Testing Merit-Order Effect in Turkey's Electricity Market: The Effect of Wind Penetration on Day-Ahead Electricity Prices

Türkiye Elektrik Piyasasında Merit Sınıflandırma Etkisinin Test Edilmesi: Rüzgar Penetrasyonunun Gün Öncesi Elektrik Fiyatlarına Etkisi

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Abstract

Due to recent support mechanisms, the share of renewable energy sources, particularly wind, in Turkey's electricity generation has increased significantly. Increasing renewable penetration is supposed to decrease the electricity prices, which is known as the merit-order effect. Main purpose of this article is to test the existence of merit-order effect in Turkish electricity market. To this end, a nonparametric Granger causality test based on wavelet transformation is applied on a daily data set covering Turkish day-ahead power market clearing prices and electricity generation from wind over the period between 2011 and 2018. The overall results confirm the existence of the merit-order effect of wind in Turkey's electricity market. It is also observed that the strength of the negative causality alters drastically over different sub-periods.

***Keywords**: Turkish electricity market, wind penetration, merit-order effect, CWT Granger causality*

***JEL Codes**: C14, D47, Q21, Q28*

Öz

Son destekleme mekanizmaları sayesinde, yenilenebilir enerji kaynaklarının, özellikle rüzgar enerjisinin, Türkiye elektrik üretimindeki payı önemli ölçüde artmıştır. Artan yenilenebilir penetrasyonunun elektrik fiyatlarını düşürmesi beklenmektedir ve bu merit sınıflandırma etkisi olarak bilinmektedir. Bu makalenin temel amacı Türk elektrik piyasasında merit sınıflandırma etkisinin test edilmesidir. Bu bağlamda, Türkiye gün öncesi elektrik piyasası takas fiyatı ve rüzgar temelli elektrik üretimi 2011 ile 2018 arası dönemi verilerini içeren günlük veri seti üzerine dalgacık dönüşümlü parametrik olmayan Granger nedensellik testi uygulanmıştır. Genel sonuçlar Türkiye elektrik piyasasında rüzgarın merit sınıflandırma etkisini doğrulamaktadır. Ayrıca, eksi yönlü nedenselliğin gücünün farklı alt dönemlerde şiddetli bir şekilde değiştiği de gözlemlenmiştir.

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JEL Kodları: *C14, D47, Q21, Q28*

1. Introduction

Turkey's electricity market has undergone substantial transformation over the recent years. Electricity Market Law (Law no. 4628) enacted in 2001 did not only create a solid basis for more competitive market but also initiated governmental support policies towards utilization of renewable potential in Turkish power generation sector. Within this context, in 2005 the Law on the Utilization of Renewable Energy Resources for the Purpose of Generating Electricity (Law no. 5346) was decreed, for the purpose of increasing the share of renewable energy sources in country's electricity generation. Main motivation behind this legislation was that modern renewable energy sources[3] would play an important role in creating a more secure and a less import dependent Turkish electricity supply (MENR, 2009). Yet, as correctly noted by Gozen (2014), the feed-in tariffs defined in Law no. 5346 were not high enough to attract renewable investments. Hence, in 2011 Turkish government initiated Renewable Energy Sources Supporting Mechanism[4] by amending the Law no. 5346.

Thanks to all of these legislations and subsidies the role of renewables in Turkish electricity generation has increased significantly. According to Turkish Electricity Transmission Corporation, the share of modern renewables in electricity generation has increased from 0.27% in 2001 to 2.51% in 2011 and further to 6.3% in 2015 (TEIAS, 2018). The renewable supporting policies have been particularly a success story for wind-based electricity generation sector. Such that, during the period from 2011 to 2017 the number of wind-based power generators applied for the support increased from 9 to 141 while their corresponding generation capacity increased from 4691 MW to 5238.7 MW, respectively. According to BP (2018), moreover, during the same period the share of wind in country's total electricity generation has increased from 2.1% (4.73 TWh) to 6.0% (17.86 TWh). Hence, over the last years almost all of the renewable penetration in Turkish electricity generation sector was originated from wind-based electricity generators.

[3] Modern renewables include solar PV and heating systems, wind-based electricity generation and biomass. In the energy economics literature hydroelectricity is referred to as a traditional renewable energy source.

[4] To see the details of the mechanism, please visit https://www.epdk.org.tr/Detay/Icerik/3-0-72/elektrikyekdem (in Turkish). Accessed on 24.08.2018.

