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Changes in the Pattern of Weekdays Electricity Real Consumption during the COVID-19 Crisis

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Abstract: In this paper, using data from Romania, we analysed the changes in electricity consumption generated during the COVID-19 crisis, and the measures taken against the spread of the coronavirus to limit the effects of the pandemic. Using a seasonal autoregressive econometric model, we found that, beyond seasonal (weekly, monthly, quarterly, yearly) effects, the average daily electricity real consumption in Romania, during the state of the emergency period (16 March 16 to 14 May 2020) decreased by −194.8 MW (about −2.9%), compared to the historical data (2006–March 2022), and this decrease is not due to the action of some random factors, and it is not a manifestation of domain-specific seasonality. The literature discusses the hypothesis that during the pandemic time, the profile of daily electricity consumption on weekdays was close to the typical Sunday profile. We tested a similar hypothesis for Romania. As a methodology, we tried to go beyond the simple interpretation of statistics and graphics (as found in most papers) and we calculated some measures of distances (the Mahalanobis distance, Manhattan distance) and similarity (coefficient of correlation, cosines coefficient) between the vectors of daily electricity real consumptions, by hourly intervals. As the time interval, we have analysed, for Romania, the electricity real consumption over the period January 2006–March 2022, by day of the week and within the day, by hourly intervals (5911 observations). We found (not very strong) evidence supporting a hypothesis that, in the pandemic crisis, the profile of electricity consumption approaches the weekend pattern only for the state of the emergency period, and we could not find the same evidence for the state of the alert period (June 2020–March 2022). The strongest closeness is to the hourly consumption pattern of Saturday. That is, for Romania, in terms of electricity consumption, "under lockdown, every day is a Sunday" (Staffell) it is rather "under lockdown, every day is (almost) a Saturday"! During the state of the alert period, consumption returned to the pre-crisis profile. Since certain behaviours generated by the pandemic have been maintained in the medium and long term (distance learning, working from home, online sales, etc.), such studies can have policy implications, especially for setting energy policy measures (e.g., in balancing load peaks).

Keywords: COVID-19; power system; hourly electricity consumption

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1. Introduction

The COVID-19 pandemic has affected the economies of most countries worldwide. Glennerster, Snyder, & Tan [1] estimated that the COVID-19 pandemic has caused a reduction in the global economic output by USD 13.8 trillion and has caused over 7 million deaths. Since March 2020, Romania, like other countries, especially in Europe, has imposed specific measures to limit the spread of the SARS-CoV-2 coronavirus and for the medical protection of the population. For this reason, by Decrees of the President of Romania, a state of emergency was established from 16 March 2020 to 14 May 2020. After this date and until 8 March 2022, the state of alert was established through successive decisions of the Romanian Government. During the state of emergency, "taking into consideration the fact that . . . an extraordinary situation, requires exceptional measures", the two decrees instituted measures in "public order, economic, health, and social protection sectors, in justice and foreign affairs domains"; suspended "all educational activities which require physical presence"; isolated people and quarantined localities; closed the border crossing points and the airports; banned meetings, cultural, religious, scientific and sports activities; limited the program of public alimentation units, and so on (in the Annex to the first Decree there are 57 articles with prohibitions, limitations, and recommendations, and in the second, there are 94 articles).

All these restrictions have severely affected economic activities, especially those that involve physical contact between people. Given the nexus between economic activities and energy, the dramatic decline in economic activities, especially during the state of emergency, has also affected energy production and consumption. In Romania, Gross Domestic Product (seasonally adjusted series) fell by −11% in the second quarter of 2020, compared to the fourth quarter of 2019, and by 8.8% compared to the corresponding quarter of the previous year (National Institute of Statistics, [2]). For the entirety of 2020, GDP fell by −3.7% (two percentage points better than in the EU27, where the contraction was −5.7%), and the decrease was recovered in 2021 (+5.1%, while in EU27, the growth was +5.4%)

According to Eurostat data (table nrg_bal_s), regarding energy, primary production decreased in Romania from 24.5 million tonnes of oil equivalent (mil. toe) in 2019 to 22.4 mil. toe in 2020 (−8.8%), while in the European Union—27 countries—the fall was −7.1%, and in the Euro area—19 countries—it was −6.6%. The total primary energy consumption decreased in Romania (2020/2019) from 32.1 to 30.9 mil. toe (−3.6%), less than in the EU27 (−8.7%) and Euro area (−9.6%). The final energy consumption decreased from 23.8 to 23.5 mil. toe (−1.5%), while at the level of the entire European Union, the decrease was −8.1%, and in the Euro area, −9.3%.

The final energy consumption for economic activities fell from 16.121 mils. toe in 2019 to 15.505 mil. toe in 2020 (−3.8%), while for households, the final energy consumption *has grown* from 7753 in 2019 to 8007 mil. toe in 2020, i.e., +3.3%, more than in the EU27 (+0.01%) and Euro area (−0.44%) (National Institute of Statistics, [3]).

According to Eurostat data (table nrg_cb_e), net electricity production in Romania decreased by −5.9% (2020/2019), more than in the EU27 (−4.03%) and recovered by 4% in 2021 (+4.3 in the EU27). Likewise, total electricity final consumption in Romania fell by −3.1% in 2020 (−3.9 for EU27, and −4.4% for the Euro area) and recovered in 2021 (+5.4%), slightly faster than in the EU27 and Euro area (+4.5%). Contrary to the evolution of consumption in economic activities, the household's final electricity consumption grew by +4.9% in 2020, under pandemic restrictions, much more than in EU27 (+1.14%) and in the Euro area (+1.03%).

Regarding the magnitude of the crisis induced by the pandemic, we mention the fact that The Economist [4], estimated that, from March 2020 to October 2022, in Romania, 67,140 people died from COVID-19 and there were 132,530 excess deaths (674 excess deaths/100,000 people, the seventh-highest rate worldwide).

In this paper, we estimated the impact of the COVID-19 crisis on electricity real consumption in Romania. To this end, we built a seasonal autoregressive econometric model and demonstrated that the drop in consumption generated by the pandemic was not caused by random factors (the calculated value for the impact size was statistically significant) and is not a period-specific effect (in the other years, no seasonal effect was identified in the respective period). After searching, we did not find similar estimates in the literature for Romania.

Then, after analysing the average daily consumption, we evaluated a hypothesis according to which the hourly structure of the actual electricity consumption on weekdays did not differ significantly/came closer to the weekend pattern during the COVID-19 crisis. Such a hypothesis has been present in the literature since the start of the COVID-19 crisis. However, the approaches are mainly informed by examples and based on some intuitions without a well-defined methodological basis. The original contribution of our paper consists of discussing and applying a methodology for measuring the effect of the crisis. The proposed methodology uses several techniques to measure the distance/similarity between objects described by several attributes. Currently, such techniques are widely used in the theory of shape analysis and pattern recognition (a fundamental paper in this area was written by Biederman (1987) [5]); another is a book by Da Fontoura Costa and Cesar (2000) [6], classification theory (Batley (2015) [7], Parrochia (2016) [8]), machine learning (Bishop (2007) [9], Banoula (2022) [10]), web search engines (Yang and Gerasoulis (2014) [11], Kameni Homte, Batchakui and Nkambou (2022) [12]), data mining (Han, Kamber, and Pei (2012) [13], Tan et al. (2018) [14]), and information retrieval (Hjørland & Pedersen, 2005 [15]), artificial intelligence (Russell and Norvig (2020) [16], Manyika (2022) [17]), and so on.

By applying four measures (two for distances, two for similarity), to assure methodological robustness, we found some similitude between the shape of electricity hourly real consumption during the first phase of the COVID-19 crisis (the state of the emergency period, i.e., 16 March 2020–14 May 2020), and a profile standard specific to weekend days (as recorded for January 2006 to February 2020). Since certain behaviours generated by the pandemic have been maintained in the medium and long term (distance learning, working from home, online sales, etc.), such studies can have policy implications, especially with regard to setting energy policy measures (e.g., in balancing load peaks).

