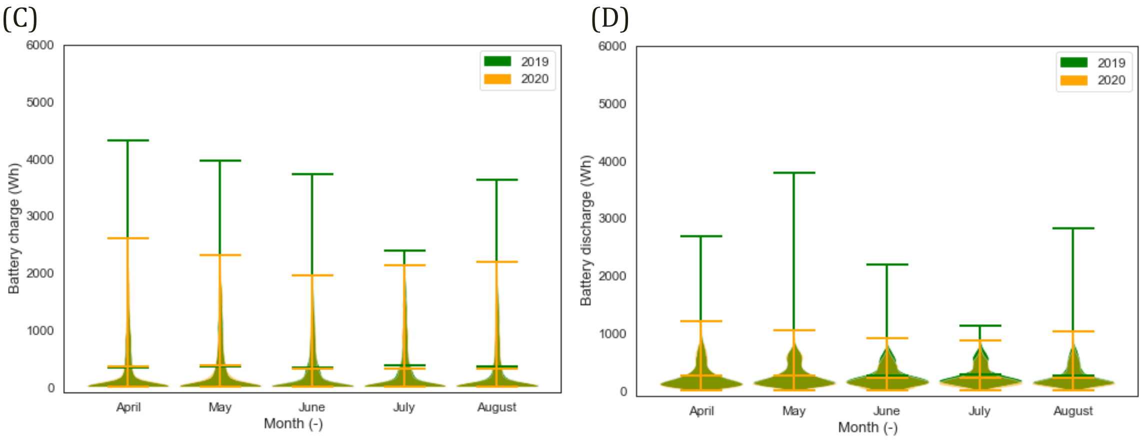


Figure 5: Minutely aggregated (A) Solar PV electricity generation, (B) Electricity export to grid, (C) BESS battery charge, and (D) BESS battery discharge comparison between April-August 2019 and 2020.

4.3 Total grid and Solar PV electricity consumption

As the aggregated electricity consumption showed a significant decrease in Figure 4, two types of instantaneous consumption were analysed in the studied homes: grid and solar PV electricity. In solar PV self-consumption, mean electricity consumption increased 7.6% and 6.9% during the lockdown in April and May 2020 than in 2019 (Figure 6A). However, after the easing of lockdown, the mean consumption increased minimal (0.3-0.8%). The consumption shifted towards the higher bins during the lockdown (April and May 2020), maintaining a unimodal distribution.