Increasing renewable based electricity generation would decrease the electricity prices, due to the fact that the marginal electricity generation cost from renewables is way too lower than that of thermal power plants that run on fossil fuels, particularly on coal and natural gas. Hence, as the share of renewables increase in comparison to the fossil fuels, the marginal generation cost, and hence the prices, in the electricity system are supposed to decrease. This is known as the merit-order effect in the energy economics literature. This paper aims at testing the existence of merit-order effect, i.e., the effects of increasing wind penetration on the day-ahead market clearing prices, in Turkish electricity market.

To this end, we use daily data on day-ahead Turkish electricity market clearing prices (TL/KWh), wind generation planning (KWh) and the share of wind in total generation (%). The dataset covers the period between January 3, 2011 and May 31, 2018 and obtained from Energy Exchange Istanbul (EXIST, hereafter)[5]. A novel causality methodology, namely continuous wavelet transform Granger-causality test, is performed on the dataset to assess the existence of the merit-order effect of wind in Turkish electricity market. The results suggest negative and significant causality from wind penetration to electricity prices; hence they mainly confirm the existence of the merit-order effect of wind in Turkish electricity market. Moreover, analyses are conducted using two sub-periods, pre- and post-2016, due to a strong structural break in the wind electricity generation data on the beginning of 2016. Results on the sub-period analyses suggest that merit-order effect is more evident after 2016. This article contributes to the related literature in two-fold.[6] Firstly, although there has been a plateau of empirical studies focusing on the merit-order effect of wind and solar in European countries and the USA, to the authors' best knowledge there is none for Turkey. Secondly, current paper differentiates from the existing studies for other countries by employing a novel non-parametric methodology to assess causality between wind penetration and electricity prices.

Structure of the paper is as follows. In Section 2 a detailed literature review is provided. Section 3 is dedicated to the brief explanation of the methodology employed and the data used. Section 4 illustrates the empirical results. Finally, in Section 5 conclusions with policy implications are provided.

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[5] Energy Exchange Istanbul (EXIST) is Turkish Electricity and Natural Gas Exchange, which is responsible for providing an effective, transparent and liquid energy market. It was founded on March 12, 2015. Website: https://www.epias.com.tr/en, accessed on: 17.08.2018.

[6] Detailed literature survey and the contribution of the paper is provided in Section 2.

2. Literature Review

Historical development, current potential and future possible role of renewable energy sources in Turkish energy system has been extensively discussed in the literature for both regional (e.g., Türksoy, 1995; Tolun, et al. , 1995; Öztopal, et al., 2000; Durak and Şen, 2002; Karsli, and Gecit, 2003; Gökçek, et al., 2007; Ucar and Balo, 2009a, 2009b; Yaniktepe, et al., 2013a; Ilkiliç and Aydin, 2015) and national (e.g., Ediger and Kentel, 1999; Aras, 2003; Oğulata, 2003; Hepbasli and Ozgener, 2004; Akpinar, 2006; Erdogdu, 2009; Ilkılıç, et al., 2011; Ilkılıç, 2012; Benli, 2013; Yaniktepe, et al., 2013b; Kaplan, 2015; Melikoglu, 2016; Ozcan, 2018) level. Almost all of these studies are suggesting that modern renewables, particularly wind, would play an important role in creating a more sustainable energy system in Turkey. For instance, after assessing the development and the potential of wind to generate electricity in Turkey, Ilkılıç (2012) suggested that country has a potential wind electricity generation capacity of around 131.75 GW. Benli (2013), pointing out this potential, stresses the economic and environmental gains that Turkey could have by developing a domestic wind energy sector. Melikoglu (2016) similarly mentions the necessity of renewable development in Turkey and suggests the high penetration of renewables, particularly wind, to be a necessary condition for fulfilling Turkey's 2023 vision. Kaplan (2015), on the other hand, points out the required policy design in order to utilize wind potential of Turkey, especially in the coastal regions. Finally, Ozcan (2018) states the importance of renewables in ensuring self-sufficiency of Turkish energy system.