2. Literature Review

Since March 2020, a vast amount of literature on the evolution and effects of the COVID-19 pandemic has emerged. Many papers provide a literature review: Nicola et al. (2020) [18], Alshater, Atayah & Khan (2021) [19], Brodeur et al. (2021) [20], Callegari & Feder (2022) [21], Podolsky et al. (2022) [22]. Some papers review the literature in specialised fields. For example, Coutinho et al. (2021) [23] have studied the literature concerning how the COVID-19 pandemic has affected people's living conditions, especially the impact on mental health. Şevgin, Alptekin & Şevgin (2021) [24] realised a literature review relating to COVID-19′s impact on the quality of life of the elderly. Rana, Keramat, and Gow (2021) [25] are studying the literature regarding the impact of the COVID-19 crisis on air quality (dynamics of pollutant concentrations). A study by Khlystova, Kalyuzhnova, and Belitski (2022) [26] reviewed 59 papers about the implications of the COVID-19 pandemic on the creative industries (they found positive effects on IT and software and negative effects on cultural activities). Haafza et al. (2021) [27] investigated studies that examine the application of Big Data to diagnosis in public health systems during the pandemic crisis.

Gunasekeran et al. (2022) [28] reviewed the literature concerning the role of social media platforms in public health communication (and identified a potential negative impact on population health, p. 1). Cachón-Zagalaz et al. (2020) [29], Marinoni, van't Land & Jensen (2020) [30], Pokhrel & Chhetri (2021) [31], Shan & Beheshti (2021) [32] and Zancajo (2021) [33] provide a literature review concerning the impact of COVID-19 Pandemic on education systems. Alifuddin & Ibrahim (2021) [34] tried a systematic literature review addressing the COVID-19 Pandemic's impact on work from home. Štreimikienė et al. (2021) [35] review the literature on the effects of the COVID-19 pandemic on agriculture (vulnerabilities, resilience, risks).

By reviewing 18,590 studies and selecting 24 of these for inclusion in a meta-analysis, Herby, Jonung, and Hanke (2022, p. 2) [36] found that, although lockdowns had a huge economic and social cost, in Europe and the USA they had a very small effect on COVID-19-related mortality (only −0.2%, p. 2).

Herby, Jonung, & Hanke [36], Agyei et al. (2022) [37], Sun & Shi (2022) [38] and Owusu Junior (2022) [39] analysed the co-movement between financial variables during the COVID-19 crisis.

Regarding the analysis of the impact of COVID-19 on the energy sector, we mention the paper of Wang, Huang & Li (2022) [40] who investigated studies in the Scopus database that analyse the impact of the COVID-19 pandemic on renewable energy. Chong et al. (2022) [41] reviewed studies in the literature on energy sustainability and carbon neutrality in the post-COVID era and advocated a holistic approach to environmental issues, energy resources, and social well-being. Radtke (2022) [42] discussed the problem of energy democracy. Dogan, Majeed & Luni (2022) [43] analysed the effect of the COVID-19 pandemic on the use of natural resources (including energy). Salisu & Adediran (2020) [44], Pastory & Munishi (2022) [45] and Shaikh (2022) [46] studied the impact of the pandemic crisis on the volatility of energy markets.

Lazo, Aguirre, and Watts (2022) [47] proposed a comprehensive literature review concerning the confinement measures' impact on the electricity sector.

The Applied Energy Review published a Special Issue (March 2021) in which 23 articles analysed the impacts of COVID-19 on energy demand and generation, as well as on the environment.

Cicala (2020, October, pp. 5, 7) [48] estimated for the USA that, in the second quarter of 2020, residential electricity consumption grew by USD 6B (+10%), while the industrial and commercial demand fell by 12% and 14%, respectively. Wang, Li, Cui, Shi, & Mingee (2022) [49] showed an increase in energy consumption in the residential sector in the U.S. continental metropolitan area at the beginning of the pandemic. Li et al. (2022) [50] found that a one percent decrease in the effective reproduction number (secondary cases caused by a primary case) for COVID-19 had a positive impact on global electricity consumption (+1.62%) in Germany and five US states.

García et al. (2021) [51] analysed the impact of COVID-19 restrictions on energy consumption and found that, from March to May 2020, residential consumption in Manzanilla (Huelva, Spain) increased by around 15%, while non-residential consumption fell by 38% (p. 1).

Cortiços & Duart (2022) [52] analysed the increase in energy consumption generated by the need to ensure airflow (ventilation) in large office buildings, to prevent the spread of the virus. Energy consumption in large commercial buildings in Dalian (China) was studied by (Su, Cheng, Wang, & Wang (2022) [53].

By studying 451 buildings in the Canton of Geneva, Todeschi et al. (2022) [54] found that the energy demanded heating and cooling increased during the lockdown.

Through logistic models, applied to 3369 responses to a questionnaire, Balest & Stawinoga (2022) [55] analysed the changes in the daily energy practices of households in Italy during the lockdown caused by the COVID-19 pandemic, in the context of issues related to the energy transition. The authors found that not all household activities were affected by the lockdown (e.g., use of the washing machine), and the change in household energy consumption was influenced by individual and household characteristics (gender, age, type of house, size of the dwelling space and technological context, household income, cultural and regional particularities).

Buechler et al. (2022) [56] and Moses (2022) [57] identified a sharp drop in electricity consumption (by 7.6% in April 2020) for 58 countries during the first phase of the pandemic. However, the consumption recovered completely over the following 6 months. According to the authors, the rapid rebound in consumption was due to the decoupling between economic activity and electricity demand. As a methodology, Buechler et al. (2022) [56] used a panel regression with random individual-specific effects and found, among other things, a relationship between changes in consumption during the pandemic and the pre-pandemic sensitivity of electricity consumption to holidays. On contrary, He & Zhang (2022, p. 1) [58] say that economic growth in OECD countries during the pandemic crises was "impeded" by energy consumption. To identify the demand shift during the pandemic, Narajewski and Ziel (2020) [59] analysed the electricity consumption in Germany, France, Italy, Spain, and Poland.

Zhang et al. (2021) [60] analysed the impact of COVID-19 on energy consumption (including renewable sources) and changes in energy policy. As a methodology, they used an artificial neural network model.

For Romania, Armeanu, Joldeș, and Gherghina (2022) [61] examined the impact of the COVID-19 crisis on the energy market, through the Granger causality tests and Autoregressive Distributed Lag (ARDL) models. They found no long-term relationships between the COVID-19 crisis and the price of electricity or natural gas. In our opinion, this result is determined by the specifics of the analysed period: daily data between 1 July 2021, and 21 December 2021. However, the increase in electricity and natural gas prices was accentuated by the restoration of supply chains and the increasing global demand in the background of the post-crisis recovery process. However, these processes were mainly manifested after January 2022 and after February, the supply deficit in the energy products market was accentuated by the political crisis (the war) in the east of the continent. Andrei et al. (2022) [62] found that the total electricity consumption of Romanian universities decreased between 20% and 36% in 2020, and the electricity due to the use of computers decreased by 75% to 96%. Undoubtedly, consumption was shifted to the households of students and professors!

Regarding the profile of households' hourly electricity consumption, the International Energy Agency (International Energy Agency, 2020, p. 23) [63] notes that, in some countries, the COVID-19 crisis has changed the pattern of "electricity consumption during the weekdays toward a form usually observed on pre-pandemic Sundays". "Under lockdown, every day is a Sunday" is also the hypothesis argued by Staffell (2020, p. 4) [64], Liasi, Shahbazian & Bina (2020) [65] and Mehlig, ApSimon & Staffel (2021) [66] for the United Kingdom, Wilson et al. (2020) [67] and Burleyson et al. (2020) [68] for the United States, Goddard (2020) [69] for Czech Republic, Germany, Spain, Italy, Belgium, and Austria.

