Renewable Energy during the Pandemic Crisis

DIANA-MIHAELA JULA
Ph.D. Student
School of Advanced Studies of the Romanian Academy (SCOSAAR)
Department of Economic, Social and Legal Sciences
diana.jula@yahoo.com

Abstract: In this paper, we studied, for Romania, whether the COVID-19 crisis induced significant changes in the pattern of electricity generation, both as total production and on different sources. We used data concerning the net electricity generation by types of fuels in the pre-crisis period (2006 - March 2020), during the state of emergency imposed in the context of the pandemic (March 2020 - May 2020) and over the state of alert (June 2020 - February 2022). As methodology, we estimated some econometric models with dummy variables applied Wald tests for the hypotheses that, in Romania, the electricity production patterns do not differ significantly in the states of emergency and alert compared to those recorded for the pre-crisis period. We found that during the state of emergency, if the dynamics were cleared by both autoregressive, seasonal and cyclical effects, as well as long-term trends, then only wind energy increased compared to the normal period (pre-crisis). During the alert period the patterns of electricity production returned to those of the period before the outbreak of the COVID-19 crisis for all generation sources.

Keywords: net electricity generation by type of fuel, renewable energy, COVID-19 pandemic

1. Introduction

During the pandemic energy demand has been influenced by declining in commercial activities and, in particular, by the drastic reductions in transport, tourism, entertainment and leisure activities and, of course, the blocking of supply chains (International Energy Agency, 2022). Although household energy consumption did not decrease, it could only partially compensate for the decline in other areas (Todeschi, et al., 2022). The electricity production has adapted to fluctuations in global demand.

There is a vast amount of literature that studies the impact of COVID-19 crisis on electricity production. Among these studies we mention Olabi, Wilberforce, Elsaid, Sayed, & Abdelkareem (2022) who analysed the impact of the pandemic on renewable energy in European Union, the United States, China and India, more specifically, on the process of "commissioning of RE projects", process that was "stalled due to lack of funding allocation and interruptions in the supply of equipment and components due to lockdown measures", affecting, in particular, solar and wind projects (p. 563).

Khanna (2021) discussed the impact of the "demand destruction", caused by the crisis, on "the beginning of the end for fossil fuels". In Khanna's words, the COVID-19 crisis could be "for the renewable energy industry ... a cloud with a silver lining". Hemrit & Benlagha (2021) also found "significant positive effects of the pandemic uncertainty on renewable energy index".

International Energy Agency (2021, p. 195) notes that, although the pandemic crisis "severely affected the global energy system", however "electricity proved to be more resilient than other energy sources. Global demand for electricity fell by only 1% in 2020". Vara (2021) claims that "COVID-19 brought a significant decline in energy generation using fossil fuel, while renewable power gained new momentum."

Radtke (2022) discussed a smart energy system in the post-crisis era. Nicola, et al. (2020) developed a review of the impact of COVID-19 on energy demand. Pastory & Munishi (2022), Salisu & Adediran (2020) and Shaikh (2022) analysed the influence of the pandemic on energy market volatility.

The impact of the COVID-19 crisis on renewable energy in European countries is presented in a Eurostat Report (Eurostat, 2021). Werth, Gravino & Prevedello (2021, p. 6) argue that in Europe, "energy generation by coal, oil and nuclear was reduced considerably, in favour of intermittent renewable sources and, in some countries, fossil gas." Other studies regarding the impact of COVID-19 on European renewable energy sector are Goddard (2020) and Kies, et al. (2021). Agdas & Barooah (2020), Au, Saldaña, Spanswick & Santerre (2020) studied the impact of COVID-19 on electricity sector in United States, Balest & Stawinoga (2022) in Italy, Bover, Fabra, García-Uribe, Lacuesta & Ramos (2021) in Spain, Mehlig, Simon & Staffel (2021) in UK. Luo, et al.

(2022) analysed the impact of COVID-19 on the green power sector in Netherlands. Wang, Huang & Li (2022), Lu, Liu, Xie & Xu (2021), Dong, Ji, Mustafa & Khursheed (2021) conducted a survey concerning the crisis impact on renewable energy in China. Shekhar, Suri, Somani, Lee & Arora (2021) studied renewable energy in India, during the pandemic.

For Romania, we mention the papers by Jula (2021a) and Jula (2021b), Iancu, Darab & Cîrstea (2021) and Soava, Mehedintu, Sterpu & Grecu (2021).

In this paper, we studied, for Romania, the impact of the COVID-19 crisis on the net production of electricity by types of fuels, in the pre-crisis period (2006 - March 2020), during the state of emergency imposed in the context of the pandemic (March 2020 - May 2020) and over the state of alert (June 2020 - February 2022). We tested whether the COVID19 crisis induced significant changes in the pattern of electricity generation, both as total production and on different sources.

2. Data and Methodology

We used monthly data concerning *net electricity generation by type of fuel* from Eurostat (table nrg_cb_pem, retrieved from https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=nrg_cb_pem&lang=en). Data of the Eurostat, in Gigawatt-hour (GWh), refer to total electricity generation, electricity produced from combustible fuels (renewable and non-renewable), coal and manufactured gases, natural gas, oil and petroleum products (excluding biofuel portion), hydro (pure, mixed and pumped hydro power), geothermal, wind (on shore and off shore), solar (thermal and photovoltaic), nuclear fuels and other fuels not elsewhere classified (n.e.c.).

Monthly electricity generation data by fuel types are available at Eurostat since January 2016. Given that the state of alert, generated by the COVID-19 pandemic, was lifted in Romania starting with March 9, 2022, we selected February 2022 as the end date of our analysis. In the Eurostat database, mentioned above, for Romania, there are no data reported on electricity produced from combustible fuels non-renewable, from mixed and pumped hydro power, geothermal, wind off shore, solar thermal and electricity from other fuels n.e.c.

As methodology, we used the econometric estimations of some models with dummy variables (Jula & Jula, Econometria seriilor de timp, 2019) and Wald tests for the hypotheses that, in Romania, the electricity production patterns do not differ significantly in the states of emergency and alert, compared to those recorded for the pre-crisis period.

3. Econometric models and results

3.1. Total electricity generation

For the time series *total electricity generation* (net electricity generation by all the sources), the standard unit root tests (Augmented Dickey-Fuller test, Phillips-Perron test, Dickey-Fuller GLS test, Elliott-Rothenberg-Stock Point-Optimal test, Ng-Perron tests) reject the null hypothesis of unit root at 5% level, in models with constant and linear trend as exogenous and the Kwiatkowski-Phillips-Schmidt-Shin test statistic do not reject the null of stationarity. Moreover, HEGY test (Hylleberg, Engle, Granger, & Yoo, 1990) rejects the unit roots for all seasonal frequencies, in the models with seasonal dummies. Based on these results, we accept the hypothesis that the series is stationary in the model with constant and trend (Figure 1).

We test whether or not electricity production during the COVID-19 crisis differs significantly from production in normal times.