Role of renewables are increasing especially since Electricity Market Law (Law no. 4628) enacted in 2001, which initiated a comprehensive program to reform Turkish electricity market to a more competitive and liberalized structure. There has been a plethora of studies on economic effects of liberalization and restructuring in Turkish electricity market (e.g., Güneği, 2002; Özkıvrak, 2005; Ulusoy and Oguz, 2007; Bahçe and Taymaz, 2008; Bagdadioglu and Odyakmaz, 2009; Erdogdu, 2010, 2011; Akkemik and Oğuz, 2011; Camadan and Erten, 2011; Camadan, 2011; Camadan and Kölmek, 2013; Karahan and Toptas, 2013; Çetin, 2014; Çetinkaya, et al., 2015; Sirin and Gonul, 2016; Avci-Surucu, et al., 2016; Asan and Tasaltin, 2017). Although there are some researchers suggesting the positive effects of full liberalization shown as the increase in the efficiency and decrease in the household prices (Akkemik and Oguz, 2011), many studies have revealed the deficiencies in Turkish market reform. Bahçe and Taymaz (2008), for instance, developed a simulation model of the Turkish electricity system and showed that when the distribution companies, emerged due to restructuring of the sector, act as regional monopolies there would be significant welfare losses. Erdogdu (2010) has pointed out the inconsistencies between the Law no. 4628 and newly established balancing and settlement system (BSS), and suggested that these inconsistencies would prevent power sector investments to be in the optimal level and eventually lead to increase in the prices. Erdogdu (2011) later showed that the price–cost margin in Turkish electricity market has increased after the market reform. Similarly, Karahan and Toptas (2013) suggested that the privatization of Turkish electricity market has not yield significant decline in retail electricity prices. Çetinkaya et al. (2015) concentrates on the development of price and income elasticities of electricity demand in households after the Turkish electricity market reform and suggest that specifically poor households are more vulnerable to electricity prices as both elasticities are found to be inelastic. Finally, Camadan and Kölmek (2013) and Asan and Tasaltin (2017) criticize the market reform as they both point out the increased risk premium for electricity generation companies in the day-ahead market.

Within the context of energy market restructuring extensive renewable subsidies have been introduced by the Law on the Utilization of Renewable Energy Resources for the Purpose of Generating Electricity in May 2005 (Law no. 5346). Many authors evaluated the effects of Turkish electricity market restructuring and legislations on renewable, particularly wind, penetration as well as the barriers in front of further renewable deployment. Most studies in this stream of literature suggested that Turkish electricity market reform has positively affected the development of wind energy in Turkish electricity generation sector (e.g., Alboyaci and Dursun, 2008; Dursun and Gokcol, 2014; Tükenmez and Demireli, 2012). Even though recent legislations in Turkish electricity market seem to be a success story for renewables so far, Nalan et al. (2009) suggested that there are still some major barriers, namely economic, technological, finance related and scientific, to overcome in order to continue further renewable deployment. Within this context, Ertürk (2012) suggests that under current feed-in tariff support scheme, large wind farms with a capacity of more than 100 GW, are not profitable. Similarly, according to Gozen (2014), recent renewable support mechanism is attractive for biomass, geothermal and solar while neutral for wind.

To sum up, literature so far suggests that despite of the fact that market restructuring has not been successful in increasing welfare by decreasing prices, the electricity market reform initiated by 2001 Electricity Market Law has created a positive economic environment for renewable penetration in Turkish electricity market. It is, however, surprising that, to the authors' best knowledge, the literature so far missed how the increased renewable penetration would affect electricity prices. Increasing renewable penetration is supposed to decrease the electricity prices, which is known as the merit-order effect. Merit-order effect is extensively studied for various countries' electricity markets in global energy economics literature (e.g., Sensfuß, et al., 2008; O'Mahoney and Denny, 2011; Woo, et al., 2011; Böckers, et al., 2013; Azofra, et al., 2014; Cludius, et al., 2014; Ketterer, 2014; Paraschiv, et al., 2014; Clò, et al., 2015; Kyritsis, et al., 2017). Sensfuß, et al. (2008), for instance, using a calibrated electricity market simulation model for Germany, namely PowerACE model, found substantial price reductions due to increase in renewables for the period between 2004 and 2006. Similarly, using German EEX day-ahead electricity market data, Paraschiv et al. (2014) employ time-varying regression model and found out that renewable energy sources decrease spot market prices in Germany. More recently, Kyritsis et al. (2017) employ a GARCH-in-Mean model on German electricity market data and suggest that solar power generation reduces the volatility of electricity prices significantly. Similar results have also been found by different researchers using various methodologies on data of other countries' electricity market. Clò et al. (2015), for example, use simple OLS regression on Italian day-ahead wholesale electricity market data and suggest that 1 GWh increase in solar and wind generation decreased the prices by 2.3€/MWh and 4.2€/MWh, respectively. Hence, in general there is a consensus in the energy economics literature towards the existence of merit-order effect in various countries.