Burleyson, Rahman, Rice, Smith, & Voisin (2021) [70] quoted a blog post from an energy market Independent System Operator (NYISO, New York, NY, USA), who reported a special pattern in daily electricity consumption at the beginning of the pandemic, profile similar to a "widespread snow day". Bahmanyar, Estebsari, and Ernst (2020) [71] found analogous patterns in April 2020, for Belgium, Italy, Netherlands, Spain, Sweden, and the UK.

Santiago et al. (2021) [72] found that the electricity demand in Spain decreased by 13% in March–April 2020 (and the CO_2 emissions by 33%) and the hourly profile of consumption changed from the usual pattern—they presented a detailed analysis for Wednesdays and Sundays.

The households' hourly electricity consumption was evaluated by Abdeen et al. (2021) [73] and Rouleau & Gosselin (2021) [74] for Canada, Hinson (2020) [75], Burleyson et al. (2020) [68], Krarti & Aldubyan (2021) [76], Brewer (2022) [77], Ku et al. (2022) [78] for the USA, Cribb, Gotlibovych & Sykes (2020) [79] and Huebner et al. (2021) [80] for the United Kingdom, Benatia (2022) [81] for France, Snow et al. (2020) [82] for Australia, Cheshmehzangi (2020) [83] for China, Bielecki et al. (2021) [84] for Poland (Warsaw region), Carvalho et al. (2020) [85] for Brazil, Bollino & d'Errico (2022) [86] for Italia, Wakashiro (2022) [87] for Japan, Hansell and Vällfors (2021) [88] for Sweden, Khan, and Sahabuddin (2021) [89] and Alavi et al. (2022) [90] for Bangladesh, Bhattacharya et al. (2021) [91] for India, and Abulibdeh, Zaidan & Jabbar (2022) [92] for Qatar.

Rana et al. (2022, p. 1) [93] and Su, Cheng, Wang, & Wang (2022, p. 16) [53] showed that the COVID-19 pandemic has changed lifestyles in the long term, which has lasting effects on energy consumption.

3. Data and Methodology

3.1. Methodology

The data generating process for time series electricity real consumption (ERC) is stationary: the Augmented Dickey–Fuller (ADF) test statistic is −5.680 (while the critical value for 1% level is −3.43) and the Kwiatkowski–Phillips–Schmidt–Shin test statistic is 0.382 (while the asymptotic critical value for 5% level is 0.463). Given the stationarity of the time series, to evaluate the size of the impact induced by the COVID-19 crisis on electricity real consumption (ERC), we built a SARX(p)$(P_s)_s$ = w,m,q,y type model (Jula & Jula, 2019 [94]), with weekly (s_w = 7 days), monthly (s_m = 30 days), quarterly (s_q = 91 days), and yearly seasonality (s_y = 365 days):

$$(1-\varphi_1 L)\,(1-\varphi_7 L^7)\,(1-\varphi_{30} L^{30})\,(1-\varphi_{91} L^{91})\,(1-\varphi_{365} L^{365})\,(ERC_t-\mu) = d_{PEREM} + \varepsilon_t \tag{1}$$

In the model, ERC is the daily average of electricity real consumption (in MW) and φ are the parameters corresponding to the autoregressive and multi-seasonal process: φ_1 modelling the autoregressive process of order 1, AR(1), and the other parameters φ are for modelling weekly (φ_7), monthly (φ_{30}), quarterly (φ_{91}) and annual (φ_{365}) seasonality. Additionally, L is the lag operator ($Ly_t = y_{t-1}$, $L^7 y_t = y_{t-7}$ and so on), μ is the mean of the process $\left(\overline{ERC}\right)$, dPEREM are dummy period (interval) variables, and ε is the error variable.

The inclusion of the moving average terms does not significantly improve the model (e.g., the inclusion of an MA term drops the Schwarz Information Criterion (SIC) from 13.6402 to 13.6392 only). Under these conditions, starting from a principle of parsimony—if two specifications lead to close results, the simpler one is preferred (Occam's razor)—we did not include in the model either moving average (MA) or seasonal moving average terms (SMA).

To assess the hypothesis that, in Romania, during the COVID-19 crisis, the hourly structure of real electricity consumption on weekdays day does not differ significantly/is close to the pattern exhibited on weekend days, we evaluated the similarities/differences between the hourly structure of each weekday and the pattern of weekend days consumption.

The literature cites multiple possibilities for measuring the similarity between two or more objects (structures). Metcalf and Casey (2016) [95] discussed metrics and similarities/dissimilarities of numeric attributes, strings, of "sets of sets".

A very well-known technique used to evaluate the dissimilarity between two vectors is the Minkowski distance of order $p \geq 1$ (ScienceDirect, 2022 [96]). Let X = (x_1, x_2, . . . , x_n) and Y = (y_1, y_2, . . . , y_n) be two structures described by *n* numeric characteristics. The Minkowski distance of order $p \geq 1$ is

$$d(X,Y)_{Minkowski} = \left(\sum_{t=1}^{n} |x_t - y_t|^p\right)^{\frac{1}{p}} \tag{2}$$

From the Minkowski distance formula, we can deduce (Han, Kamber, & Pei, 2012, pp. 72–74 [13]):

for $p = 1$, the Manhattan distance $\left(\sum_{t=1}^{n} |x_t - y_t|\right)$,

for $p = 2$, the Euclidian distance $\left(\sqrt{\sum_{t=1}^{n} (x_t - y_t)^2}\right)$,

for $p \to \infty$, the Chebyshev distance $\left(\max_{t=1}^{n} |x_t - y_t|\right)$.

A technique that considers the (possibly) different measurement scale of the analysed variables is the Mahalanobis distance:

$$d(X,Y)_{Mahalanobis} = \sqrt{(X-Y)\Sigma^{-1}(X-Y)'}$$

where Σ is the covariance matrix and the apostrophe ($'$) stands for transposition. The Mahalanobis distances are also used when the variables are correlated (Tan, Steinbach, Karpatne, & Kumar, 2018, p. 116 [14]).

For similarity, the linear correlation coefficient is frequently used. The well-known Pearson formula is:

$$\mathrm{corr}(X, Y) = \frac{\sum_{t}^{n}(x_t - \overline{x})(y_t - \overline{y})}{\sqrt{\sum_{t}^{n}(x_t - \overline{x})^2}\sqrt{\sum_{t}^{n}(y_t - \overline{y})^2}}$$

where $\overline{x}$ and $\overline{y}$ are the means of X and Y, respectively.

A variant of this coefficient—namely the uncentered correlation coefficient, known as the cosine similarity coefficient—is:

$$\cos(X, Y) = \frac{\sum_{t}^{n} x_t y_t}{\sqrt{\sum_{t}^{n} x_t^2}\sqrt{\sum_{t}^{n} y_t^2}} \text{ or, } \cos(X, Y) = \frac{\langle X, Y \rangle}{\|X\|\|Y\|}$$

where <X, Y> is the inner product and $\|X\|$ is the vector norm. The angle between X and Y is computed using the arccosine function.

We mention that the coefficient of correlation is invariant to scaling (multiplication by a nonzero value) and to translation (adding a constant), while the cosine of an angle is invariant to scaling but not to translation. The Minkowski distance (including the Euclidean, Manhattan, and Chebyshev distance) is neither translation nor scaling invariant (Tan, Steinbach, Karpatne, & Kumar, 2018, pp. 105–108 [14]).

There are other techniques for measuring proximity (similarity/dissimilarity) between objects when the characteristics are of different types, and/or may be of differing importance. We do not detail these techniques because, for the analysis followed in this paper, the structure vectors are constructed starting from the electricity consumption in different time intervals, so that the values are of the same type, the same order of magnitude (scale), and the same importance.