We considered three periods (pre-crisis, state of emergency, state of alert) and built an econometric model as the following:

$$\begin{aligned}\mathrm{TEG}_t &= a_1 D_{2016m01-2020m02} + a_2 D_{2020m03-2020m05} + a_5 D_{2020m06-2022m02} + \\ &\quad + b_i D\left(\mathrm{month}_i\right) + \mathrm{trend} + \mathrm{cycle} + e_t \qquad \text{[Eq.1]} \\ e_t &\ \square\ \mathrm{SAR}(p)(P)_{s=12}\end{aligned}$$

where

t – time index (t = 1, for 2016m01, i.e., January 2016, …, t = 74, for 2022m02, i.e.. February 2022)

TEG – total electricity generation

$D_{2016m01-2020m02}$ – dummy variable for pre-crisis period, with the value 1 between January 2016 – February 2020 and zero between March 2020 – February 2022.

$D_{2020m03-2020m05}$ – dummy variable for the state of emergency period, with the value 1 between March 2020 – May 2020 and zero otherwise (the state of emergency has been introduced on March 16, 2020 and ended on 14 May 2020)

$D_{2020m06-2022m02}$ – dummy variable for the state of alert period, with the value 1 between June 2020 – February 2022 and zero between January 2016 – May 2020 (the state of alert was in effect from May 15, 2020, until March 8, 2022)

$D(month_i)$ – dummy variables for each month. In order to avoid the perfect collinearity with the dummy variables introduced for the periods of pre-crisis, the state of emergency, the state of alert respectively, we dropped the dummies for January and December.

trend – polynomial time function

cycle – cyclic component (usually, four years)

$SAR(p)(P)_{s=12}$ – seasonal autoregressive process, with p - the order of the autoregressive part, P - the order of the seasonal autoregressive part and seasonality (s) = 12 months

e_t – error variable

$a_1 \dots a_5$ – coefficients of the dummy variables

b_i – coefficients of the dummy variables for each month (i = 2, …, 11)

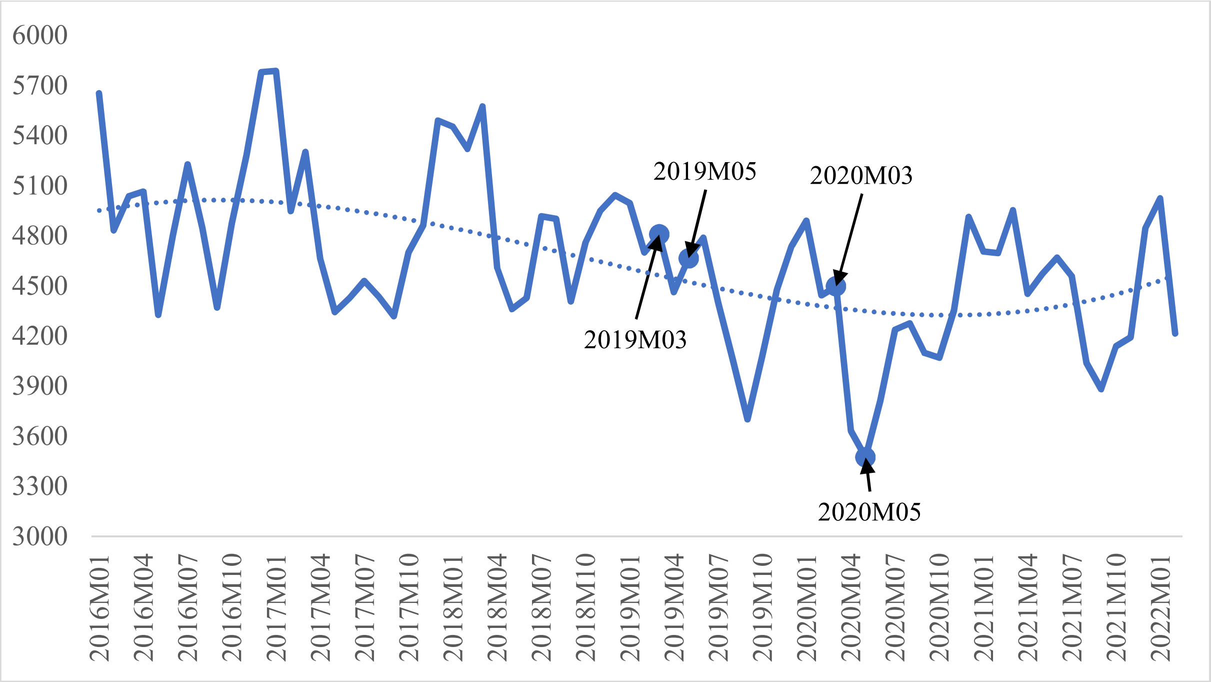

Figure 1. Total electricity generation

Source: Eurostat database (table nrg_cb_pem),
https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=nrg_cb_pem&lang=en

The coefficient a_1 estimates the average, in normal times (before the pandemic), of total net electricity generation, if the dynamics were cleared by both autoregressive, seasonal and cyclical effects, as well as long-term trends. The a_2 estimates the average of production during the state of emergency, while a_3 evaluates the average during the state of alert. If the coefficients a_2 and a_3 differ significantly from the a_1, then the COVID-19 pandemic meaningfully affected the total net electricity generation.

Next, instead of considering the period of the state of emergency homogeneous, we detailed it by months. This version of econometric model is the following:

$$\begin{aligned} TEG_t &= a_1 D_{2016m01-2020m02} + a_2 D_{2020m03} + a_3 D_{2020m04} + a_4 D_{2020m05} \\ &\quad + a_5 D_{2020m06-2022m02} + b_i D(month_i) + trend + cycle + e_t \qquad [Eq.2] \\ e_t &\sim SAR(p)(P)_{s=12} \end{aligned}$$

where
$D_{2020m03}$ – dummy variable for March 2020 (the state of emergency has been introduced since March 16, 2020)
$D_{2020m04}$ – dummy variable for April 2020 (April 2020 is the only month that has been fully covered by the state of emergency)
$D_{2020m05}$ – dummy variable for May 2020 (the state of emergency ceased on 14 May 2020)
and the other symbols are identical to those in the first model.

Here, the coefficients a_2, a_3 and a_4 estimate the average of production during each month from the state of emergency period, while a_5 evaluate the average during the state of alert. If the coefficients a_2, a_3, a_4 and a_5 differ significantly from the a_1, then the COVID-19 pandemic meaningfully affected the total net electricity generation. The estimators for both econometric models are in Table 1.