This paper contributes to the related literature in two-fold. Firstly, to the authors' best knowledge merit-order effect in Turkish electricity market has not been studied before. Provided that Turkish policy makers are spending a lot of effort to increase the renewable energy, particularly wind, based electricity generation in Turkish energy system, it would be valuable to understand if increase in the wind penetration lead to decline in electricity prices. Secondly, although the topic is extensively studied for different countries in energy economics literature, our paper differentiates from the previous ones by employing a novel approach, namely Continuous Wavelet Transform Granger-causality test. Our methodology is advantageous to that of previous studies, as it is based on non-parametric modeling, which does not restrict data generation process to fit into a predetermined model. Thus, possibility of spurious causality due to misspecified errors caused by vector autoregression modeling are eliminated by this nonparametric causality test. Moreover, this causality test provides a three-dimensional causality map, thus it enable causality pattern investigated over different time scales.

3. Methodology and Data

3.1. Methodology

In order to assess whether there exists merit-order effect of wind in Turkish day-ahead electricity market, we conduct Continuous Wavelet Transform (CWT, hereafter) Granger-causality test on a daily data set on Turkish electricity prices and wind electricity generation covering the period between January 3, 2011 and May 31, 2018. CWT Granger-causality is a nonparametric causality test, which is a modified version of the correlation measure in continuous wavelet transform proposed by Rua (2003) by introducing phase difference indicator function of Olayeni (2016).[7]

Real world data frequently exhibit slowly changing trends or oscillations interspersed with abrupt changes. Wavelet analysis is useful to distract oscillations and produce time – frequency visualization of data efficiently. Thus, oscillations with different frequencies and amplitudes are revealed to evaluate dynamics of the data. A wavelet is a function of promptly decreasing, wave-like oscillation with zero mean. Projecting data onto both scaled and shifted mother wavelet function of $\Psi_{s,\tau}(t) = \Psi((t-\tau)/s)/\sqrt{s}$ gives the continuous wavelet transform (CWT) coefficients:

$$W_X(s,\tau) = (x * \Psi_{s,\tau})(t) = \int_{-\infty}^{\infty} x(t) \frac{1}{\sqrt{s}} \tilde{\Psi}\left(\frac{t-\tau}{s}\right) dt \tag{1}$$

Where $\tilde{\Psi}(.)$ denotes complex conjugate of $\Psi(.)$. Time-frequency representation of data is obtained through varying scale parameter *s* and shifting along τ, which gives the position of wavelet function. Following Olayeni (2016) Morlet wavelet, a plane wave modulated by a Gaussian: $\Psi(\eta) = \pi^{-1/4} \exp(i\omega\eta)\exp(-\eta/2)$ with $\omega = \omega_0 = 6$, is chosen as wavelet function. The Gaussian envelop, $\exp(-\eta/2)$, effectively localizes the wavelet between the resolution in time and in frequency and radian frequency ω determines time/frequency resolution. The terms scale and frequency are used interchangeably. The wavelet is stretched in time by varying its scale s, so that $\eta = s.t$. Discretization of Equation 1 for data $\{x_n : n = 1, 2, ..., N\}$ yields spectrum of the data:

$$W_X^m(s,\tau) = \frac{\delta t}{\sqrt{s}} \sum x_n \tilde{\Psi}\left((m-n)\frac{\delta t}{s} \right), \; m = 1, 2, ..., N-1 \tag{2}$$

Where denotes a uniform step size. Wavelet power spectrum $\left|W_X^m(s,\tau)\right|^2$ captures the variability in the data both in time and in frequency. Cross – spectrum of data x_n and y_n, which is the equivalent of covariance matrix in time domain, is defined as $W_{XY}^m(s,\tau) = W_X^m(s,\tau)\tilde{W}_Y^m(s,\tau)$ where $\tilde{W}_Y^m(s,\tau)$ denotes complex conjugate of $W_Y^m(s,\tau)$. Then, wavelet transform are decomposed into real and imaginary part through $W_X^m(s,\tau) = \Re\{W_X^m(s,\tau)\} + i\Im\{W_X^m(s,\tau)\}$ to compute local phase ,

[7] Below we explained the CWT Granger-causality test briefly. For detailed explanation of the methodology please refer to Li et al. (2015).

$\varphi_X(s,\tau) = \tan^{-1}\left\{\Im\left(W_X^m(s,\tau)\right) / \Re\left(W_X^m(s,\tau)\right)\right\}$, and also phase difference, in which information on lead-lag relationship is encoded, to calculate spectral Granger causality by using wavelet correlation.