Dobrescu (2011, pp. 7–11) [97] and Jula & Jula (2013, pp. 57–58) [98] analyses ten methods of similarity/dissimilarity: Manhattan distance, Euclidian distance, Canberra distance, Bhattacharyya coefficient, coefficient of correlation (Pearson), the Herfindahl–Hirschman index, the Kullback–Leibler divergence measure, the Jaccard index, the Hellinger distance, and the Cosine similarity coefficient.

To assess changes in energy demand due to the COVID-19 pandemic, Bahmanyar, Estebsari, and Ernst (2020, p. 3) [71] used a so-called Demand Variation Index defined by the following equation:

$$\mathrm{DVI} = \frac{\sum_{i=1}^{n}\left(P_{t_i}^{old} - P_{t_i}^{new}\right)}{n \cdot \overline{P}^{old}} \cdot 100$$

where P is power demand, $\overline{P}^{old}$ is average of power demand over the reference period, t_i—time, n—the number of recorded demands, old—reference period, new—actual period (the symbols are those used by the above-mentioned authors).

This “index” raises some problems: on the one hand, after summing, the positive values $\left(P_{t_i}^{old} - P_{t_i}^{new} > 0\right)$ can offset the negative ones $\left(P_{t_i}^{old} - P_{t_i}^{new} < 0\right)$, and thus, the DVI index masks the amplitude of the variation. On the other hand, based on simple algebra, the DVI can be written as follows:

$$\mathrm{DVI} = \frac{\sum_{i=1}^{n}\left(P_{t_i}^{old} - P_{t_i}^{new}\right)}{n \cdot \overline{P}^{old}} \cdot 100 = \frac{1}{\overline{P}^{old}}\left(\frac{\sum_{i=1}^{n} P_{t_i}^{old}}{n} - \frac{\sum_{i=1}^{n} P_{t_i}^{new}}{n}\right) \cdot 100 = \left(1 - \frac{\overline{P}^{new}}{\overline{P}^{old}}\right) \cdot 100$$

This means that the DVI of Bahmanyar, Estebsari, and Ernst (2020) [71] can only measure the average change in electricity consumption during the pandemic, compared to consumption in pre-pandemic time. So, DVI cannot assess the closeness (or divergence) between the weekday electricity consumption hourly structures during the pandemic and the weekend consumption profile. Santiago et al. (2021) [72] avoid the compensation problem by considering the difference between the pandemic and pre-pandemic values in absolute value (the Manhattan distance).

In this paper, to assess the degree of similarity/dissimilarity between the hourly electricity real consumption on the weekdays and the corresponding vector for weekend days, we calculate three measurement indicators: the linear correlation coefficient, the Manhattan distance, and the angle between the structure vectors. We also calculate a more complex measure, namely the Mahalanobis distance, even if the values of our vectors are of the same type, the same order of magnitude (scale), and of equal importance. Nevertheless, the vectors of hourly electricity consumption are correlated (the correlations are more powerful for closer time intervals). We calculate several more measures to check for the methodological robustness of each estimate: in other words, we check whether several evaluations lead to the same conclusions.

Let h_d and h_s be the following vectors:

$$h_d = \left(h_1^d, h_2^d, h_3^d, \ldots, h_{24}^d\right)$$

the vector of hourly electricity real consumption in the weekday d;

$$h_s = (h_1^s, h_2^s, h_3^s, \ldots, h_{24}^s)$$

the corresponding vector for weekend days s, and the components of the vectors are defined as follows:

h_t^d—is electricity real consumption for weekday d ∈ {Monday, Tuesday, Wednesday, Thursday, Friday} and time interval t, t = 1 for 0:00–0:59 interval, . . . , t = 24 for 23:00–23:59 interval.
h_t^s—is electricity real consumption for weekend day s ∈ {Saturday, or Sunday}, and time interval t, so that t = 1 for 0:00–0:59 interval, . . . , t = 24 for 23:00–23:59 interval.

For these vectors, the measures of distance (Manhattan and Mahalanobis) and similarity (the coefficient of correlation and the cosine/angle between the structure vectors) are calculated as follows:

The coefficients of correlation:	$\mathrm{correl}(h_d, h_s) = \frac{\sum_{t=1}^{24}\left(h_t^d - \overline{h}^d\right)\left(h_t^s - \overline{h}^s\right)}{\sqrt{\sum_{t=1}^{24}\left(h_t^d - \overline{h}^d\right)^2}\sqrt{\sum_{t=1}^{24}\left(h_t^s - \overline{h}^s\right)^2}}$
The Manhattan distance (the Euclidian 1-norm):	$\mathrm{Manhattan}(h_d, h_s) = \sum_{t=1}^{24}\left\lvert \frac{h_t^d}{\overline{h}^d} - \frac{h_t^s}{\overline{h}^s} \right\rvert$
The cosine of the angle between the structure vectors (uncentered coefficient of correlation) . . .	$\cos(h_d, h_s) = \frac{\sum_{t=1}^{24} h_t^d h_t^s}{\sqrt{\sum_{t=1}^{24}\left(h_t^d\right)^2}\sqrt{\sum_{t=1}^{24}\left(h_t^s\right)^2}}$
. . . and the angle between the structure vectors:	$\alpha_{ds} = \arccos[\cos(h_d, h_s)]$
The Mahalanobis distance	$\mathrm{Mahalanobis}(h_d, h_s) = \sqrt{(h_d - h_s)\Sigma^{-1}(h_d - h_s)'}$

In the above formulas, $\overline{h}^d$ is the average consumption on weekday d, $\overline{h}^s$ is the average consumption on weekend day s and Σ^{-1} is the inverse of the covariance matrix.

The measures adopted in the state of emergency and alert have affected the evolution of most economic and social activities, including electricity consumption. So, we separately estimated the models for three time periods:

- Non-COVID19 time (1 January 2006–15 March 2020).
- State of emergency (16 March 2020–14 May 2020).
- State of alert (15 May 2020–8 March 2022).

We chose these intervals taking into account the fact that, based on Decree no. 195/16 March 2020 (President of Romania, 2020) [99], the state of emergency was established in the territory of Romania, starting on 16 March 2020. The state of emergency has been extended up to 14 May 2020, by Decree no. 240/14 April 2020 (President of Romania, 2020) [100]. By Law no. 55 of 15 May 2020, the state of alert was established at the national level and the measures from the state of emergency were gradually relaxed. The state of alert has been extended by government decisions given at 30-day intervals until the beginning of March 2022 (8 March 2022).

3.2. Data

In the paper, we used data regarding the electricity real consumption in Romania between 1 January 2006, and 8 March 2022 (the end date of the alert state due to COVID-19, in Romania). The data (5911 observations) come from Transelectrica statistics. According to Romanian Government Ordinance No. 627/2000,

> "Transelectrica is the Romanian Transmission and System Operator which plays a key role in the Romanian electricity market. (. . .) Transelectrica is responsible for electricity transmission, system, and market operation, grid and market infrastructure development ensuring the security of the Romanian power system. It also serves as the main link between electricity supply and demand, matching all the time power generation with demand". (https://www.transelectrica.ro/en/web/tel/despre-noi1, accessed on 23 April 2022).

Data relating to the daily reports concerning the electricity real consumption are available online on the Transelectrica website, Transparency section. They can be found either by accessing the site directly https://www.transelectrica.ro/en/web/tel/rapoarte-zilnice (from the website select "Realized Consumption"), accessed on 24 November 2022, or following this path: Transelectrica (https://www.transelectrica.ro/en/web/tel/home) → select *Transparency* → then *Balancing and Ancillary Services* → *Daily Reports* → and finally, select "Realized Consumption".