Table 1. Total net electricity generation

Dependent Variable: Total electricity generation

Variable	Coefficient (Std. Error)	[t-Statistic] Prob.	Variable	Coefficient (Std. Error)	[t-Statistic] Prob.
$D_{2016m01-2020m02}$	5584.684 (67.67495)	[82.52218] 0.0000	$D_{2016m01-2020m02}$	5585.596 (62.9910)	[88.67295] 0.0000
$D_{2020m03-2020m05}$	5387.135 (232.0771)	[23.21270] 0.0000			
			$D_{2020m03}$	5337.661 (338.9654)	[15.74692] 0.0000
			$D_{2020m04}$	5146.278 (271.9079)	[18.92655] 0.0000
			$D_{2020m05}$	5507.192 (257.0961)	[21.42075] 0.0000
$D_{2020m06-2022m02}$	5550.766 (148.1768)	[37.46043] 0.0000	$D_{2020m06-2022m02}$	5560.998 (138.3696)	[40.18944] 0.0000
$\cos(2\pi t/48)$	-150.8561 (54.19134)	[-2.783768] 0.0074	$\cos(2\pi t/48)$	-144.8918 (48.36602)	[-2.995735] 0.0000
t	-11.01293 (1.997918)	[-5.512200] 0.0000	t	-11.07255 (1.920959)	[-5.764074] 0.0247
AR(1)	0.387630 (0.102623)	[3.777235] 0.0004	AR(1)	0.395949 (0.099667)	[3.972700] 0.0002
AR(3)	0.366594 (0.128596)	[2.850736] 0.0062	AR(3)	0.362852 (0.137249)	[2.643748] 0.0108
AR(4)	-0.468397 (0.124169)	[-3.772238] 0.0004	AR(4)	-0.502631 (0.134169)	[-3.746249] 0.0005
SAR(12)	-0.595404 (0.120803)	[-4.928715] 0.0000	SAR(12)	-0.633361 (0.116832)	[-5.421106] 0.0000
Monthly dummy variables			Monthly dummy variables		
R-squared		0.887319	R-squared		0.895172

Source: Econometric estimates based on Eurostat data (table nrg_cb_pem), on line at https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=nrg_cb_pem&lang=en.

All coefficients a_i are significantly different from zero, at the threshold $p < 10^{-4}$. The time series for total net electricity generation has a four-year cyclical component. For the first model, when the dynamics were cleansed of cyclical, seasonal, autoregressive and trend effects, the probabilities associated (in the Wald test) with the hypotheses that the coefficients in COVID-19 crisis periods do not differ significantly from those in pre-crisis time are 0.34 (for the state of emergency) and 0.75 (state of alert), respectively. Both probabilities are well above the standard threshold of 0.05! Besides, the probability associated with the hypothesis that all the coefficients are equals among them (i.e., statistically, $a_1 = a_2 = a_3$) is 0.63. This means that, taken as a whole, the electricity generation patterns during COVID-19 crisis do not differ significantly from those in the pre-crisis period (Table 2).

Table 2. Wald test on coefficient equality in econometric equations of total net electricity generation

The null hypothesis: if the dynamics were cleansed of seasonal, autoregressive and trend effects, then ...	Probability	Obs.: Wald test for coefficients from …
Average of total net electricity generation during the state of emergency = average on pre-crisis period	0.338	Eq. 1
Average of total net electricity generation on March 2020 = average on pre-crisis period	0.447	Eq. 2
Average of total net electricity generation on April 2020 = average on pre-crisis period	0.088	Eq. 2
Average of total net electricity generation on May 2020 = average on pre-crisis period	0.745	Eq. 2
Average of total net electricity generation during the state of alert = average on pre-crisis period	0.749	Eq. 1
Averages of total net electricity generation in all periods are equal to each other	0.630	Eq. 1

Source: Econometric estimates based on Eurostat data (table nrg_cb_pem), on line at https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=nrg_cb_pem&lang=en

For a more detailed analysis, we divided the emergency period (March 16, 2020 - May 14, 2021) by months. Econometrically, we solved a model like the one described by equation 2. For this model, the probability associated in Wald test with the hypothesis that the coefficient of dummy variable for April 2020 ($\hat{a}_3 = 5146.278$) do not differ significantly from pre-crisis period (when the estimator is $\hat{a}_1 = 5585.596$) is 0.089. April 2020 is the only month that has been fully covered by the state of emergency. This means that, the average of total net electricity generation on April 2020 is significantly smaller than the average before the COVID-19 crisis, when the dynamics were cleansed of cyclical, seasonal, autoregressive and trend effects. For March 2020 and May 2020, the coefficients do not differ significantly for pre-crisis parameter (for March, this probability is 0.44, in Wald test and for May 2020, the probability is 0.74). Moreover, the pattern of production in state of alert returned to the pre-crisis standing: if we reject the hypothesis that, statistically, $a_5 = a_1$, then the risk of error is 0.80 (well above the standard threshold of 0.05!). This means that the COVID-19 pandemic negatively affected the Romanian total net electricity generation in April 2020 and did not significantly affect the pattern of production in the other months of the emergency and alert states. This finding is consistent with the International Energy Agency remark (International Energy Agency, 2021, p. 195) that, even if the pandemic crisis "severely affected the global energy system", however "electricity proved to be more resilient than other energy sources. Global demand for electricity fell by only 1% in 2020" (see also Jula, 2021b).

3.2. Electricity generation by combustible fuels

As in the case of total electricity production, discussed above, for the time series *electricity generation by combustible fuels* (Figure 2), the standard unit root tests (Augmented Dickey-Fuller test, Phillips-Perron test, Dickey-Fuller GLS test, Elliott-Rothenberg-Stock Point-Optimal test, Ng-Perron tests) reject the null hypothesis of unit root at 5% level, in models with constant and linear trend as exogenous and the Kwiatkowski-Phillips-Schmidt-Shin test statistic do not reject the null of stationarity. Moreover, HEGY test (Hylleberg, Engle, Granger, & Yoo, 1990) rejects the unit roots for all seasonal frequencies, in the models with seasonal dummies. Based on these results, we accept the hypothesis that the series is stationary, in the model with constant and linear trend.

We test if *electricity production by combustible fuels* during the COVID-19 crisis differs significantly from production in normal times.