Phase difference is defined as:

$$\phi_{XY}(s,\tau) = \phi_X(s,\tau) - \phi_Y(s,\tau) = \tan^{-1}\left(\frac{\Im\left(W_{XY}^m(s,\tau)\right)}{\Re\left(W_{XY}^m(s,\tau)\right)}\right) \tag{3}$$

With the range $-\pi \le \phi_{XY}(s,\tau) \le \pi$ that can be subdivided into four intervals. Each interval gives information about the direction and lead-lag feature of the causality. $\phi_{XY}(s,\tau) \in (0, \pi/2)$ indicate that Y precedes X with positive comovement while $\phi_{XY}(s,\tau) \in (-\pi, -\pi/2)$ denote Y precedes X with negative comovement. Likewise, $\phi_{XY}(s,\tau) \in (-\pi/2, 0)$ X precedes Y with positive comovement while $\phi_{XY}(s,\tau) \in (\pi/2, \pi)$ denote X precedes Y with negative comovement. In wavelet analysis, causality running from Y to X at a particular time and frequency exists when Y precedes X. (for detailed technical discussion, see Aguirar-Conraria, and Soares (2014) and Li et al. (2015)).

Olayeni (2016) proposes causality test through indicator function using phase difference sub-intervals to incorporate wavelet correlation for separating the embedded causal links from the non-causal content. Indicator function is the function takes the value of one if the phase difference is defined over the required interval and zero otherwise. Thus, indicator functions impose restrictions on wavelet correlations for specific direction and lead-lag features of causality. For instance, indicator function focusing positive causality that Y precedes X defined as:

$$I_{Y \to X}(s,\tau) = \begin{cases} 1, & \text{if } \phi_{XY}(s,\tau) \in (0, \pi/2) \\ 0, & \text{otherwise} \end{cases} \tag{4}$$

Thus, CWTC investigating positive predictive information flow from y to x is defined as:

$$G_{Y \to X}(s,\tau) = \frac{\zeta\left\{s^{-1}\left|\Re\left(W_{XY}^m(s,\tau)\right) I_{Y \to X}(s,\tau)\right|\right\}}{\zeta\left\{s^{-1}\sqrt{\left|W_X^m(s,\tau)\right|^2}\right\}\zeta\left\{s^{-1}\sqrt{\left|W_Y^m(s,\tau)\right|^2}\right\}} \tag{5}$$

where $\zeta(.) = \zeta_{scale}(\zeta_{time}(.))$ with ζ_{scale} and ζ_{time} as the smoothing operator along scale axis and time axis, respectively.

3.2. Data

This paper uses a data set on daily day-ahead electricity market clearing prices (price, hereafter), final day-ahead wind electricity generation planning (wind, hereafter) and wind penetration, measured as the share of wind in total generation in Turkish day-ahead electricity market (windshare, hereafter). The data set is taken from EXIST and covers the period between January 3, 2011 and May 31, 2018. There are two reasons to choose this specific time horizon. Firstly, due to the extended effects of global financial crisis in 2008, the electricity market in 2009 and to a lesser extent in 2010 had quite high volatility. Secondly, 2011 was the year when Turkish government initiated an extensive renewable subsidy mechanism, namely Renewable Energy Sources Supporting Mechanism. Hence, the analysis on this particular time horizon would also shed some light on how successful has this renewable subsidy mechanism been in decreasing electricity prices in Turkey.

Table 1. Summary statistics on price, wind and wind_share

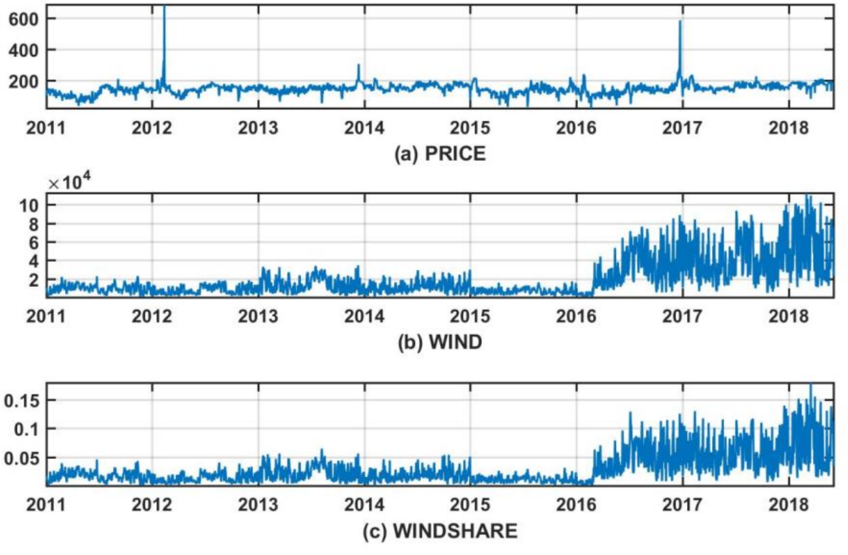
	price	**wind**	**windshare**
Mean	149.20	18986.51	0.03
Standard Deviation	33.89	19375.8	0.02
Maximum	687.00	112255.00	0.18
Minimum	22.93	440.94	0.00
Skewness	2.25	1.93	1.84
Kurtosis	37.46	6.49	6.42
# of Observations	2710	2710	2710