The data concerning electricity consumption (in megawatts, MW) are structured by years, months, days, and intraday, by time intervals (the data are described in the Annex). From January 2006 until January 2021, the data were presented at 24 h intervals. After February 2021, the data were available at 15 min intervals. Under these conditions, we calculated the hourly electricity real consumption by aggregation, as a simple arithmetic mean of the consumptions in the four hourly sub-intervals.

4. Results

First, we tested the hypothesis that average daily electricity real consumption (in MW) in Romania during the state of the emergency period (16 March to 14 May 2020) decreased compared to the historical average from 2006 to March 2022, and that this decrease was not due to the action of some random factors and was not just a manifestation of domain-specific seasonality. Namely, we built a model of daily electricity real consumption (ERC) dynamics with weekly (s_w = 7 days), monthly (s_m = 30 days), quarterly (s_q = 91 days), and annual (s_y = 365 days) seasonality.

In the first model, we tested the presence of a specific period effect for the interval 16 March–14 May. For this purpose, in the SAR(p)$(P_s)_s$ = w,m,q,y model, we defined the period dummy variables (*dPEREM*) as follows:

$$d_{PEREM} = a_{2018} \cdot d_{PEREM,2018} + a_{2019} \cdot d_{PEREM,2019} + a_{2020} \cdot d_{PEREM,2020} + a_{2021} \cdot d_{PEREM,2021},$$

where $d_{PEREM,t}$ is an interval dummy that takes the value 1 for each record from 16 March to 14 May, in each year t (the interval corresponds to the period during which the state of emergency was declared in 2020) and zeroes for the rest. We considered two pre-crisis years (2018 and 2019) and the two crisis years (2020–2021). If, for all the years, the coefficients of the $d_{PEREM,t}$ variables are significant and of the same sign, this means that we are in the presence of a period effect (for example, if the coefficients are significant and negative, this signals a negative seasonality: that is, the reduction in electricity consumption in spring, compared to winter, due to the reduction in electricity consumption for heating, and compared to summer, due to reduced use of cooling devices). The results are as follows:

$$\begin{aligned} ERC_t - \overline{ERC} = & -\underset{(-0.0060)}{1.3823} \cdot d_{PEREM_{2018}} - \underset{(-0.0739)}{15.5962} \cdot d_{PEREM_{2019}} - \underset{(-1.8124)}{192.4823} \cdot d_{PEREM_{2020}} + \underset{(0.2531)}{61.8053} \cdot d_{PEREM_{2021}} \\ & + \left[AR(1) = \underset{(174.3626)}{0.8550}\right] + \left[SAR(7) = \underset{(83.4010)}{0.6024}\right] + \left[SAR(30) = -\underset{(-4.1661)}{0.0282}\right] \\ & + \left[SAR(91) = \underset{(40.8940)}{0.3009}\right] + \left[SAR(365) = \underset{(8.0929)}{0.0505}\right] \end{aligned}$$

(below the estimators, in parentheses, are the t-Statistic values, and $\overline{ERC}$ is the mean of the daily average of electricity real consumption series).

Among the coefficients of the dummy variables, only that of the year 2020 is statistically relevant (it is significantly different from zero at the threshold of 0.035). All the other dummy variables are not significant (the probabilities attached to the null hypothesis in the unilateral Student's t-test are between 0.40 and 0.50). In addition, for the variable redundancy tests, the probability attached to the null hypothesis ($d_{PEREM,2018}$, $d_{PEREM,2019}$ and $d_{PEREM,2021}$ are jointly insignificant) is 0.9698 for the F statistic and 0.9691 for the Likelihood ratio. Instead, the coefficients of the seasonal variables are statistically relevant, at a threshold of 0.00001 or less. This means that after removing the weekly, monthly, quarterly, and annual seasonality, the model does not signal the presence of an effect specific to the period from 16 March to 14 May 2020.

To test whether there is a specific effect only during the state of emergency (16 March–14 May 2020), we respecified the previous model by removing non-significant dummy variables (corresponding to the years 2018, 2019, and 2021). The results are as follows:

$$\begin{aligned} ERC_t - \overline{ERC} = & \underset{(-1.8442)}{-194.82452} \cdot d_{PEREM_{2020}} + \left[AR(1) = \underset{(175.1402)}{0.85494}\right] + \left[SAR(7) = \underset{(83.3808)}{0.60244}\right] \\ & + \left[SAR(30) = -\underset{(-4.1703)}{0.02823}\right] + \left[SAR(91) = \underset{(40.9242)}{0.30096}\right] + \left[SAR(365) = \underset{(8.0973)}{0.05059}\right] \end{aligned}$$

(under the estimators, in parentheses, are the t-Statistic values; sample: 1 January 2006–8 March 2022, 5910 included observations; R^2 = 0.909, DW = 1.931). The coefficient of the dummy variable is significant at the 0.03 threshold, and all other parameters in the model are statistically significant at the threshold of 0.00001 or lower.

The model results support the hypothesis that, beyond seasonal effects (weekly, monthly, quarterly, yearly), the COVID-19 crisis has negatively affected electricity real consumption during the state of emergency (16 March–14 May 2020) and this decrease is not due to random factors (the coefficient attached to the dummy variable is significantly different from zero, at the 0.03 threshold) nor to the individual specific period effect (for the other years, the individual specific effects to the respective period are not statistically significant). On average, the daily electricity real consumption decreased by −194.8 MW, during the state of emergency, compared to the historical average of the period 2006–March 2022.

Concerning the second problem analysed, we mention that, for Romania, the average daily profiles of electricity real consumption (MW) on weekdays and weekend days, for the time intervals from 00:00–00:59 to 23:00–23:59, during the state of emergency (16 March

2020–14 May 2020) and the state of the alert period, compared to time without COVID-19 (1 January 2006–15 March 2020) are shown in Figures 1 and 2.

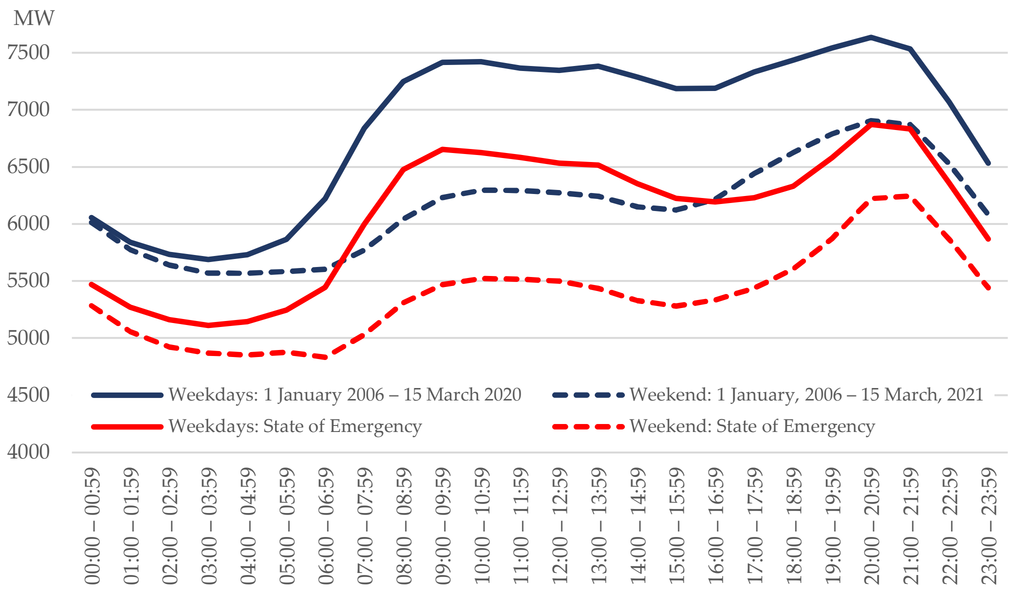

Figure 1. Average daily profiles of electricity real consumption (MW), in Romania, during the state of emergency (16 March 2020–14 May 2020) compared to non-COVID-19 time (1 January 2006–15 March 2020). Source: authors' estimations based on hourly electricity real consumption data (MW) from Transelectrica, starting with January 2006, until 8 March 2022 (the end date of the alert state due to COVID-19, in Romania).