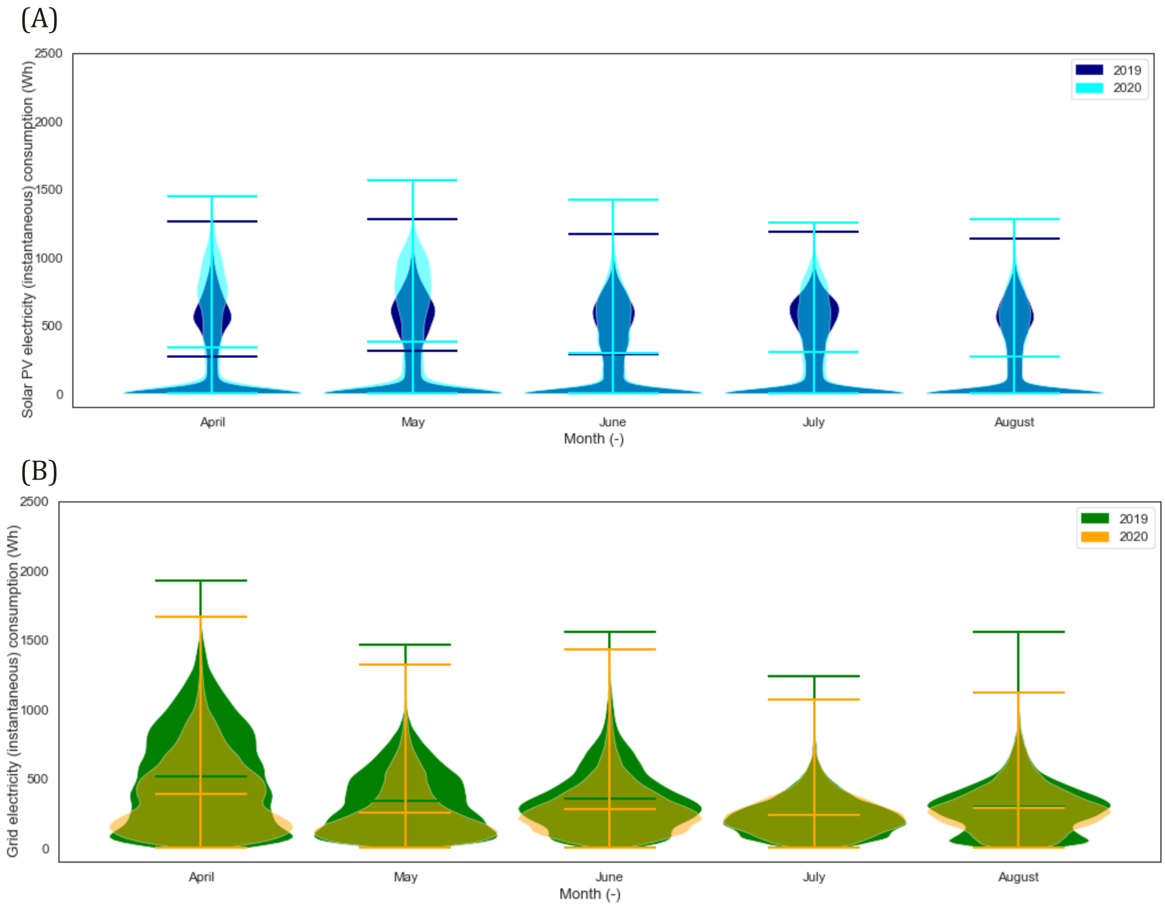


Figure 6: Minutely aggregated (A) Solar PV electricity consumption, (B) Grid electricity consumption comparison between April-August 2019 and 2020.

On the other hand, the grid electricity consumption demonstrated a 2-25% average demand reduction (Figure 6B). During the lockdown, the reduction was the largest in April (25%) and May (24%) 2020 compared to 2019. In June, the average demand reduced 20% but increased 2% in July and decreased 2.5% in August 2020. The electricity demand shifted towards lower bins creating bimodal distribution in April but maintained unimodal distribution in May 2020.

4.4 Time of the electricity use: Solar PV and grid

To explore the impact of lockdown on the time of use of electricity, we divided the day into five parts: Morning (05:00-11:59), afternoon (12:01-17:59), evening (16:00-20:59), Early Night (21:00-23:59) and Late Night (24:00-04:59). The Solar PV electricity consumption increased 39-56% (weekdays) and 25-84% (weekends) in the morning in April-August 2020 (Figure 7). Furthermore, the electricity demand elevated 12.6-13.5% (weekdays) and 2-5% in the afternoon during the lockdown. The demand reduced in the evening in April-August 2020 than in 2019.

(A) (B)