Summary statistics of the variables are provided in Table 1, and Figure 1 plots the variables in three panels; the price in panel (a), wind in panel (b) and windshare in panel (c). As can be noted easily on Table 1 and panel (a) of the Figure 1, price generally fluctuates around a mean of 149.2 TL/MWh over the whole period. Yet, two significant price spikes occurred on February 13, 2012 and on December 23, 2016, which are worthwhile explaining. First of all on February 13, 2012, Turkish electricity system went through an important supply and demand balancing problem and prices reached a record high of around 2000 TL/MWh by noon of the same day making daily average 687 TL/MWh. This spike is particularly attributed to the extremely cold weather and gas supply shortages occurred over the preceding week.[8] Again on December 23, 2016, similar problems occurred in the Turkish electricity market leading electricity prices to a second record high of around 1900 TL/MWh at 2 pm making daily average 587 TL/MWh

[8] Please see: https://enerjienstitusu.org/2012/02/12/pmum-serbest-elektrik-piyasasinda-cumhuriyet-tarihi-rekoru/ (in Turkish). Access date: July 21, 2018.

on the same day. These two price spikes have been considered carefully while examining the causal relation between price and wind generation.

Figure 1. Daily electricity market clearing price (price) in TL/MWh, final generation planning from wind (wind) in MW and the share of wind in total generation planning (windshare) in % over the period between January 3, 2011 and May 31, 2018.



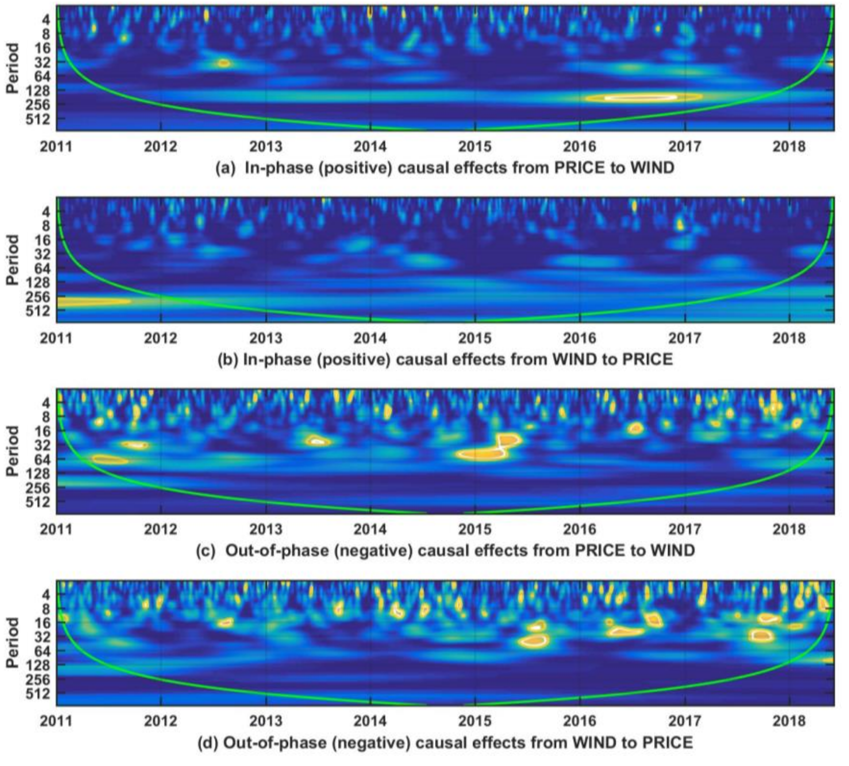
The most important issue to mention about the wind data provided on panel (b) of the Figure 1 is the structural break that occurred on March 1, 2016. Prior to that date total amount of daily wind generation planning in the day-ahead market fluctuates around a mean of 9781.7 MWh. After the structural break the mean daily wind generation planning increased extensively reaching to 39981.4 MWh for the period between March 2016 and May 2018. This structural break can be attributed to the subsidies that are provided to wind generation thanks particularly to Renewable Energy Sources Supporting Mechanism designed by the Turkish government. A similar structural break could be observed for the share of wind in total electricity generation planning in the day-ahead Turkish market, which is provided on Panel (c) of Figure 1. Extensive increase in the wind generation on March 2016 seems to drive up also the share of wind in total generation. The mean share of wind prior to and after that date occurred around 1.6% and %5.7, respectively. As these structural breaks can alter the causality dynamics, the results are provided in two sub-periods, i.e., pre and post March 2016, in addition to the whole period.

