# Reshaping electricity demand during COVID-19 containment measures

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## ABSTRACT

The New Zealand government introduced strict containment measures in response to the Covid-19 virus. We assess the impact of containment measures on wholesale electricity demand using the augmented auto-regressive-moving-average model. The Alert Level-4 lockdown had the largest, significant and negative effect on electricity demand compared to other containment level measures. Alert Level 4 resulted in a 15.5 % reduction in wholesale electricity demand. Structural breaks in the data are evident as containment progressed to Alert Level 1.

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**Abstract**

The New Zealand government introduced strict containment measures in response to the Covid-19 virus. We assess the impact of containment measures on wholesale electricity demand using the augmented auto-regressive-moving-average model. The Alert Level-4 lockdown had the largest, significant and negative effect on electricity demand compared to other containment level measures. Alert Level 4 resulted in a 15.5 % reduction in wholesale electricity demand. Structural breaks in the data are evident as containment progressed to Alert Level 1.

## 1. Introduction

Emergency measures imposed by governments have had a massive impact on the energy sector, resulting in a dramatic drop in total energy demand. Following a New York statewide stay-at-home order in March 2020, the electricity load averaged 22% less than during the month of January (Van Vactor, 2020). Load reductions in the 20-30% range have also been reported in Italy (Ghiani, et al., 2020), and India (Beyer, et al., 2020). In response to the emergency measures implemented by governments changes in the daily load profiles of electricity are also evident. For example, confinement measures in Australia resulted in an overall reduction in total daily load and a dramatic increase in residential demand (Mastropietro et al., 2020).

In this paper we examine the impact of the New Zealand government's Covid-19 emergency measures on wholesale electricity demand. Data on the composition of final demand are not available. We proceed as follows. Section 2 describes the data and the timing of the four Alert levels, beginning with Alter Level 4 March 26th 2020 through to return to Alert Level 1 June 9th 2020. Results are presented in Section 3 and conclusions follow in Section 4.

## 2. Data and Methodology

### 2.1 Data

The data are taken from the wholesale market provided by the New Zealand Electricity Authority and are available on the Electricity Market Information website.[1] The wholesale data includes price trends, grid generation trends, grid demand trends, and HVDC transfer. We use the demand trends data. According to the alert system introduced in March 2020, we select the study period from 15 Febuary 2020 to 9 July 2020.[2] We further divide it into five sub-periods:

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[1] https://www.emi.ea.govt.nz/Wholesale/Dashboards/NMVSIC?_si=db|NMVSIC,s|dmt,v|0
[2] Alert system overview is available on https://covid19.govt.nz/covid-19/alert-system/alert-system-overview/#:~:text=Dates%20when%20different%20Alert%20Levels%20came%20into%20force&text=COVID

