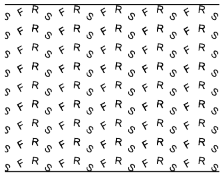
Assessing Pandemic Response of Singaporean Households using Electricity Consumption Data



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(FRS) FUTURE RESILIENT SYSTEMS

- → During a pandemic, like COVID-19, policymakers need to know how populations' daily behaviours change in order to evaluate and adapt public health interventions. Here, we propose to use domestic electricity-consumption data to showcase the behaviour of households in the first few months of this pandemic.
- → Studying over 10,200 Singaporean households, we find that daily new COVID-19 cases predominantly influenced the electricity demand before a lockdown was implemented. However, this influence waned during the lockdown, signifying that residents settled into their new lifestyles. This implies that Singaporean residents increasingly stayed in or performed more activities at home during the evenings before a lockdown, despite there being no government mandates – a finding that surprisingly extends across all demographics.
- → Overall, this study enables policymakers to close the loop by utilizing residential electricity usage as a measure of population response during unprecedented and disruptive events, such as a pandemic.

Household Electricity Demand as an Accurate and Real-time Indicator of Population Response

To mitigate the coronavirus disease 2019 (COVID-19) pandemic, individuals across the world are required to alter their behaviours significantly, at least until pharmaceutical interventions such as vaccines are developed and made available at scale (Bavel 2020). In this context, it is imperative to accurately assess populations' responses, which enables policymakers to adjust interventions such as health advisories and mobility-reduction measures – particularly during critical periods such as the initial stages of the pandemic – adaptively as well as retrospectively (Hatchett 2007). For instance, showing that people are actively modifying their daily routines – e.g., by increasingly working from home and avoiding venturing into public spaces – can inform authorities about the extent to which they follow through on recommendations from public health experts. The challenge, then, is to identify specific measurable indicators that can constantly and accurately capture such behavioural changes.

By reviewing the pertinent literature, we have identified the following indicators that are currently being used to study social behavioural changes during the COVID-19 pandemic. The first indicator comprises responses gathered from the population by means of surveys. Thereby, researchers have attempted to obtain an overview of public perceptions (e.g., Lazarus 2020). But this approach has several disadvantages: 1) Self-reported responses could either be untrue or exhibit a skew toward ideal or expected behaviours, rather than reflecting the reality (e.g., respondents could report that they are concerned about the pandemic and are self-isolating, while in reality taking no such actions); and 2) surveys only present snapshots of the population's behaviour at a particular time. Therefore, it may be difficult to glean any meaningful trends, given the fast-changing environment. The second indicator encompasses anonymized data from mobile phones, including passive geolocation data collected by mobile phone operators and actively collected contact-tracing data through dedicated applications (apps) (e.g., Grantz 2020). By determining the time spent by people at their homes and outside (e.g., in workplaces, shops, etc.) and analyzing how these behaviours change over time, recent studies (e.g., Chang 2021) have attempted to discern the social response and design targeted interventions. However, this approach

suffers from limitations as well: 1) Contact-tracing apps may not be used by many phone users, especially at the early stages of the pandemic; 2) individuals could own more than one mobile phone, or multiple individuals may share a phone; and 3) demographic differences in phone usage exist, with groups such as children and the elderly potentially underrepresented. These factors could distort the outcomes of such studies.

Yet, while the above indicators attempt to gain insight into people's daily behaviours during the pandemic, surprisingly, studies in this context to date have not considered another potential indicator: residential electricity consumption. These data are routinely collected through smart energy meters, available to policymakers in real time, and avoid all of the previously mentioned limitations. Importantly, the electricity consumption of a household truly represents the occupants' evolving at-home behaviours during the pandemic. In other words, there are no concerns of inaccuracies due to self-reporting. Secondly, since the electricity consumption of all the homes in the population is metered, regardless of their demographics, using electricity data to assess the population's behaviour will result in a more representative assessment.