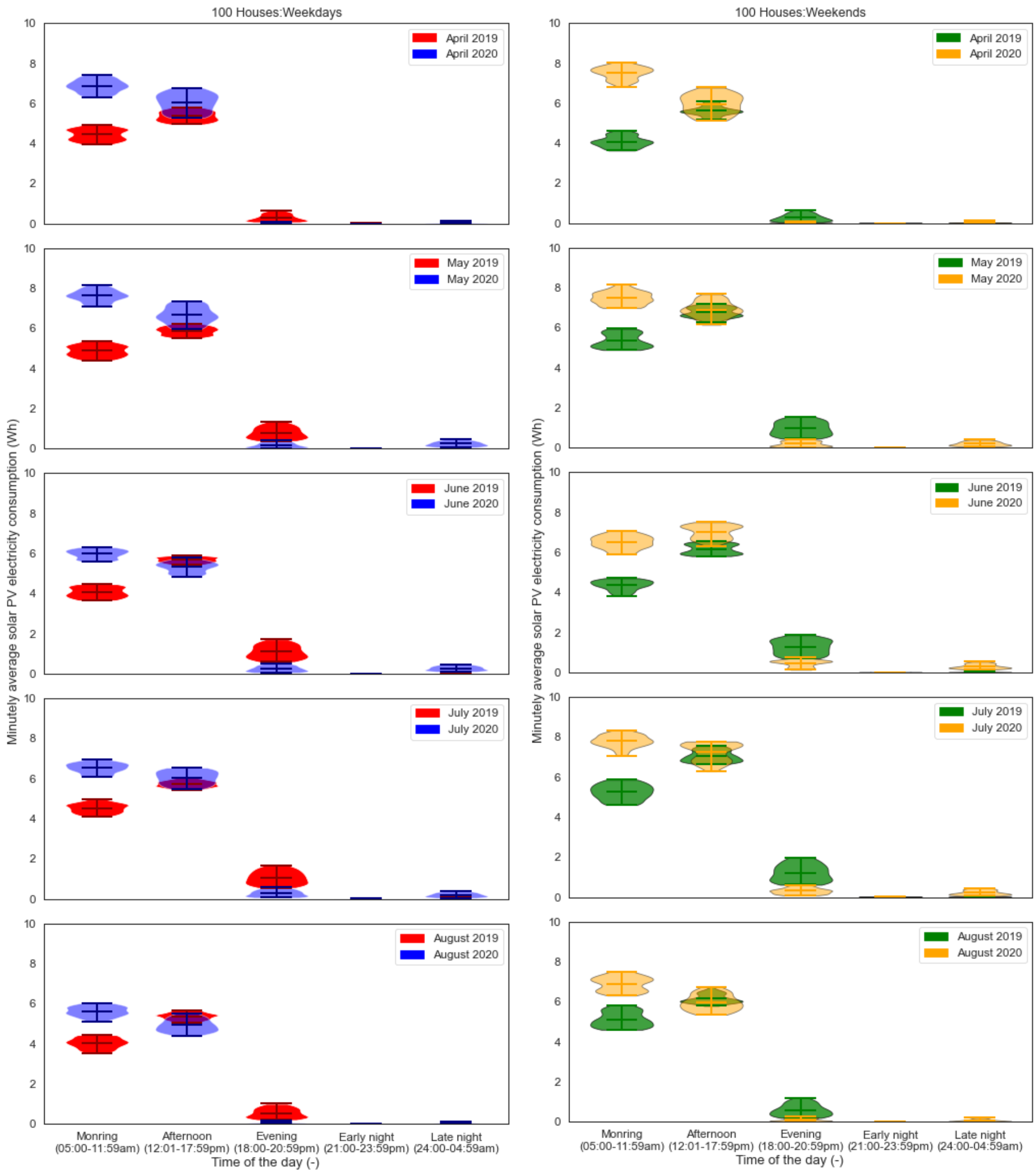


Figure 7: Minutely average solar PV electricity consumption during (A) weekdays and (B) weekends.

In the case of the grid electricity consumption by the studied homes, demand reduced 21-34% (Weekdays) and 30-53% (Weekends) in the morning during April-May 2020 than in 2019 (Figure 8). In the afternoon, demand increased 5% on weekdays and decreased 53% at weekends in April 2020 than in 2019. However, the demand decreased 7% on weekdays and 4% at weekends in May. The grid electricity demand decreased 7-30% (Weekdays) and 7-48% (Weekends) in the evening, early night, and late nights during the first lockdown in 2020 than in 2019. The reduction gap in grid electricity demand mostly reduced in June 2020 after the lockdown. Furthermore, the electricity demand in the different parts of the days (weekdays and weekends) in July and August 2020 was very similar to 2019.