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pre-lockdown (15 February 2020 -25 March 2020), COVID-19 Alert Level 4 (26 March 2020 -27 April 2020), COVID-19 Alert Level 3 (28 April 2020 – 13 May 2020), COVID-19 Alert Level 2 - 14 May 2020 – 8 June 2020; COVID-19 Alert Level 1 - 9 June 2020 – 9 July 2020. Electricity demand in the corresponding weekdays in 2019 is used as the baseline incorporating seasonal patterns such as increases in electricity consumption in winter to derive percentage change in electricity consumption as the dependent variable. We compare electricity demand on 15/2/2020 Saturday with electricity demand on 16/2/2019 Saturday to obtain the difference, and then divide the difference by electricity demand on 16/2/2019 to derive the percentage change on 15/2/2020. Likewise, we compare electricity demand on 16/2/2020 Sunday with that on 17/2/2019 Sunday, and so on to obtain the rest of the percentage change in electricity demand.
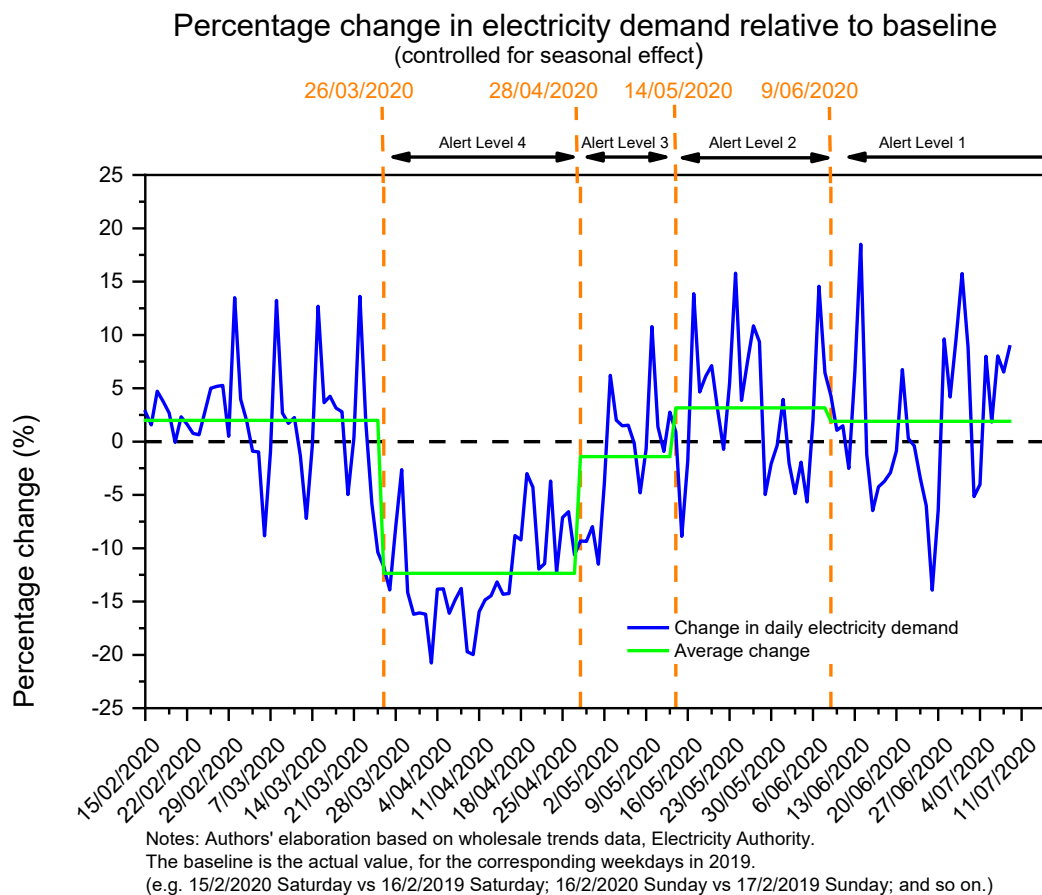


Figure 1. Electricity demand pattern changes relative to baseline 2019

Figure 1 illustrates the percentage change in electricity demand over the five sub-periods. The horizontal line indicates the average change. Compared to electricity demand in the corresponding weekdays and weekends last year, electricity demand experienced a minimal, about 2%, increase on average before the lockdown. A significant decrease, on average, approximately 12% was observed during the Alert Level-4 lockdown due to the reduced

%2D19%20Alert%20Level%203,59pm%20Monday%208%20June%202020.

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commercial and industrial activity. From Alert Level 3 onwards, electricity demand increased due to the less restrictive containment measures, or cold weather which we are unable to control.