4. Empirical Results

In this section we provide CWT Granger-causality test results applied to assess causality between price and wind, and between price and windshare, in Turkish electricity market over the whole period, i.e. January 3, 2011–May 31, 2018, and two sub-periods, i.e., pre–2016 and post–2016. First of all, Figure 2 shows the results on the relationship between price and wind covering the whole period. Four panels on the figure represent in-phase (positive) and out-of-phase (negative) causalities between two variables[9], x-axis shows the time horizon covered, y-axis represents the period (frequency) of the causality defined in number of days. Moreover the strength and the significance of the causality are represented by the color code, such that while dark blue color does not represent any causality, light yellow or white shaded areas indicate strong and significant causality between variables. Finally, the green line represents the cone-of-influence (COI), outside of which results are not reliable as they are highly driven by the edge effects.

[9] While, panels (a) and (b) show whether there exist positive causalities from price to wind and from wind to price, respectively, panels (c) and (d) represent the negative counterparts.

Figure 2. CWT Granger-causality between price and wind based on daily data covering the whole period from January 2011 to May 2018.



Overall, Figure 2 suggests that there exists significant and negative bidirectional causality between price and wind over the whole period. Yet, as it is also evident, the causality between two variables is quite intermittent with changing frequencies. For instance, the causality remains short-term, up to 14 days of frequency, until 2015 and relatively medium-term, up to 64 days of frequency since then.[10] Moreover, more detailed analyses on each panel on Figure 2 would shed more light on the dynamics of the causality. For instance, according to panel (a), there exists strongly significant and positive causality from price to wind during almost all 2016. The causality is in relatively longer-term, i.e., around 256 days of frequency. This positive relation needs to be explained as it creates an inconsistency on the general results, which suggest negative bidirectional causality. As mentioned above, in the beginning of 2016 there has been a sharp structural break in the wind

[10] Since we are using daily data, we define short-term to be up to 14 days, i.e., two weeks, medium-term from couple of weeks up to 2-3 months and long-term from 2-3 months onwards. Although, we are aware of the fact that this is an artificial classification, for the sake of clarity we stick to these periods while explaining the results.

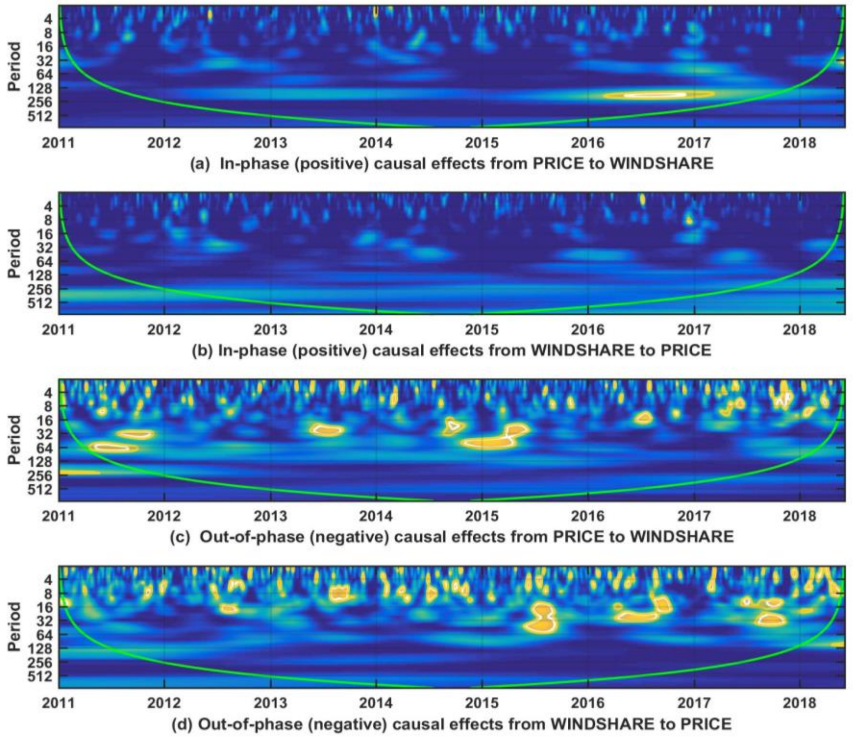
data, created by vast increase in the wind electricity generation in Turkey. Hence, this positive causality could easily be attributed to this extensive increase in the wind generation rather than the effect of the price on wind. Furthermore, in panel (b), there seems to be a positive long-term causality (256 to 512 days frequency) from wind to price between years 2011 and 2012. Yet this result is unreliable due to the fact that it lies outside the COI. Accordingly, there does not exist any significant positive causality from wind to prices over the whole period.