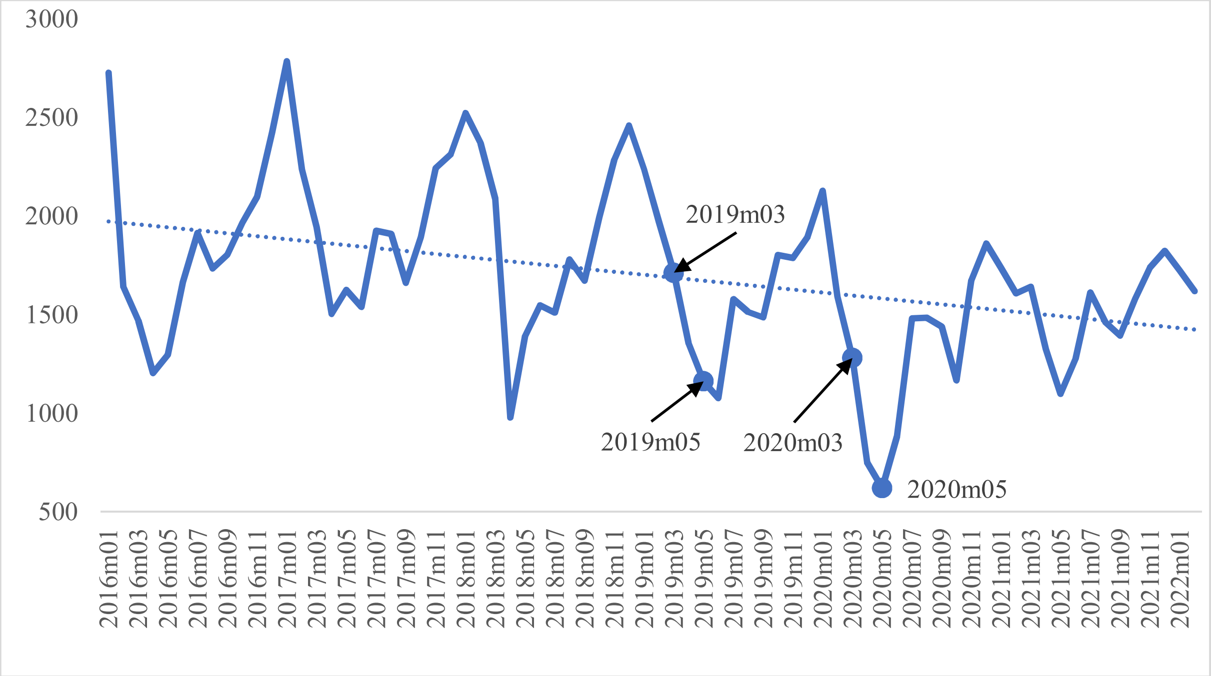

Figure 2. Electricity generation by combustible fuels

Source: Eurostat database (table nrg_cb_pem),
https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=nrg_cb_pem&lang=en

We have considered, as above, three periods (pre-crisis, state of emergency, state of alert) and built an econometric model as the following:

$$\begin{aligned} CF_t &= a_1 D_{2016m01-2020m02} + a_2 D_{2020m03-2020m05} + a_5 D_{2020m06-2022m02} + \\ &+ b_i D\left(\text{month}_i\right) + \text{trend} + \text{cycle} + e_t \qquad \text{[Eq.3]} \\ e_t &\ \square\ SAR\left(p\right)\left(P\right)_{s=12} \end{aligned}$$

where CF is electricity generation by combustible fuels and the other symbols are identical to those in the model described by Eq. 2. The estimators for econometric models are in Table 3.

Table 3. Electricity generation by combustible fuels

Dependent Variable: Electricity generation by combustible fuels

Variable	Coefficient (Std. Error)	[t-Statistic] Prob.
$D_{2016m01-2020m02}$	2331.013 (54.06268)	[43.11685] 0.0000
$D_{2020m03-2020m05}$	1866.608 (227.2754)	[8.212976] 0.0000
$D_{2020m06-20220m02}$	1926.900 (82.04903)	[23.48474] 0.0000
$\cos(2\pi t/48)$	-125.1142 (48.62657)	[-2.572960] 0.0127
AR(1)	0.336174 (0.146501)	[2.294678] 0.0254
R-squared	0.840751	

Source: Econometric estimates based on Eurostat data (table nrg_cb_pem), on line at https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=nrg_cb_pem&lang=en.

All coefficients a_i are significantly different from zero, at the threshold of 0.1%. The average of electricity generation by combustible fuels during the state of emergency ($\hat{a}_2$ = 1866.6) is significantly smaller than the average after the COVID-19 crisis ($\hat{a}_1$ = 2331.0), when the dynamics were cleansed of cyclical, seasonal, autoregressive and trend effects: the probability associated (in the Wald test) with the hypothesis that the coefficients do not differ significantly (i.e., statistically, $a_2 = a_1$) is around of 0.039, and for $a_1 = a_2 = a_3$ the probability is less than 0.0001. This means that the COVID-19 pandemic negatively affected the net electricity generation by combustible fuels, especially during the state of emergency period. When we detailed the state of emergency period over months, the model coefficients were not economically significant.

3.3. Electricity generation by renewable sources (hydro, wind and solar)

For the time series *electricity generation by combustible fuels* (Figure 3) the standard unit root tests (Augmented Dickey-Fuller test, Phillips-Perron test, Dickey-Fuller GLS test, Elliott-Rothenberg-Stock Point-Optimal test, Ng-Perron tests) reject the null hypothesis of unit root at 5% level, in models with constant as exogenous and the Kwiatkowski-Phillips-Schmidt-Shin test statistic do not reject the null of stationarity. Moreover, HEGY test (Hylleberg, Engle, Granger, & Yoo, 1990) rejects the unit roots for all seasonal frequencies, in the models with seasonal dummies. Based on these results, we accept the hypothesis that the series is stationary.

We test whether *electricity generation from renewable sources* (hydro, wind, and solar) during the COVID-19 crisis differs significantly from pre-crisis generation.

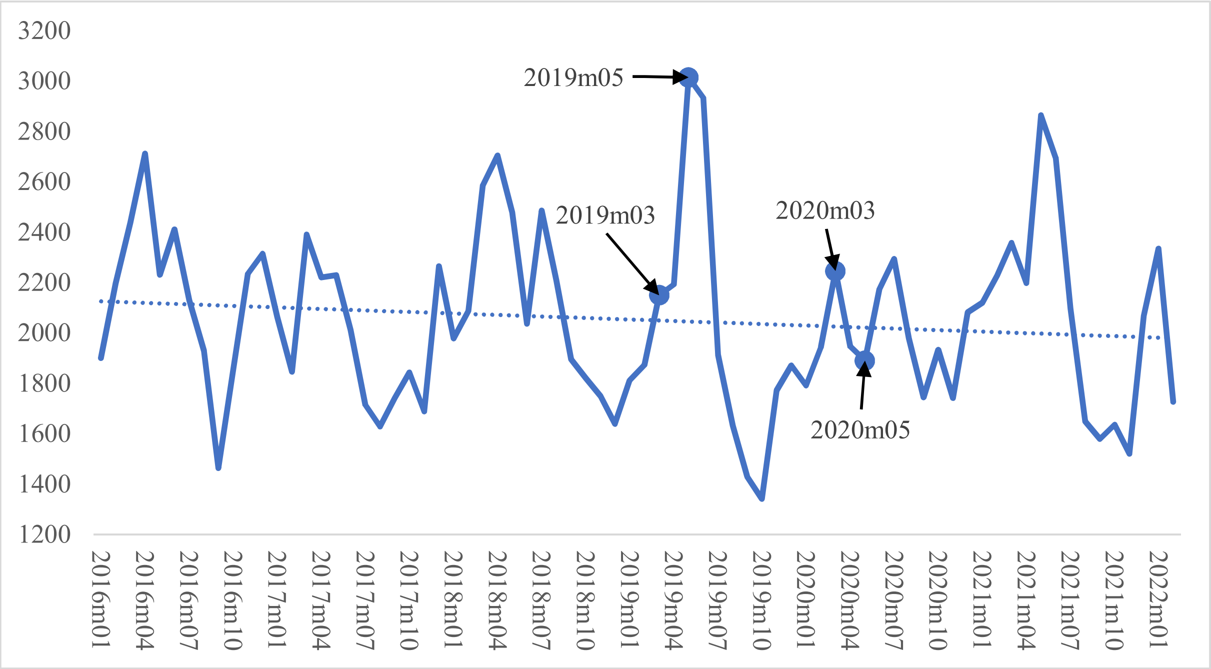

Figure 3. Electricity generation by renewable sources (hydro, wind and solar)