Figure 2 illustrates the weekly and daily electricity demand comparison between 2020 and 2019. In Figure 2(a), the blue line shows the trend in total national electricity demand for the third week entering Alert Level 4 (6/4/2020-12/4/2020) and the red line shows the demand for a reference week in 2019. The electricity demand pattern in 2020 weekdays is similar to 2020 weekends (see blue line). The gap between these lines shows the reduction in electricity demand due to the most strict government containment measure – Alert Level 4 - lockdown. During the lockdown, most businesses closed except for essential services and lifeline utilities. The reduced activities in commercial and industrial businesses reduced electricity demand during both weekdays and weekends. During Alert Level 4  people were instructed to stay at home, work remotely if possible and maintain social distancing if outside, which led to an increase in domestic demand. In April, according to Electricity Market Information, monthly business electricity demand reduced by 24% compared to 2019; in contrast, monthly residential electricity demand increased by 9% compared to 2019.[3]
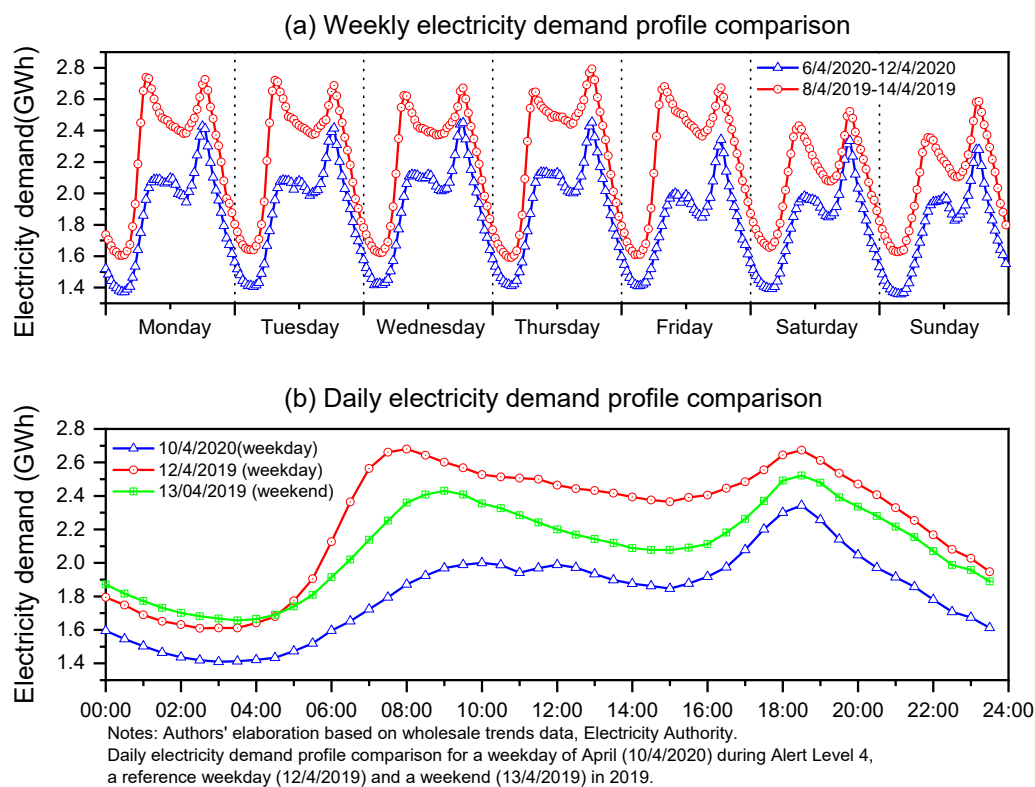


(a) Weekly electricity demand profile comparison

(b) Daily electricity demand profile comparison

Notes: Authors' elaboration based on wholesale trends data, Electricity Authority.
Daily electricity demand profile comparison for a weekday of April (10/4/2020) during Alert Level 4,
a reference weekday (12/4/2019) and a weekend (13/4/2019) in 2019.