Key Results

We obtained the electricity consumption of 10,246 households in Singapore from smart-meter data collected by their electricity service provider. With this, we assessed whether the residents proactively responded to public health authorities' calls to curtail the pandemic by avoiding crowded public places on a voluntary basis. Specifically, we studied if their evening-time electricity consumption increased, which would likely correlate with staying at home more during this time or shifting behaviours by doing more activities at home rather than outside.

To evaluate if this indeed happened in the initial stages of the pandemic in Singapore, we obtained the peak value of the aggregated residential consumption (which occurs in the evening; see Figs. 1A and 1B) and studied if any relationships exist between the daily peak consumption and the progression of the pandemic. In particular, we used two metrics for the latter: the number of daily new COVID-19 positive cases and the number of daily recovered cases announced by the Ministry of Health through daily situation updates and subsequently reported by the news media (see Fig. 1C). These two variables constitute the only immediate information made available to the public that allow the people to assess the progression of the disease. We selected both of these data for our analysis due to their potential opposing influences on the society's response – while the former may encourage people to be more cautious and avoid crowded public places, the latter may signal low disease severity to the public and encourage them to continue with business as usual. Fatality counts due to COVID-19 were not considered as a potential influencing factor, owing to the relatively low death toll in Singapore when compared globally.

Fig. 2 presents the cross-correlations between the COVID-19 case numbers and the peak demand. Here, while we observe statistically significant correlations ($p \ll 0.05$) between the peak aggregate demand and both the daily new and recovered COVID-19 cases, we find that the correlation between the latter pair is weaker. We further confirmed the presence of cointegration for both pairs using the Engle–Granger test, suggesting that there indeed is a link between the response of the society and progression of the disease.

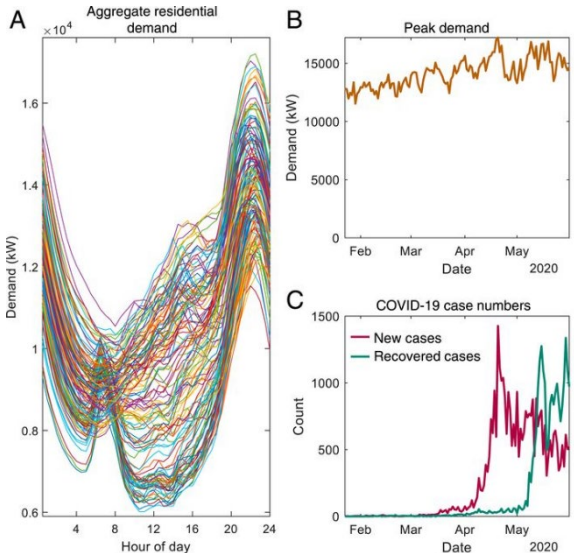

Figure 1 (A) Electricity-consumption profiles, aggregated for 10,246 households, for each day in the period of 23 January 2020 to 31 May 2020. (B) Daily peak values from A. (C) Daily new COVID-19 cases and recovered cases announced by the Ministry of Health Singapore.

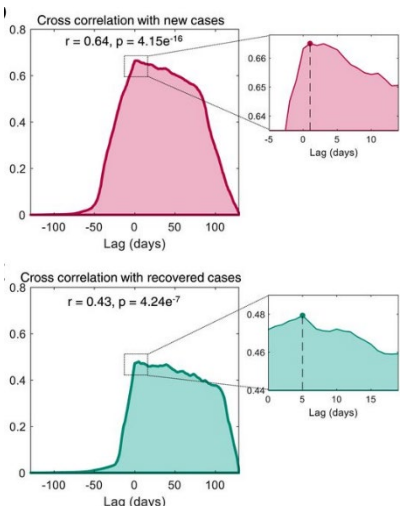

Figure 2 Normalized cross-correlation between the peak aggregate demand with (top) new COVID-19 cases and (bottom) recovered COVID-19 cases.