Source: Eurostat database (table nrg_cb_pem),
https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=nrg_cb_pem&lang=en

We have considered, as above, three periods (pre-crisis, state of emergency, state of alert) and built an econometric model as the following:

$$\begin{aligned} \mathrm{Renew}_t &= a_1 D_{2016m01-2020m02} + a_2 D_{2020m03-2020m05} + a_5 D_{2020m06-2022m02} + \\ &+ b_i D(\mathrm{month}_i) + \mathrm{trend} + \mathrm{cycle} + e_t \qquad \text{[Eq.4]} \\ e_t &\sim \mathrm{SAR}(p)(P)_{s=12} \end{aligned}$$

where *Renew* is electricity generation by renewable sources (hydro, wind and solar) and the other symbols are identical to those in the model described by Eq. 1. We also estimated a model in which we detailed the state of emergency, by months, similar to Eq. 2. The estimators for econometric models are in Table 4.

Table 4. Electricity by renewable sources (hydro, wind and solar)

Dependent Variable: Electricity generation by renewable sources (hydro, wind and solar)

Variable	Coefficient (Std. Error)	[t-Statistic] Prob.	Variable	Coefficient (Std. Error)	[t-Statistic] Prob.
$D_{2016m01-2020m02}$	1992.095 (50.02085)	[39.82529] 0.0000	$D_{2016m01-2020m02}$	1988.654 (46.21333)	[43.03203] 0.0000
$D_{2020m03-2020m05}$	1597.550 (228.5363)	[6.990355] 0.0000			
			$D_{2020m03}$	1678.969 (601.4599)	[2.791489] 0.0072
			$D_{2020m04}$	1232.781 (417.1901)	[2.954963] 0.0046
			$D_{2020m05}$	1689.610 (301.7218)	[5.599893] 0.0000
$D_{2020m06-2022m02}$	2028.967 (71.18291)	[28.50358] 0.0000	$D_{2020m06-2022m02}$	2031.560 (66.25892)	[30.66093] 0.0000
AR(1)	0.317997 (0.126893)	[2.506027] 0.0150	AR(1)	0.360767 (0.130991)	[2.754132] 0.0079
SAR(12)	-0.465966 (0.153064)	[-3.044265] 0.0035	SAR(12)	-0.551522 (0.143227)	[-3.850671] 0.0003
Monthly dummy variables			Monthly dummy variables		
R-squared		0.701086	R-squared		0.723497

Source: Econometric estimates based on Eurostat data (table nrg_cb_pem), on line at https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=nrg_cb_pem&lang=en.

All coefficients a_i are significantly different from zero, at the threshold of 0.01. The average of electricity generation by renewable sources (hydro, wind, solar) during the state of emergency ($\hat{a}_2 = 1597.55$) is significantly smaller than the average after the COVID-19 crisis ($\hat{a}_1 = 1992.10$), when the dynamics were cleansed of cyclical, seasonal, autoregressive and trend effects: the probability associated (in the Wald test) with the hypothesis that the coefficients do not differ significantly (i.e., statistically, $a_2 = a_1$) is around of 0.079. By months, the strongest decline was in April 2020. This means that the COVID-19 pandemic negatively affected the net electricity generation by renewable sources during the state of emergency period. Over the state of alert period, the average ($\hat{a}_3 = 2028.97$) is slightly higher than that recorded before the COVID-19 crisis, but the positive difference is not statistically significant. This denotes a return of electricity generation from aggregate renewable sources to the normal pattern.

These findings contradict certain statements in the literature, for example: "COVID-19 brought a significant decline in energy generation using fossil fuel, while renewable power gained new momentum." (Vara, 2021) and "Renewable energy largely spared from pandemic effects" (Eurostat, 2021). There are also studies that have come to similar conclusions with us: Dong, Ji, Mustafa, & Khursheed (2021, p. 1) found that "COVID-19 pandemic has significantly reduced the renewable energy production in China, both in the short and long run."

We have detailed the analysis on the main sources of electricity production in Romania (hydropower, wind and solar).

a. Hydro electricity generation

For the time series *electricity generation by hydro source* (Figure 4) the standard unit root tests (Augmented Dickey-Fuller test, Phillips-Perron test, Dickey-Fuller GLS test, Elliott-Rothenberg-Stock Point-Optimal test, Ng-Perron tests) reject the null hypothesis of unit root at 5% level, in models with constant as exogenous and the Kwiatkowski-Phillips-Schmidt-Shin test statistic do not reject the null of stationarity. Moreover, HEGY test (Hylleberg, Engle, Granger, & Yoo, 1990) rejects the unit roots for all seasonal frequencies, in the models with seasonal dummies. Based on these results, we accept the hypothesis that the series is stationary.