Figure 2. Electricity demand profile comparison

Notes: Authors' elaboration based on wholesale trends data, Electricity Authority.
   (a) Weekly comparison for the third week entering Alert Level 4 (6/4/2020-12/4/2020) and a reference week in 2019 (8/4/2019-14/4/2019)
   (b) Daily comparison for a weekday of April during Alert Level 4 (10/4/2020) and a reference weekday (12/4/2019) and a weekend (13/4/2019) in 2019

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[3] Authors' elaboration based on the Business demand trends and Residential consumption data provided by the New Zealand Electricity Authority. Please refer to www.emi.ea.govt.nz for more information.

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Figure 2(b) shows the daily comparison for a weekday of April during Alert Level 4 (10/4/2020) and a reference weekday (12/4/2019) and a weekend (13/4/2019) in 2019. The blue line illustrates the trend in electricity demand on 10/4/2020, a weekday, the red line for a similar weekday in 2019, and the green line for a similar weekend in 2019. Interestingly, as expected, the electricity demand pattern with morning and evening peaks of weekdays during the lockdown was similar to those for a weekend in 2019 because most people stayed and worked at home over the weekdays in 2020. The morning peak demand in 2020 was delayed by a few hours compared to 2019 weekdays, possibly reflecting less concentrated household activity that was common prior to leaving for work and school. There was a significant reduction in energy demand in 2020 weekday demand compared to 2019 weekends and weekdays. This is probably due to the reduced commercial and industrial loads over the lockdown. Figure 2(b) also indicates that a large portion of businesses was active during the weekends. The weekly and daily electricity demand pattern changes between the lockdown in 2020 and the corresponding time in 2019 in New Zealand are quite similar to those in Spain (Bahmanyar et al., 2020).

## 2.2 Empirical model

The autoregressive-moving-average (ARMA) model initially described by Whittle (1951) and popularized by Box and Jenkins (1970) provides a parsimonious description of a stationary stochastic process. We use an augmented ARMA model to examine the impact of alert levels on electricity demand.

$$\Delta Elec_t = \sum_{i=1}^{p} \varphi_i \Delta Elec_{t-i} + \sum_{i=1}^{q} \theta_i \varepsilon_{t-i} + x_t \beta + \mu + \varepsilon_t \tag{1}$$

In Equation (1), the modified ARMA model combining both $P$ autoregressive terms and $q$ moving average terms is represented by ARMA ($p$, $q$); $\mu$ denotes a constant term and $\varepsilon_t$ is the residual term at $t$ which is assumed independent and identically normally distributed as $N(0, \sigma^2)$; $\Delta Elec_t$ is the change in electricity demand at $t$; which is related to changes in electricity demand in previous periods – the first term in the right-hand side of Equation (1), and also related to the current residual and the residuals from previous periods – the second term. $x_t$ is a 1 x k vector, representing alert levels; and β is a k x 1 coefficient vector, estimating the impact of alert levels on electricity demand.

## 2.3 Cumulative sum test

The cumulative sum test proposed by Brown et al. (1975) and later developed by Ploberger and Krämer (1992) is used to check for the presence of structural breaks in the time series of the annual growth rate of electricity consumption over the period 15/2/2020 – 9/7/2020. The principle of this test is to determine whether the cumulative sum of the partial sequences occurring in the tested sequence is too large or too small relative to the expected behaviour of that cumulative sum for random sequences. The change rate of electricity demand is estimated as a function of its first-order lag with a constant term. Under the null hypothesis, the cumulative sum of residuals will have mean zero. If the null hypothesis is rejected, it implies the existence of a structural break in the data.

## 3. Results and discussion

### 3.1 ARMA models results

Dickey-Fuller test (Dickey and Fuller, 1979) and Phillips-Perron test (Phillips and Perron, 1988) are used to examine if changes in electricity demand follow a unit-root process. The null hypothesis was rejected at 1% level.[4] We use an autocorrelation function (ACF) to find q (cuts off after lag $q$ – MA($q$)) and partial autocorrelation function (PACF) to find $p$ (cuts off after lag $p$-AR($P$)). We find p=1 or 8 and q=1, 7. Therefore, ARMA($p,q$) has four combination models: ARMA(1,1); ARMA(1,7); ARMA(8,1); ARMA(8,7). Then we use Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC) to measure the goodness of fit. A lower AIC or BIC value indicates a better fit. We also check the significance of the coefficients when selecting the best model.