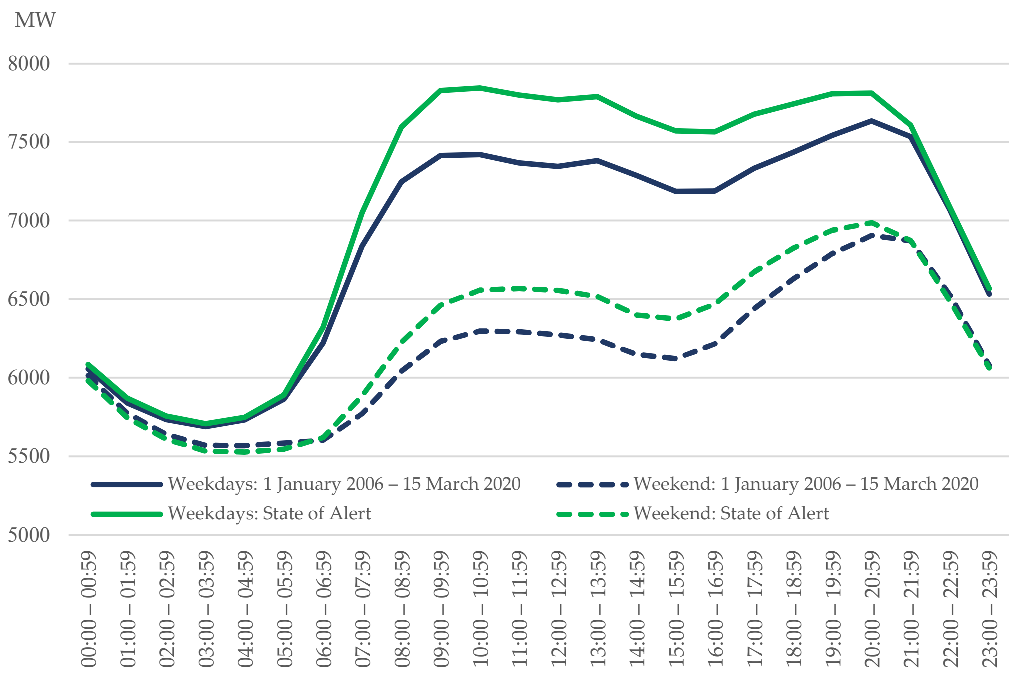

Figure 2. Average daily profiles of electricity real consumption (MW) in Romania, during the state of alert (15 May 2020–8 March 2022), compared to non-COVID-19 time (1 January 2006–15 March 2020). Source: authors' estimations based on hourly electricity real consumption data (MW) from Transelectrica, starting with January 2006, until 8 March 2022 (the end date of the alert state due to COVID-19, in Romania).

The average electricity real consumption during the state of emergency (the blue line, for weekdays, and the dashed blue line for weekend days in Figure 1) is under the corresponding consumption during the pre-crisis periods (the red lines in Figure 1). This means that both aggregated and in each time interval, the impact of the COVID-19 crisis on electricity consumption was negative. These developments are consistent with those recorded in most states around the world during the first phase of the COVID-19 crisis, developments recorded as such in the literature: e.g., International Energy Agency (2020) [63] for the countries of the world; Bahmanyar, Estebsari, and Ernst (2020) [71] for Europe; Armeanu, Joldeș and Gherghina (2022) [61] for Romania, and so on.

The weekdays' average electricity real consumption profile during the state of emergency (the red line in Figure 1) is close to the weekend days profile of non-COVID-19 time (the dashed blue line in Figure 1). This finding is consistent with the *International Energy Agency* hypothesis: "the pattern on weekdays now resembles the pattern usually seen only on Sundays" (International Energy Agency, 2020, p. 23) [63].

During the state of alert (15 May 2020–8 March 2022), the electricity real consumption (the green lines in Figure 2) in Romania is higher than the consumption in the non-COVID-19 period (1 January 2006–15 March 2020, the blue lines in Figure 2) and the daily profiles are similar both for weekdays and for weekend days. This means that the decrease in total electricity real consumption during the state of emergency was relatively quickly recovered in the state of alert period. From 7 a.m. to 10 p.m., in each hourly interval, the average electricity real consumption was greater in the state of the alert period than in the pre-crisis period. Throughout the night, consumption behaviour during the state of alert period returned to the pre-crisis profile.

To go beyond the simple interpretation of the graphs, we calculated the distance and similarity measures between the daily vectors of electricity consumption (each with 24 components).

First, we used data for 24 h time intervals (0:00 a.m. to 11:59 p.m.) and computed the coefficient of correlation, as a similarity measure between hourly electricity real consumption during the weekdays and the corresponding consumption on weekend days. We found that the values calculated for *the state of the emergency* period (16 March 2020–14 May 2020) are slightly higher than the historical average (1 January 2006–15 March 2020), concretely 0.8622 compared to 0.8522. By days, the correlations are slightly higher in the state of emergency compared to the multiannual averages on Monday, Tuesday, and Friday, and as average Monday–Friday, and they are slightly lower on Wednesday and Thursday (Table 1).

Table 1. Distance between the hourly electricity real consumption during the weekdays and the corresponding consumption of weekend days for all time intervals.

Time Interval: All-Day	Monday	Tuesday	Wednesday	Thursday	Friday	Average Monday–Friday
	The coefficient of correlation (values between −1 and +1, values closer to 1 representing stronger positive correlation)					
1 January 2006–15 March 2020	0.8484	0.8514	0.8546	0.8522	0.8522	0.8522
16 March 2020–14 May 2020	0.8580	0.8519	0.8533	0.8410	0.8973	0.8622
15 May 2020–8 March 2022	0.7975	0.7877	0.7933	0.7892	0.7837	0.7913
	The Manhattan distance (a smaller Manhattan distance suggests that two distributions are more statistically similar to each other)					
1 January 2006–15 March 2020	1.5555	1.1289	1.0949	1.0831	1.0326	1.1645
16 March 2020–14 May 2020	1.4164	1.1780	1.0551	1.0114	0.6958	1.0639
15 May 2020–8 March 2022	2.0191	1.6239	1.5760	1.5299	1.4631	1.6340
	The angle between the vectors of the structures (values between 0 and 90 degrees; the smaller the value, the closer the structures are)					
1 January 2006–15 March 2020	4.3267°	3.0447°	2.9461°	2.8986°	2.7209°	3.1520°
16 March 2020–14 May 2020	3.9923°	3.1937°	2.8807°	2.7631°	1.9342°	2.8882°
15 May 2020–8 March 2022	5.4179°	4.2204°	4.0987°	3.9620°	3.7608°	4.2616°

Source: authors' estimations based on hourly electricity real consumption data (MW) from Transelectrica, starting with January 2006, until 8 March 2022 (the end date of the alert state due to COVID-19 in Romania).

If we compare the difference (dissimilarity) between the structural vectors of hourly consumption, through the Manhattan distance and the angle between the vectors, the conclusions are similar: the differences registered during the state of emergency on weekdays are slightly lower compared to the historical averages for weekend days, i.e., 1.0639 for 1.1645 (Manhattan distance), respectively, 2.8882 for 3.1520 (angle between vectors). The coefficients of correlation calculated for the state of the alert period (15 May 2020–8 March 2022) are higher than in the state of emergency, but the differences are not large in absolute values. The Manhattan distances and the angles between the structural vectors are closer to the historical averages than to the indices calculated for the period of the state of emergency. This means a gradual return to pre-COVID-19 crisis consumer behaviour.