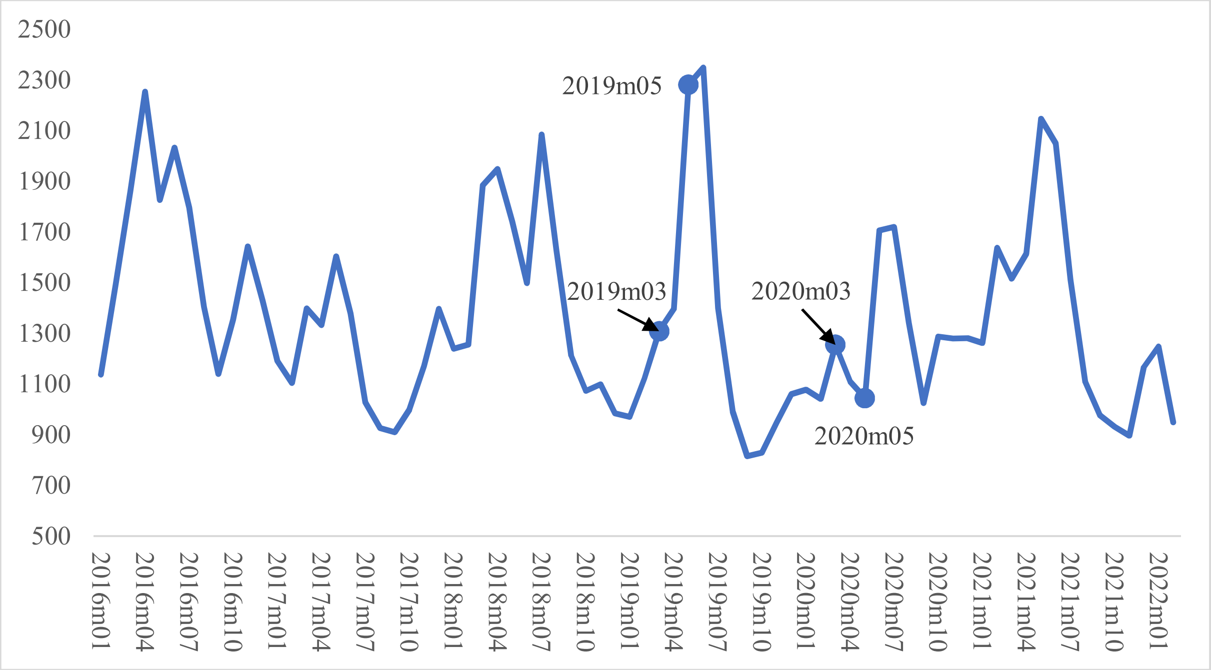

Figure 4. Electricity generation by hydro sources

Source: Eurostat database (table nrg_cb_pem),
https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=nrg_cb_pem&lang=en

We test whether *electricity generation from hydro sources* during the COVID-19 crisis differs significantly from pre-crisis generation.

We have considered, as above, three periods (pre-crisis, state of emergency, state of alert) and built an econometric model as the following:

$$\begin{aligned} \mathrm{Hydro}_t &= a_1 D_{2016m01-2020m02} + a_2 D_{2020m03-2020m05} + a_5 D_{2020m06-2022m02} + \\ &\quad + b_i D(\mathrm{month}_i) + \mathrm{trend} + \mathrm{cycle} + e_t \qquad \text{[Eq.5]} \\ e_t &\sim \mathrm{SAR}(p)(P)_{s=12} \end{aligned}$$

where *Hydro* is electricity generation by hydro sources and the other symbols are identical to those in the model described by Eq. 1. We also estimated a model in which we detailed the state of emergency, by months, similar to Eq. 2. The estimators for econometric models are in Table 5.

Table 5. Electricity generation by hydro sources

Dependent Variable: Electricity generation by hydro sources

Variable	Coefficient (Std. Error)	[t-Statistic] Prob.	Variable	Coefficient (Std. Error)	[t-Statistic] Prob.
$D_{2016m01-2020m02}$	1167.401 (62.98506)	[18.53457] 0.0000	$D_{2016m01-2020m02}$	1165.228 (61.76362)	[18.86594] 0.0000
$D_{2020m03-2020m05}$	546.9054 (154.0143)	[3.551004] 0.0008			
			$D_{2020m03}$	595.7222 (219.3298)	[2.716102] 0.0088
			$D_{2020m04}$	280.9938 (436.2650)	[0.644090] 0.5221
			$D_{2020m05}$	558.2846 (261.5807)	[2.134273] 0.0372

Variable	Coefficient (Std. Error)	[t-Statistic] Prob.	Variable	Coefficient (Std. Error)	[t-Statistic] Prob.
$D_{2020m06\text{-}2022m02}$	1212.370 (96.80410)	1217.532 (99.23301)	$D_{2020m06\text{-}2022m02}$	1217.532 (99.23301)	[12.26943] 0.0000
AR(1)	0.507172 (0.111065)	0.537342 (0.105360)	AR(1)	0.537342 (0.105360)	[5.100040] 0.0000
SAR(12)	-0.649293 (0.102385)	-0.680558 (0.114071)	SAR(12)	-0.680558 (0.114071)	[-5.966112] 0.0000
Monthly dummy variables			Monthly dummy variables		
R-squared		0.813975	R-squared		0.825524

Source: Econometric estimates based on Eurostat data (table nrg_cb_pem), on line at https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=nrg_cb_pem&lang=en.

Except for the coefficients of the dummy variables attached to March 2020 and April 2020, all other coefficients in both models are significantly different from zero at the 0.01 threshold. The average of electricity generation by hydro sources during the state of emergency ($\hat{a}_2 = 546.91$) is significantly smaller than the average after the COVID-19 crisis ($\hat{a}_1 = 1167.40$), when the dynamics were cleansed of cyclical, seasonal, autoregressive and trend effects: the probability associated (in the Wald test) with the hypothesis that the coefficients do not differ significantly (i.e., statistically, $a_2 = a_1$) is 0.0001. By months, the strongest decline was in April 2020. This means that the COVID-19 pandemic negatively affected the net electricity generation by hydro sources during the state of emergency period. Over the state of alert period, the average ($\hat{a}_3 = 1217.53$) is slightly higher than that recorded before the COVID-19 crisis, and the positive difference is statistically significant (for Wald test on $a_3 = a_1$, the probability is 0.049). This denotes a return of electricity generation from hydro sources to the normal pattern (even with a slight growth).

b. Wind electricity generation

For the time series *wind electricity generation* (Figure 5) the standard unit root tests (Augmented Dickey-Fuller test, Phillips-Perron test, Dickey-Fuller GLS test, Elliott-Rothenberg-Stock Point-Optimal test, Ng-Perron tests) reject the null hypothesis of unit root at 1% level, in models with constant as exogenous and the Kwiatkowski-Phillips-Schmidt-Shin test statistic do not reject the null of stationarity. Moreover, HEGY test (Hylleberg, Engle, Granger, & Yoo, 1990) rejects the unit roots for all seasonal frequencies, in the models with seasonal dummies. Based on these results, we accept the hypothesis that the series is stationary.

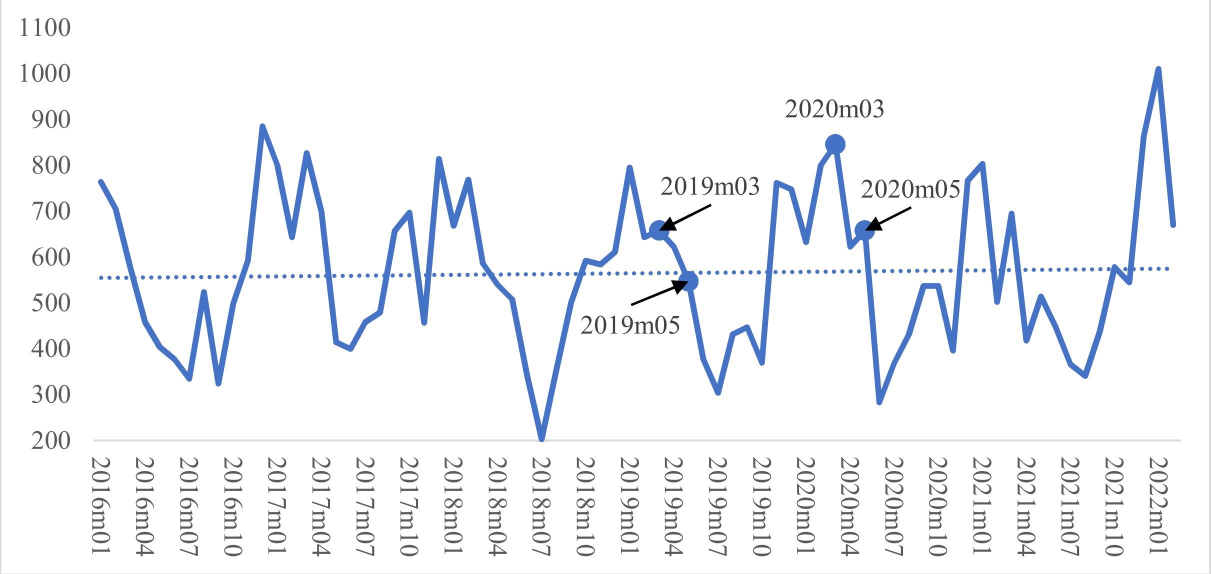

Figure 5. Wind electricity generation

Source: Eurostat database (table nrg_cb_pem), https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=nrg_cb_pem&lang=en