Table 1. The impact of COVID-19 containment measures on changes in electricity demand

|  | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| VARIABLES | ARMA (1,1) | ARMA (1,7) | ARMA (8,1) | ARMA (8,7) |
| *COVID-19 Alert Levels* |  |  |  |  |
| COVID-19 Alert Level 4 | -13.674*** | -10.633*** | -14.030*** | -15.508*** |
|  | (2.122) | (2.827) | (1.468) | (0.530) |
| COVID-19 Alert Level 3 | -3.337 | -0.702 | -2.681 | -1.250* |
|  | (2.293) | (3.164) | (2.141) | (0.730) |
| COVID-19 Alert Level 2 | 1.166 | 1.072 | 1.403 | 1.414** |
|  | (1.916) | (2.872) | (1.434) | (0.550) |
| COVID-19 Alert Level 1 | 0.377 | 2.731 | 0.145 | -0.972* |
|  | (1.762) | (2.856) | (1.432) | (0.527) |
| Lagged AR terms | Yes^ | Yes | Yes | Yes |
| Lagged MA terms | Yes | Yes | Yes | Yes |
| AIC | 914.3996 | 885.2507 | 869.484 | 863.817 |
| BIC | 938.2685 | 927.0212 | 914.238 | 913.4891 |
| Observations | 146 | 146 | 146 | 146 |

Notes: ^Yes denotes variables are included in the model.
Standard errors in parentheses;*** p<0.01, ** p<0.05, * p<0.1
Reference category: the pre-lockdown period 15 February 2020 -25 March 2020;
COVID-19 Alert Level 4 (lockdown) - 26 March 2020 -27 April 2020;
COVID-19 Alert Level 3 (Restrict) - 28 April 2020 – 13 May 2020;
COVID-19 Alert Level 2 (Reduce) - 14 May 2020 – 8 June 2020;
COVID-19 Alert Level 1 (Prepare) - 9 June 2020 – 9 July 2020
ARMA (8, 7) performs better than the other three models based on the significance of the coefficients and low AIC and BIC. The full results are available upon request.

Table 1 presents the estimation results of alternative ARMA models. ARMA (8, 7) in Colum 4 of Table 1 performs best than others due to its lower AIC and containing the most significant coefficients. As expected, the strictest containment measure – Alert Level 4 - lockdown has the

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[4] Results of unit root tests are reported in Appendix Table A1.

largest significant and negative impact on the percentage change in electricity demand than other containment measures. Alert Level 4 reduced the percentage change in electricity demand by 15.5 % compared to that in the pre-lockdown period. The magnitude of containment measures effects drops significantly from 15.5% to 1.3% at Alert Level 3, but the effect still is negative. Under Alert Level 2, businesses opened, people went back to work, and the economy returned to normal only if following public health guidance and keeping physical distancing, likely boosting electricity demand. We find a significant and positive effect (1.4%) of Alert Level 2 on the change in electricity demand. After transiting to Alert Level 1- no restriction on most activities, a small negative effect of Alert Level 1 is found in comparison to the pre-lockdown period.