To verify that the observed increase in the demand was due to the response of the populace to COVID-19 and not just the warmer weather (see Raman 2018), we constructed a vector error correction model (VECM) while considering both as contributing factors. VECMs are used to capture complex relationships between multiple time-series data, when the latter are driven by a common stochastic trend (i.e., they are cointegrated). The results of the forecast error variance decomposition are presented in Fig. 3, which shows the relative influence of each influencing factor, i.e., COVID-19 progression and the

weather on the demand. We find that new COVID-19 cases account for over 93% of the variance while the weather plays a relatively minor role (<3%). Therefore, although the government did not implement mobility restrictions prior to the Circuit Breaker, our results show that people proactively responded to the increasing new COVID-19 cases; the increasing electricity consumption suggests that people either stayed in to a greater extent or performed more activities at home rather than outside during the evenings.

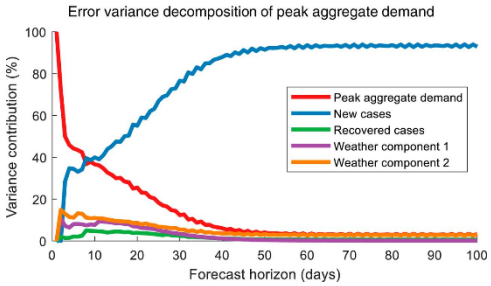

Figure 3 Results from the VECM for the peak electricity consumption of 10,246 households in Singapore. The figure shows the error variance decomposition of the influencing factors – daily new and recovered COVID-19 cases and the weather – on the electricity consumption.

To study how the lockdown – called Circuit Breaker – influenced the residents' behaviour, we applied the VECM for three different periods before and during the lockdown, see Figs. 4A and 4B. Clearly, the influence of the new COVID-19 cases on the electricity consumption reduces as time progresses. Even during the pre-Circuit Breaker period – while it remains the most dominant factor – its influence on the peak demand during Period-2 falls to 89% from its original contribution of 93% in Period-1. Once the lockdown is implemented (i.e., during Period-3), however, its variance contribution is only 3.3%. As for the weather, we observe the opposite trend, with the combined

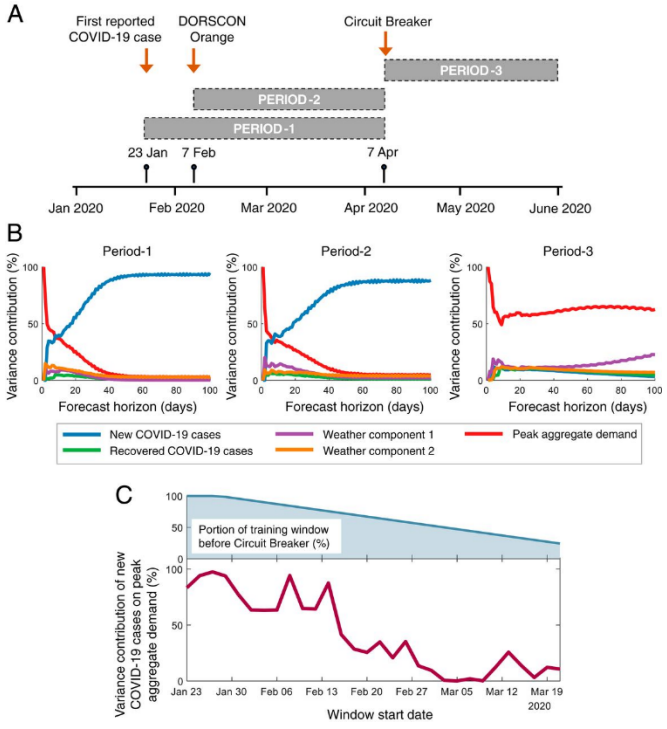

Figure 4 How the VECM results vary for different time periods before and during the lockdown (Circuit Breaker).

influence of the two weather components increasing over time. As an alternative analysis, we employed a sliding training window for the VECM; Fig. 4C illustrates how the relative influence of new COVID-19 cases reduces progressively in this case as well.