We test whether *wind electricity generation* during the COVID-19 crisis differs significantly from pre-crisis pattern production. We have considered, as above, three periods (pre-crisis, state of emergency, state of alert) and built an econometric model as the following:

$$\begin{aligned} \mathrm{Wind}_t &= a_1 D_{2016m01-2020m02} + a_2 D_{2020m03-2020m05} + a_5 D_{2020m06-2022m02} + \\ &\quad + b_i D(\mathrm{month}_i) + \mathrm{trend} + \mathrm{cycle} + e_t \qquad \text{[Eq.6]} \\ e_t &\sim \mathrm{SAR}(p)(P)_{s=12} \end{aligned}$$

where *Wind* is wind electricity generation and the other symbols are identical to those in the model described by Eq. 1. We also estimated a model in which we detailed the state of emergency, by months, similar to Eq. 2. The estimators for econometric models are in Table 5.

Table 6. Wind electricity generation

Dependent Variable: Wind electricity generation

Variable	Coefficient (Std. Error)	[t-Statistic] Prob.	Variable	Coefficient (Std. Error)	[t-Statistic] Prob.
$D_{2016m01-2020m02}$	784.0107 (28.34712)	[27.65751] 0.0000	$D_{2016m01-2020m02}$	784.0107 (28.67771)	[27.33868] 0.0000
$D_{2020m03-2020m05}$	927.0204 (67.84051)	[13.66470] 0.0000			
			$D_{2020m03}$	959.7538 (112.2423)	[8.550734] 0.0000
			$D_{2020m04}$	858.1538 (112.2423)	[7.645549] 0.0000
			$D_{2020m05}$	963.1538 (112.2423)	[8.581025] 0.0000
$D_{2020m06-2022m02}$	776.7258 (32.51755)	[23.88636] 0.0000	$D_{2020m06-2022m02}$	776.7258 (32.89678)	[23.61100] 0.0000
Monthly dummy variables			Monthly dummy variables		
R-squared		0.726979	R-squared		0.729735

Source: Econometric estimates based on Eurostat data (table nrg_cb_pem), on line at https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=nrg_cb_pem&lang=en.

All coefficients a_i are significantly different from zero, at the threshold of 0.0001. We did not identify seasonal autoregressive (SAR) structures, trend, or cycle. The average of wind electricity generation during the state of emergency ($\hat{a}_2$ = 927.02) is significantly higher than the pre-crisis average ($\hat{a}_1$ = 784.01), when the dynamics were cleansed of cyclical, seasonal, autoregressive and trend effects: the probability associated (in the Wald test) with the hypothesis that the coefficients do not differ significantly (i.e., statistically, $a_2 = a_1$) is 0.025. The average values are higher than those recorded before the COVID-19 pandemic during all the months of emergency period. This means that the COVID-19 pandemic does not affect the wind electricity generation during the state of emergency period. Over the state of alert period, the average ($\hat{a}_3$ = 776.7258) is close to pre-crisis value and this denotes a return to the normal pattern.

c. Solar (photovoltaic) electricity generation

For the time series *solar (photovoltaic) electricity generation* (Figure 6) the standard unit root tests (Augmented Dickey-Fuller test, Phillips-Perron test) reject the null hypothesis of unit root at 1% level, in models with constant as exogenous and the Kwiatkowski-Phillips-Schmidt-Shin test statistic do not reject the null of stationarity. Moreover, HEGY test (Hylleberg, Engle, Granger, & Yoo, 1990) rejects the unit roots for all seasonal frequencies, in the models with seasonal dummies. Based on these results, we accept the hypothesis that the series is stationary.

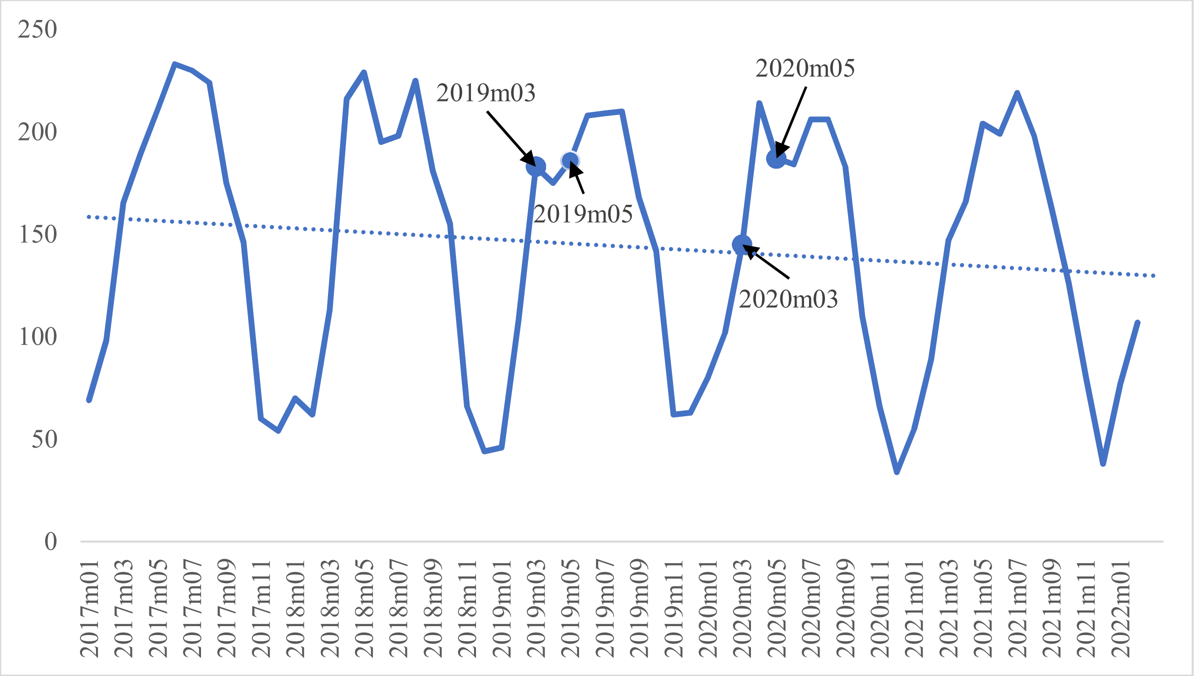

Figure 6. Solar (photovoltaic) electricity generation

Source: Eurostat database (table nrg_cb_pem),
https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=nrg_cb_pem&lang=en