### 3.2 Cumulative sum test result

The percentage of changes in electricity demand experience a decline over Alert Level 4 and Alert Level 3. We use the cumulative sum test to determine whether the decrease in the percentage change in electricity demand during the study period is attributed to structural change. The existence of structural breaks depends on if the plot of a recursive cumulative sum process breaks its corresponding confidence intervals. Figure 3 is the recursive cumulative sum plot of changes in electricity demand. The cumulative sum test statistic shows a 5 percent level of significance, indicating the changes over the period from earlier April to late May 2020 are structurally significant. [5] The occurrence of structural change reflects the disruptive change in electricity demand due to the strictest containment measure. The primary reason is the reduction in economic activity that significantly reduced electricity consumption.
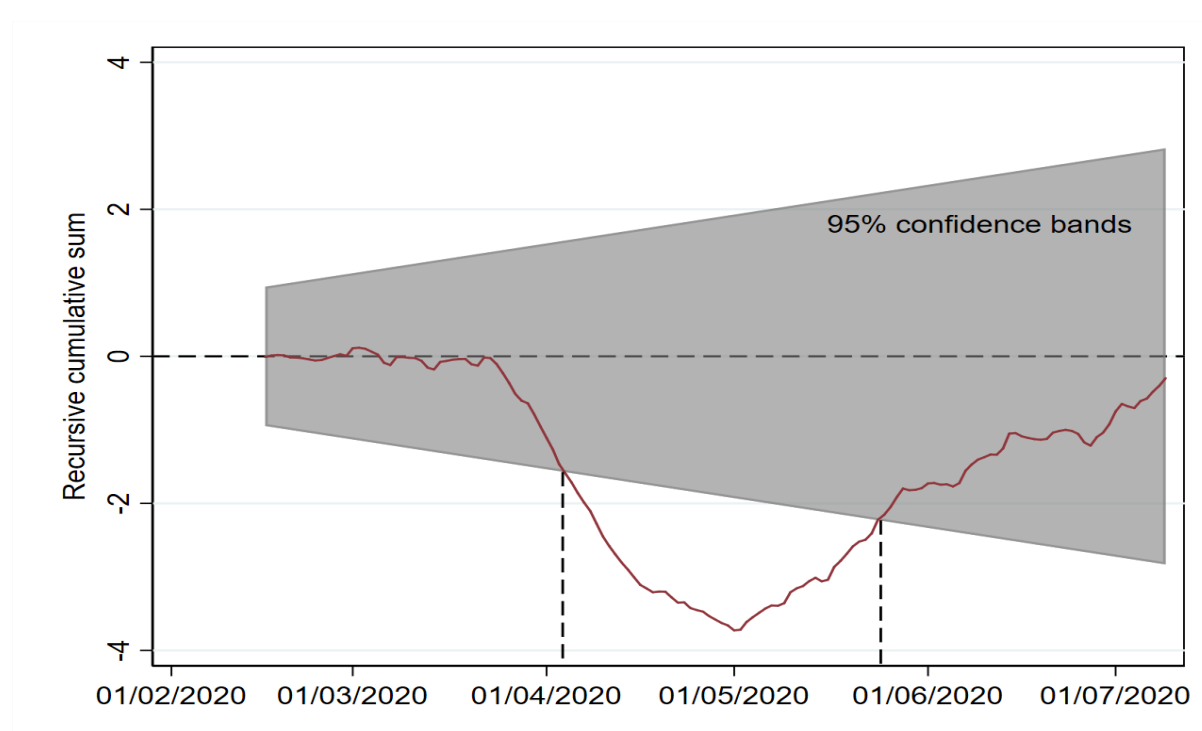


Figure 3. Recursive cumulative sum plot of changes in electricity demand

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[5] The cumulative sum test result of changes in electricity demand is reported in Appendix Table A2.

## 4. Concluding remarks

Covid-19 containment measures reshaped electricity demand. Results show that the Alert Level-4 lockdown had the largest, significant and negative effect on electricity demand compared to other containment measures. The lockdown led to a 15.5 % reduction in electricity demand. The structural breaks associated with the progressive return to Alert Level 1 are evidenced in the data.