(A) (B)

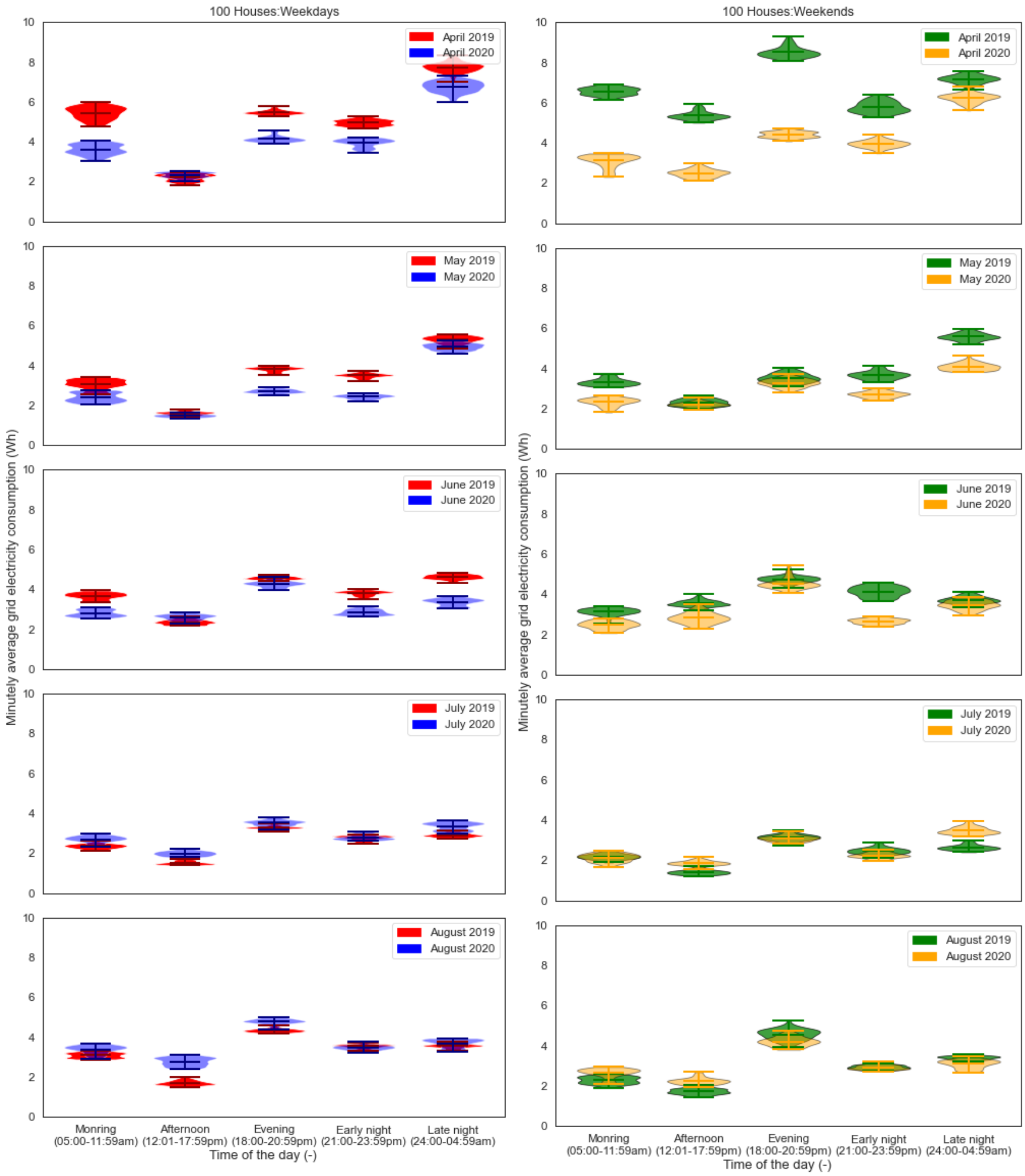


Figure 8: Minutely average grid electricity consumption during (A) weekdays and (B) weekends.