We test whether *solar (photovoltaic) electricity* during the COVID-19 crisis differs significantly from pre-crisis pattern production. We have considered, as above, three periods (pre-crisis, state of emergency, state of alert) and built an econometric model as the following:

$$\begin{aligned} \mathrm{Solar}_t &= a_1 D_{2016m01-2020m02} + a_2 D_{2020m03-2020m05} + a_5 D_{2020m06-2022m02} + \\ &+ b_i D(\mathrm{month}_i) + \mathrm{trend} + \mathrm{cycle} + e_t \qquad \text{[Eq.7]} \\ e_t &\ \square\ \mathrm{SAR}(p)(P)_{s=12} \end{aligned}$$

where *Solar* is solar (photovoltaic) electricity generation and the other symbols are identical to those in the model described by Eq. 1. We also estimated a model in which we detailed the state of emergency, by months, similar to Eq. 2. The estimators for econometric models are in Table 7.

Table 7. Solar (photovoltaic) electricity

Dependent Variable: Solar (photovoltaic) electricity generation

Variable	Coefficient (Std. Error)	[t-Statistic] Prob.	Variable	Coefficient (Std. Error)	[t-Statistic] Prob.
$D_{2016m01\text{-}2020m02}$	58.64311 (2.991507)	[19.60320] 0.0000	$D_{2016m01\text{-}2020m02}$	58.49432 (2.640023)	[22.15675] 0.0000
$D_{2020m03\text{-}2020m05}$	52.82115 (9.184318)	[5.751233] 0.0000			
			$D_{2020m03}$	74.48598 (14.64677)	[5.085488] 0.0000
			$D_{2020m04}$	59.56651 (14.79459)	[4.026236] 0.0002
			$D_{2020m05}$	21.45024 (14.21183)	[1.509322] 0.1384
$D_{2020m06\text{-}2022m02}$	51.20313 (3.392917)	[15.09118] 0.0000	$D_{2020m06\text{-}2022m02}$	51.25087 (3.015039)	[16.99841] 0.0000

Variable	Coefficient (Std. Error)	[t-Statistic] Prob.	Variable	Coefficient (Std. Error)	[t-Statistic] Prob.
cos(2πt/6)	18.17438 (5.612054)	[3.238454] 0.0022	cos(2πt/6)	18.03467 (4.944337)	[3.647540] 0.0007
SAR(12)	-0.440513 (0.116588)	[-3.778386] 0.0005	SAR(12)	-0.543663 (0.118320)	[-4.594851] 0.0000
Monthly dummy variables			Monthly dummy variables		
R-squared		0.959373	R-squared		0.729735

Source: Eurostat database (table nrg_cb_pem),
https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=nrg_cb_pem&lang=en

Except for the coefficients of the dummy variables attached to May 2020, all other coefficients in both models are significantly different from zero at the 0.001 threshold. The average of Solar (photovoltaic) electricity generation during the state of emergency ($\hat{a}_2$ = 52.82) is close to the average after the COVID-19 crisis ($\hat{a}_1$ = 58.64), when the dynamics were cleansed of cyclical, seasonal, autoregressive and trend effects: the probability associated (in the Wald test) with the hypothesis that the coefficients do not differ significantly (i.e., statistically, $a_2 = a_1$) is 0.502. By months, in March 2020, the average is higher than in normal times, but in May 2020 there was a sharp decrease. This means that the COVID-19 pandemic does not affect Solar (photovoltaic) electricity generation during the state of emergence. Over the state of alert period, the average ($\hat{a}_3$ = 51.2) is slightly lower than that recorded before the COVID-19 crisis, and the negative difference is statistically significant (for Wald test on $a_3 = a_1$, the probability is 0.015).

4. Conclusions

The COVID-19 pandemic has directly affected Romania's economy since March 2020. Statistically, the Gross Domestic Product decreased in 2020 compared to 2019 by -3.7% (according to Eurostat data, *GDP and main components*, table nama_10_gdp). These developments have influenced the consumption and production of electricity. Total net electricity generation decreased from 53874 million kilowatt-hours in 2019 to 50693 in 2020 and recovered to 53702 in 2021. Electricity generation by renewable sources (hydro, wind, solar) slowly decreased in 2020, at 23767 mil. KWh, from 23937 mil. KWh in 2019 and increased in 2021, to 25017 mil. KWh (data are calculated from Eurostat database, table nrg_cb_pem).

In this paper, we have not made a simple statistical comparison between electricity production (total and on generation sources) during the COVID-19 crisis and production in normal times (before the crisis). We built econometric models to evaluate the autoregressive, cyclical and seasonal components in electricity generation dynamics, as well as long-term trends. After removing these structural elements from the production dynamics by generation sources, we compared the evolution during the pandemic (separately for the state of emergency, when the restrictions were stronger and the state of alert, when the restrictions were progressively relaxed) with the production dynamics from normal times (before the COVID-19 crisis). We found, for Romania, the following:

- ✓ The COVID-19 pandemic negatively affected the Romanian *total* net electricity generation in April 2020 (April 2020 is the only month that was fully covered by the state of emergency) and did not significantly affect the pattern of production in the other months of the emergency and alert states.
- ✓ The COVID-19 pandemic negatively affected the net electricity generation by *combustible fuels* during the state of emergency period and the pattern of electricity generation in state of alert returned to the pre-crisis standing.
- ✓ The average of electricity generation by *renewable sources* (hydro, wind, solar) during the state of emergency is significantly smaller than the average before the COVID-19 crisis. By months, the strongest decline was in April 2020. Over the state of alert period, the average of electricity production by renewable sources is slightly higher than that recorded before the COVID-19 crisis. This denotes a return of electricity generation from aggregate renewable sources to the normal pattern.
- ✓ The average of electricity generation by *hydro sources* during the state of emergency is significantly smaller than the average before the COVID-19 crisis. Over the state of alert period, the average is slightly higher than that recorded before the COVID-19 crisis, and the positive difference is statistically significant: COVID-19 crisis negatively affected the net electricity generation by hydro sources during

the state of emergency period and there is a return to the normal pattern (even with a slight growth) during the state of alert.

- ✓ The average of *wind electricity generation* is significantly higher than the pre-crisis average, during the state of emergency and return to normal pattern over the state of alert.
- ✓ The average of *solar (photovoltaic) electricity generation* during the state of emergency is close to the average before the COVID-19 crisis, but over the state of alert period, the average is slightly lower than that recorded before the COVID-19 crisis, and the negative difference is statistically significant.

All those findings are under the hypothesis that the dynamics were cleaned from the autoregressive, cyclical and seasonal components, as well as long-term trends.

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