The findings in this study provide the empirical evidence on changes in the level and pattern of electricity demand due to containment measures. Electricity demand and economic activity are obviously correlated and in the absence of evidential data we would expect changes in GDP to correlate with changes in electricity demand. Associated with the reduced electricity demand, there was 62.5% drop in electricity price compared to 2019 during the Alert Level-4 lockdown. [6] We conjecture that changes in the merit-order stack could explain this. With the drop in demand higher-cost sources of electricity will not be dispatched by the system operator and leaving base load sources such as geothermal and low-cost sources such as wind being offered to the market. The damping electricity price may discourage renewable energy investment (see Wen et al. (2020)). Thus, the disruptive reduction in electricity demand due to the COVID-19 outbreak may delay the transition to net-zero carbon emissions by 2050 set by the New Zealand government.

## References

Bahmanyar, A., Estebsari, A., & Ernst, D. (2020). The impact of different COVID-19 containment measures on electricity consumption in Europe. *Energy Research & Social Science*, 101683.

Beyer, R.C.M, Franco-Bedoya, S. & Galdo, V.(2020). Examining the Economic Impact of COVID-19 in India through Daily Electricity Consumption and Nightime Light Intensity. Policy Research Working paper 9291, World Bank, June 2020.

Box, G., & Jenkins, G. (1970). Time Series Analysis: Forecasting and Control. San Francisco: Holden-Day.

Brown, RL., Durbin, J., & Evans, JM. (1975). Techniques for Testing the Constancy of Regression Relationships over Time. *Journal of the Royal Statistical Society,* 37:149-192.

Dickey, D. A., & Fuller, W. A. (1979). "Distribution of the Estimators for Autoregressive Time Series with a Unit Root". *Journal of the American StatisticalAssociation,* 74 (366): 427–431. doi:10.1080/01621459.1979.10482531. JSTOR 2286348.

Ghiani, E., Galici, M. Mureddu, M. & Pilo, F. (2020). Impact on Electricity Consumption and Market Pricing of Energy and Ancillary Services during Pandemic of COVID-19 in Italy. *Energies,* 13. doi:10.3390/en13133357

Mastropietro, P., Rodilla, P., & Batlle, C. (2020). Emergency Measures to Protect Energy Consumers During the Covid-19 Pandemic: A Global Review and Critical Analysis. *Energy Research & Social Science*, 101678.

Phillips, P. C. B., & Perron, P. (1988). Testing for a Unit Root in Time Series Regression. *Biometrika,* 75 (2): 335–346. doi:10.1093/biomet/75.2.335.

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[6] Authors' elaboration based on the wholesale price trends data provided by the New Zealand Electricity Authority. Please refer to www.emi.ea.govt.nz for more information.

Ploberger, W., & Krämer, W. (1992). The Cusum Test with Ols Residuals. *Econometrica*, 60:271-285.

Van Vactor, S. A. (2020). The Impact of Covid-19 on Energy Markets. *IAEE Energy Forum*, Special Covid-19 Edition 2020, p.12-16.

Wen, L., Sharp, B., & Sbai, E. (2020). Spatial Effects of Wind Penetration and its Implication for Wind Farm Investment Decisions in New Zealand. *The Energy Journal,* 41(2): 47-72. doi: 10.5547/01956574.41.2.lwen

Whittle, P. (1951). Hypothesis Testing in Time Series Analysis. Almquist and Wicksell.

**Appendix**

Table A1. Results of unit root tests

| Variable | Changes in electricity demand |
|---|---|
| Dickey-Fuller test | -4.836*** |
| Phillips-Perron test | -4.670*** |

Notes: ***1% level of significance; **5% level of significance, *10% level of significance.

Table A2. Cumulative sum test of changes in electricity demand

| Period | Statistic | Test statistic | 1% critical value | 5% critical value | 10% critical value |
|---|---|---|---|---|---|
| 15/2/2020 - 9/7/2020 | Recursive | 1.820*** | 1.143 | 0.948 | 0.850 |

Notes：***, **, and * denote statistical significance at the 1%, 5 % and 10% levels respectively.