The three indicators (coefficient of correlation—for similarity, Manhattan distance, and angle between vectors for dissimilarity), computed for each day of the week, are shown in Table 1 and Figures 3–5.

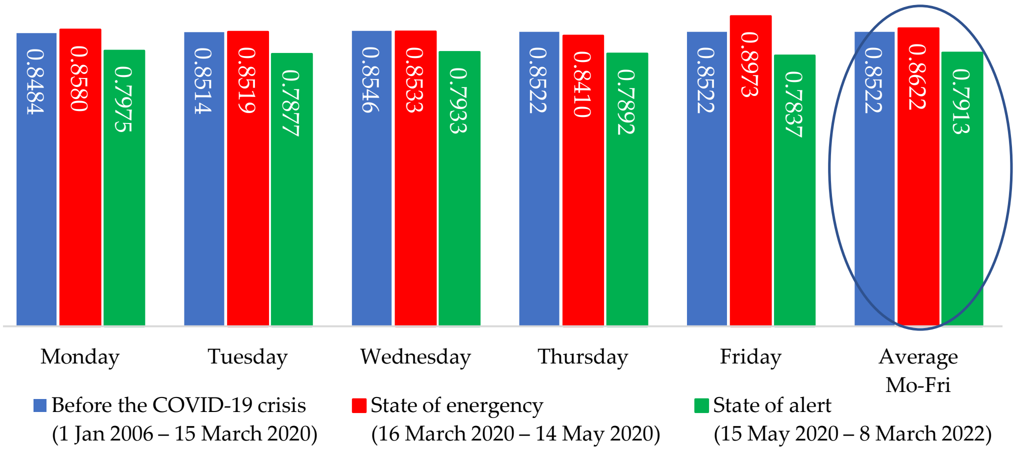

Figure 3. Coefficients of correlation between the hourly electricity real consumption during the weekdays and the typical corresponding profile consumption of weekend days. Note 1: Coefficient of correlation measures the similarity between two objects, values are between −1 and +1, values closer to 1 representing stronger positive correlation. Note 2: Values for the coefficients of correlation differ among the days of the week. We marked the weekly average values (Monday to Friday) with the blue ellipse. Source: Table 1.

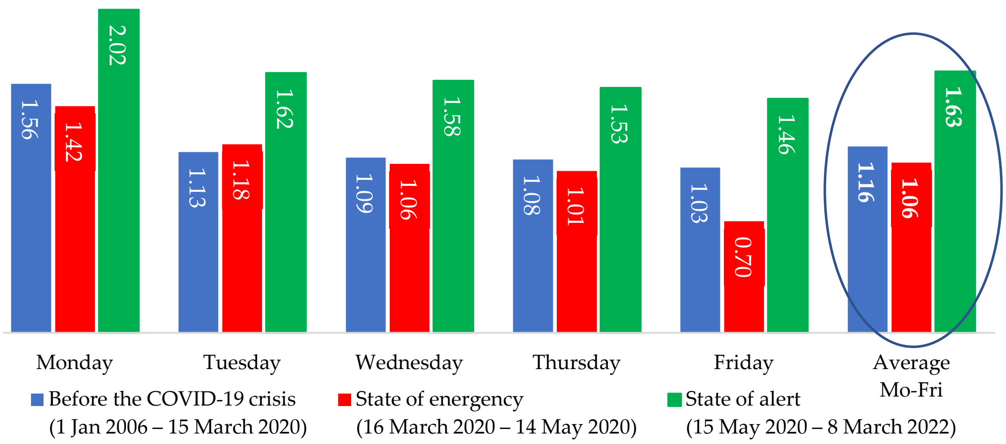

Figure 4. Manhattan distances between the hourly electricity real consumption during the weekdays and the typical corresponding profile consumption of weekend days. Note 1: A smaller Manhattan distance suggests that two distributions are more statistically similar to each other. Note 2: Values for the Manhattan distance differ among the days of the week. We marked with the blue ellipse the weekly average values (Monday to Friday). Source: Table 1.

Technically, the values compared to the average of the weekends are between those of Saturday (the greatest similarity) and Sunday (the greatest dissimilarity).

For the state of alert, the correlations are weaker, and the dissimilarities are higher than in the state of emergency and they are closer to the values recorded in the period before the outbreak of the COVID-19 pandemic.

Another interesting finding for Romanian electricity real consumption is that the hourly consumption profile on weekdays, during the state of emergency, is closer to the specific structure of Saturday than Sunday (Table 2).

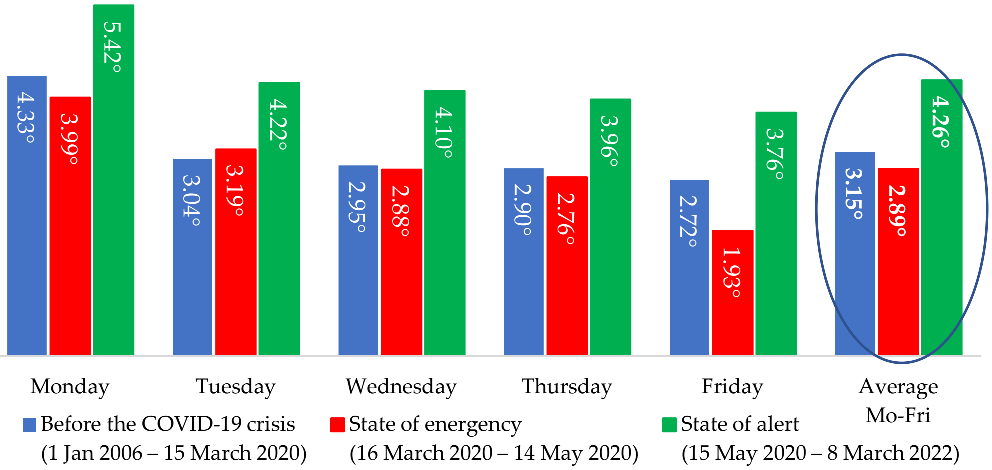

Figure 5. The angle between the vectors of the structures (degrees) between the hourly electricity real consumption during the weekdays and the typical corresponding profile consumption of weekend days. Note 1: Values between 0 and 90 degrees; the smaller the value, the closer the structures. Note 2: Values differ among the days of the week. We marked the weekly average values (Monday to Friday) with the blue ellipse. Source: Table 1.

Table 2. Distance between the hourly electricity real consumption in a state of emergency during the weekdays and the profile of consumption corresponding to Saturday, Sunday, and the average of the weekend days, respectively.

The Weekdays' Consummation in a State of Emergency Compared to:	**Monday**	**Tuesday**	**Wednesday**	**Thursday**	**Friday**	**Average Monday–Friday**
	The coefficient of correlation (values between −1 and +1, values closer to 1 representing stronger positive correlation)					
Average of weekend days	0.8580	0.8519	0.8533	0.8410	0.8973	0.8622
Saturday	0.9311	0.9307	0.9297	0.9198	0.9472	0.9349
Sunday	0.7368	0.7249	0.7288	0.7144	0.8001	0.7413
	The Manhattan distance (a smaller Manhattan distance suggests that two distributions are more statistically similar to each other)					
Average of weekend days	1.4164	1.1780	1.0551	1.0114	0.6958	1.0639
Saturday	1.2351	0.9431	0.8266	0.7742	0.4974	0.8343
Sunday	1.6689	1.4764	1.3609	1.3234	0.9663	1.3516
	The angle between the vectors of the structures (values between 0 and 90 degrees; the smaller the value, the closer the structures are)					
Average of weekend days	3.9923	3.1937	2.8807	2.7631	1.9342	2.8882
Saturday	3.4171	2.5435	2.2329	2.1138	1.4248	2.2576
Sunday	4.6825	3.9508	3.6404	3.5256	2.6366	3.6362

Source: authors' estimations based on hourly electricity real consumption data (MW) from Transelectrica, starting with January 2006 until March 8, 2022 (the end date of the alert state due to COVID-19 in Romania).