4.5 Seasonal-Trend decomposition using Loess (STL) analysis

The previous aggregated and time of the day for electricity use analysis showed a significant impact of the lockdown on the solar PV generated and grid electricity consumption. We conducted STL analysis to investigate the seasonal trend of the electricity consumption (Solar PV and grid). In the Solar PV electricity, the demand increased in week 1 and 2, before reducing in week three and increasing in week 4 (April 2020) than in 2019 (Figure 9). In May 2020, the demand reduced in week one but increased in Week 2-4 than in 2019. After the lockdown, the difference in the seasonal trend in demand was minimal in June-August 2020.

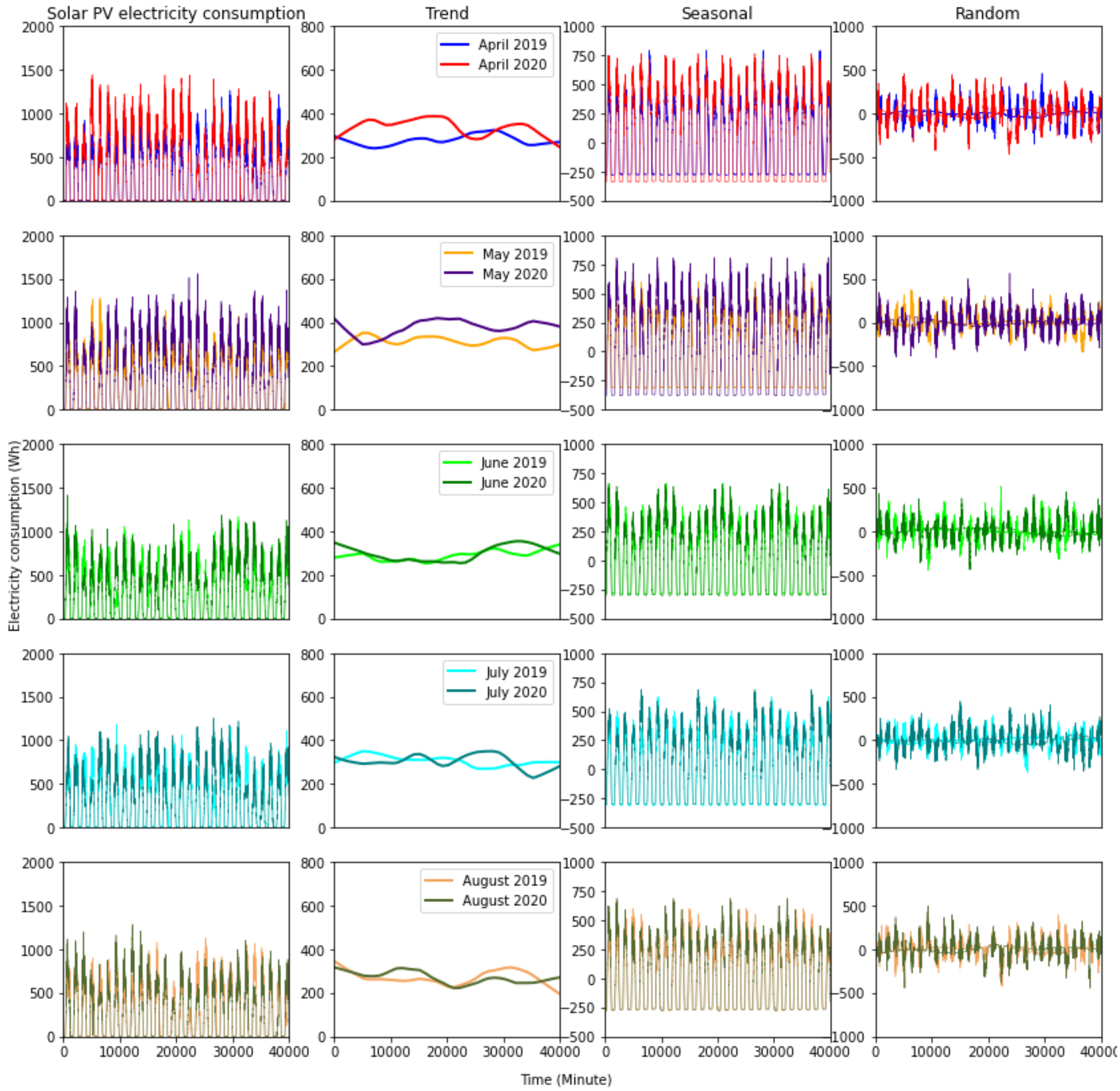


Figure 9: Seasonal-Trend decomposition using Loess (STL) analysis of minutely aggregated solar PV electricity consumption during April-August 2019 and 2020.

In the case of grid electricity, during the lockdown, the demand reduced in week 1-2, before increasing in week three and again decreased in week 4 in April 2020 than in 2019 (Figure 10). The reduction continued in May 2020, with a slight increase in weeks 1 and 2. After the lockdown, the seasonal trend in demand was minimal in June-August 2020. With the STL analysis, the minutely solar PV and grid electricity demand showed opposite trends during UK's first lockdown. As the lockdown started to ease in mid-May 2020, the increase in solar PV and decreased grid electricity consumption started to show a similar trend as in 2019.