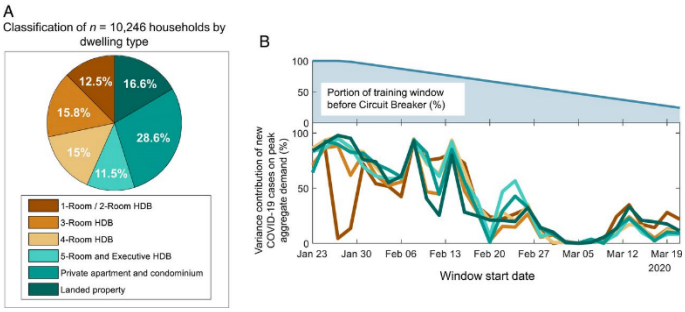

Figure 5 Influence of demographics on Singaporean residents' response to the pandemic.

Social response during the pandemic may be very different for different sections of the population. To understand if demographic factors played a role in determining peoples' response in the Singaporean context, we classified the 10,246 households into six different dwelling types, see Fig. 5A. These dwelling types exhibit clear disparities in their family composition, average number of residents per household, and average income, with larger units more likely to be family homes with more residents and higher incomes.

For each dwelling type, we aggregated the demands of all the households belonging to that type. Subsequently, we employed the VECM for each, and performed forecast error variance decomposition. These results, presented in Fig. 5B, show that there are no significant differences in the reactions of the households based on the dwelling type. For each dwelling type, the overarching trend is consistent – the peak value of the electricity demand depends more on the progression of the disease during the initial stages of the pandemic than later on during the Circuit Breaker period.

We also analyzed the cross-correlation between new and recovered COVID-19 numbers and the aggregate demand for each dwelling type, which again shows similar responses by households, regardless of their demographics.

Implications

While uncovering previously unknown behavioural trends during the pandemic in Singapore, our study has implications on the pandemic response of Singapore and other countries.

First, policymakers can estimate the overall proclivity of the populace toward embracing risk-reduction behaviours. If people respond proactively at the beginning of the pandemic, they are most likely to maintain a responsive attitude to future interventions as well. While public attitudes may change over the long-term, e.g., due to fatigue, nevertheless, our study can anchor the necessary level of effort put into related public health campaigns, particularly in the absence of other real-time

feedback.

Second, policymakers can anticipate the speed of response of the population to their interventions. Our analysis suggests that Singaporean households responded to news of new COVID-19 cases with a delay of about 1 to 3 days. Therefore, if a specific intervention in the near future fails to produce an impact within this time frame, it may portend the need to revise its design and/or implementation.

Third, our VECM suggests that people respond more to public health updates that focus on the extent of the disease spread during the pandemic, i.e., the number of newly infected patients, rather than the number of recoveries. This has implications in designing future pandemic updates to the public. As such, our study suggests that Singaporean authorities' efforts at the beginning of the pandemic (before the lockdown) were indeed effective in persuading Singaporeans about the severity of the disease and the need to effect immediate behavioural changes to tackle its spread.

Fourth, policymakers can gain crucial insight into whether populations belonging to specific demographics require additional interventions, especially by combining electricity-consumption data with the corresponding location information (though unavailable to us due to privacy reasons). For example, if at any time we find inaction among certain demographics or residents in a particular locality, additional resources could be allocated to these groups. In particular, this approach can be harnessed during the global vaccine roll-out that is underway at the time of writing of this note; if certain groups are unable to reduce exposure, even during evenings, they can be targeted in the vaccination program. Specific to the Singaporean population, our study suggests that households of all dwelling types responded in a cohesive manner before the lockdown to reduce the risk of exposure, despite significant disparities in their family composition, household size, and income. Given that to protect oneself during an infectious disease outbreak is to protect the society at large, this broad response from all the demographics in the population could have contributed to the effectiveness of Singapore's response to COVID-19.

In closing, we note that while our experiments show that new COVID-19 cases influenced the peak household electricity consumption, they do not specify the particular modifications in the residents' behaviour or the underlying intentions that resulted in these demand changes. Our interpretation is that these stem from the residents proactively staying in during the evening to a larger extent and/or performing more activities at home rather than outside, with the intention of reducing potential exposure to the disease. In any case, one can argue that any behavioural change in response to the progression of the pandemic and in the absence of government mandates qualifies as a proactive response.

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