We also estimated the Mahalanobis distances (Table 3) between the vectors of hourly electricity real consumption during the pandemic period and the corresponding vectors in normal (pre-pandemic) times.

The Mahalanobis distances between the actual electricity consumption per hourly step, on average over weekdays, and the corresponding consumption on weekend days are lower for the state of emergency period. In addition, the distances between the weekday consumption profile of the emergency period and the consumption profile of the pre-crisis weekends (3.57) are smaller than the distances between the profiles corresponding to the days of pre-crisis weekdays and weekend days (4.14). During the state of alert, the hourly patterns of real electricity consumption returned to the normal profile (observed before the crisis).

Table 3. Mahalanobis distances between the hourly electricity real consumptions on weekdays and corresponding consumptions on weekend days.

				Mahalanobis Distances
Average weekdays' hourly profile of electricity real consumption in:	pre-crisis period	and Saturday	in pre-crisis period	4.33
		and Sunday		4.05
		and weekend average		4.14
	state of emergency period	and Saturday	in pre-crisis period	3.73
		and Sunday		3.52
		and weekend average		3.57
		and Saturday	in a state of emergency period	2.77
		and Sunday		3.10
		and weekend average		2.85
	state of the alert period	and Saturday	in pre-crisis period	4.35
		and Sunday		4.12
		and weekend average		4.19
		and Saturday	in the state of the alert period	4.55
		and Sunday		3.61
		and weekend average		3.99

Note: A smaller Mahalanobis distance suggests that two distributions are more statistically similar to each other. Source: Author's estimations based on hourly electricity real consumption data (MW) from Transelectrica, starting with January 2006 until 8 March 2022 (the end date of the alert state due to COVID-19 in Romania).

5. Conclusions

The COVID-19 crisis and the measures against the spread of the pandemic—the lockdown measures, work from home, online education, blocking of tourist and leisure activities, of sports and cultural activities, closure of theatres, movie theatres, restaurants, bars, and nightclubs, restriction of commercial activities in stores, and so on—have severely affected economic and social activities, which has had negative effects on electricity supply and consumption.

In the paper, we analysed the changes in electricity consumption generated by COVID-19 and the measures taken against the spread of the coronavirus to limit the effects of the pandemic. We found that on average, the daily electricity real consumption decreased by −194.8 MW during the state of emergency compared to the historical average of the period 2006–March 2022. The dimension of the COVID-19 impact represents approximately −2.84%, compared to the average of the actual electricity consumption of 2019 (6858.7 MW) and −2.94%, compared to the related period from 2019.

For comparison, Soava et al. (2021) [101], found that, in the first 11 months of 2020, total energy consumption decreased by approx. 4%. According to Eurostat data (table nrg_cb_e), total electricity final consumption in Romania fell by −3.1% in 2020 (−3.9 for EU27, and −4.4% for the Euro area), and recovered in 2021 (+5.4%), slightly faster than in the EU27 and Euro area (+4.5%).

The literature has analysed the structural changes generated by the decline in commercial electricity consumption, which were partially compensated by the increase in household consumption (Jula D.-M., 2021) [102].

Based on this finding, it was hypothesised that the profile of daily electricity consumption on weekdays is close to the typical Sunday profile (International Energy Agency, 2020 [63]; Burleyson et al., 2020 [68]; Goddard, 2020 [69]; Staffell, 2020 [64]; Wilson et al., 2020 [67]; Mehlig et al., 2021 [66]). In general, this is a conclusion based on logical deductions and the analysis of some graphs.

To go beyond the simple interpretation of the graphs, for Romania, we calculated some measures of distance and similarity between the daily vectors of electricity real consumption (each with 24 hourly components). To assess the degree of similarity/dissimilarity between the pattern of hourly electricity real consumption on the weekdays and the corresponding vector for weekend days, we calculated the linear correlation coefficient and the angle between the structure vectors (for similarity evaluation), the Manhattan distance and the

Mahalanobis distance (for dissimilarity estimation). The standard consumption structures were calculated as averages for the period until 1 January 2006, to 15 March 2020.

We separately estimated the models for three time periods: before the COVID-19 outbreak (1 January 2006–15 March 2020), the state of the emergency episode (16 March 2020–14 May 2020), and the state of the alert period (15 May 2020–8 March 2022).

Concerning the profile of weekdays' electricity consumption, we found some pieces of evidence of the Saturday effect for Romania, only for the state of emergency period and not for the state of alert period. During the state of alert, consumption returns to the pre-crisis profile.

That is, for Romania, in terms of electricity consumption, "under lockdown, every day is a Sunday" of Staffell (2020, p. 4) [64], it is rather "under lockdown, every day is (almost) a Saturday"! Additionally, this effect is not extraordinarily strong. This is because (Liasi, Shahbazian, & Bina, 2020 [65]) there are activities which, in normal times, were carried out on weekends, which stopped (e.g., shows, tourism) or slowed down (e.g., direct purchases in stores) during lockdown. Additionally, some activities were not stopped during the pandemic (for example, activities that do not involve direct interaction between people, or medical activities).

Habitually, the evaluation of Mahalanobis distances would have been sufficient to support the paper's conclusions. However, the value obtained for the determinant of the covariance matrix Σ was very large, which could have generated, mathematically, a certain inaccuracy in the calculation of the inverse (Σ^{-1}). For safety (and methodological robustness), we estimated and used analysis indicators from different classes. All the quantitative estimates converge toward the same conclusions mentioned above.

A limitation of the study is that it does not provide quantitative assessments of cause–effect relationships, by factors. The effects of the crisis on changes in energy consumption behaviour by days and hours are measured, but the consequences by types of actions (individual factors) are not measured (e.g., the direct effect of school closures on household electricity consumption, the direct effect of working from home, the effect of illnesses and hospitalisations). The paper only measures the overall result.

These elements open several paths for future research. An interesting direction of study is the establishment of methodological benchmarks for analysing electricity consumption in universities during the pandemic and estimating consumption in the households the students come from. The main methodological difficulties refer to the identification of solutions to separate the effects on electricity consumption induced by students' online learning from other factors that occur at the same time (for example, work from home for parents or other family members, the effects of the school closures for younger siblings, etc.). Such an analysis could have interesting policy implications from the perspective of expanding and diversifying forms of online learning.

Our present study could have useful policy implications, especially for energy policy, not only from the perspective of the emergence of similar crises but also starting from the (plausible) hypothesis that certain processes that emerged in the context of the pandemic crisis will tend to be maintained in the medium and long term: a preference for working from home, maintaining and developing some forms of online learning, increasing and diversifying the online commerce, maintaining certain forms of social distancing, etc.

Author Contributions: Conceptualization, N.-M.J. and D.J.; methodology, D.J.; software, B.O.; validation, R.-M.P.; formal analysis, D.J.; resources, B.O.; data curation, D.-M.J.; writing—original draft preparation, D.J.; writing—review and editing, D.J. and N.-M.J.; visualization, B.O and D.-M.J.; supervision, D.J. All authors have read and agreed to the published version of the manuscript.

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Data Availability Statement: Transelectrica website, Transparency section (Transelectrica is the Romanian Transmission and System Operator in the Romanian electricity market). In addition to direct access to data, by accessing the site (https://www.transelectrica.ro/en/web/tel/rapoarte-zilnice (from the website select "Realized Consumption"), accessed on 24 November 2022, we enclosed an alternative access path: Transelectrica (https://www.transelectrica.ro/en/web/tel/home) → select Transparency → then Balancing and Ancillary Services → Daily Reports → and finally, select "Realized Consumption".

Conflicts of Interest: The authors declare no conflict of interest.

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