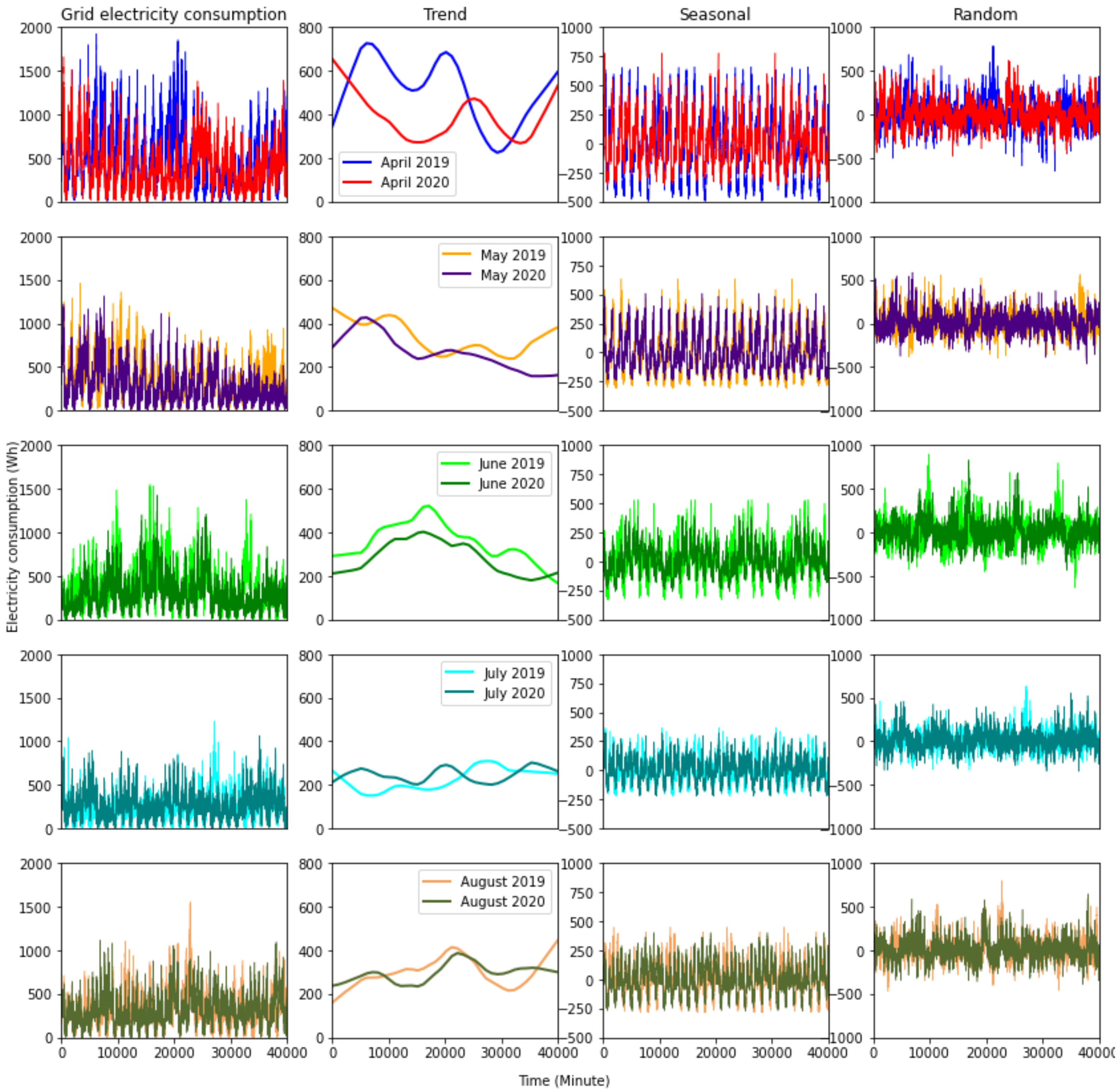


Figure 10: Seasonal-Trend decomposition using Loess (STL) analysis of minutely aggregated grid electricity consumption during April-August 2019 and 2020.

5 Discussion

In the presented study, the aggregated electricity demand showed a 1.4-10% decrease in consumption. As the studied homes had BESS, the supplied electricity was provided by solar PV and grid. The results showed the solar PV electricity demand increased 7.6-6.9%, whereas grid electricity consumption decreased 24-25% during the lockdown. Solar PV electricity increased in the morning and afternoon during the lockdown, which might be due to extended working and schooling from home. However, the grid electricity demand decreased in the same period denoting the high dependency of residential consumption on Solar PV.

As the instantaneous consumption (self-consumption) of solar PV electricity increases during the lockdown, most likely due to working and schooling from home, employers working from home should get financial incentives. Because first, the houses were selling the electricity to the grid, but when they are consuming the energy from Solar PVs, they are mostly consuming during the morning and afternoon. Also, self-consumption reduces their overall consumption during the night period but increases the electricity demand during the lockdown. Thus, the working from home practice can increase decentralised renewable solar electricity, as seen during the lockdown. But the use of decentralised renewable solar electricity reduced to a similar amount in 2019 after the lockdown (June-August 2020).

However, it was unclear why solar PV electricity was increasing while grid consumption decreased and how the high self-consumption affected the financial return of grid feed-in. Our study instigated more intriguing questions regarding household practice change. The increased consumption of Solar PV generated electricity during lockdown would require further investigation, which we intend to conduct.

6 Conclusion

COVID-19 pandemic induced the first lockdown in the UK significantly influenced people's daily life. However, how such a scenario affected electricity consumption through the change in routine and practice were ambiguous. This study investigated the 1-minutely electricity consumption data of 100 houses with BESS to investigate the impact of lockdown on residential electricity use, especially on-grid and decentralised solar PV electricity consumption, by comparing between April-August 2020 and 2019.

Our analysis showed a 1.4-10% reduction in minutely aggregated electricity consumption compared to the same period of 2019, likely due to working from home and children being home the whole day as many of the houses had children. Aggregated minutely electricity consumption per month for April-August 2020 showed a substantial shift in consumption data distribution from unimodal distribution to bimodal distribution, suggesting that two distinctive consumption patterns were happening in those 100 houses.

The electricity consumption from the grid and solar PVs showed different impacts during the lockdown. The results showed the solar PV electricity demand increased (7.6-6.9% in 2020 than 2019), whereas grid electricity consumption decreased (24-25% in 2020 than 2019) during the lockdown. Solar PV electricity increased in the morning and afternoon during the lockdown, which might also be due to extended working and schooling from home. However, the grid electricity demand decreased in the same period denoting the dependency shift of residential consumption towards Solar PV generated electricity.

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