The results in panel (c) exhibit the existence of negative, significant, yet very intermittent short- to medium-term, i.e., up to 64 days of frequency, negative causality from price to wind over the whole period. Negative causality is more evident between December 2014 and May 2015. The results are surprising hence it is generally supposed to experience positive causality from electricity prices to wind, because of the fact that higher electricity prices would attract more investment into renewables. In Turkish electricity market though, thanks particularly to renewable subsidies provided by Turkish government, wind electricity generators became quite competitive against thermal power plant operators, whose input costs are highly dependent on imported natural gas and hard-coal prices. As it can be observed from Figure 1, electricity prices dropped significantly to 32.8 TL/MWh on May 10, 2015 from a local peak of 217.7 TL/MWh on January 15, 2015. Hence, the negative causality means that even dropping electricity prices have driven wind electricity generation up during this period.

Finally, panel (d), which is of significant importance for the research question of the paper at hand, shows negative and significant causality from wind to price, confirming the existence of merit-order effect in Turkish day-ahead electricity market. Until 2015 the negative causality from wind to price is up-to 16 days of frequency, representing short-term effect. Since 2015 though, the causality seems to be extended upon a larger frequency, i.e., up to 64 days. The significance of the causality is also more evident since 2015. Moreover, the intermittency of the causality decreases considerably in 2018, pointing the merit-order effect of wind even more clearly.

The analyses so far were based on the causal relation between the electricity market clearing price and total amount of daily wind electricity generation. It would also be valuable to discuss the causal relationship between price and windshare, which provides information on the competitive power of wind against alternative energy sources in electricity generation. Using windshare would also lead to more meaningful results, as it directly serves a proxy measure for the wind penetration in Turkish day-ahead electricity market. To this end, Figure 3 represents the CWT Granger-causality test results between price and windshare.

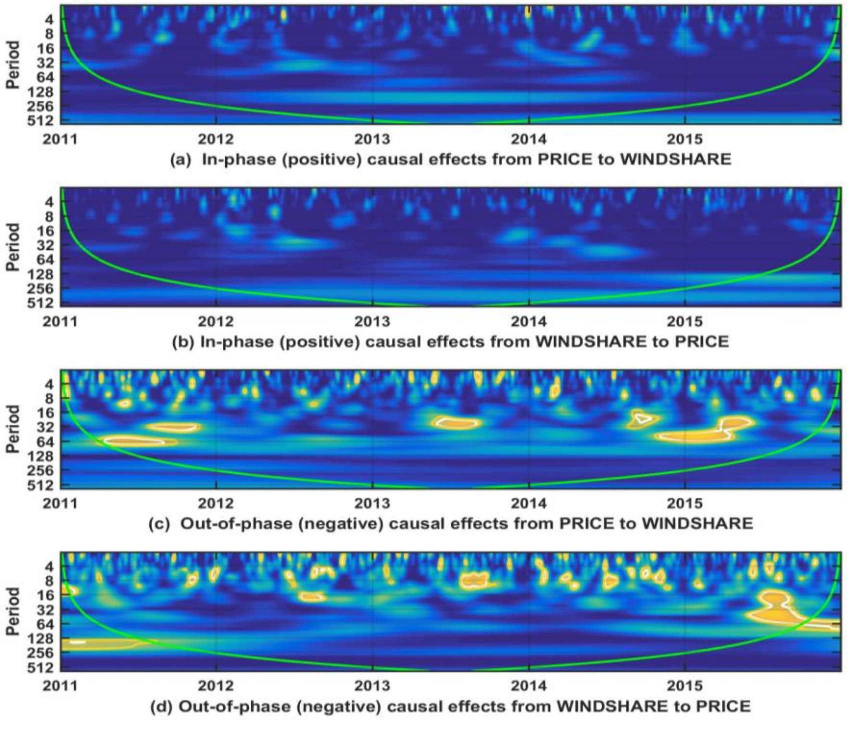
Figure 3. CWT Granger-causality between price and windshare based on daily data covering the whole period, from January 2011 to May 2018.



Overall, the results are highly similar to those represented in Figure 2, such that one can still observe long-term positive causality from price to windshare during 2016 (panel a) and short to medium-term negative causality from price to windshare over the whole period (panel c). The results still do not suggest any positive causality from windshare to price (panel b) and there exists negative, significant and intermittent causality from windshare to price (panel d). This negative causality is in short-term until 2015 and extended up on a longer term (around 64 days of frequency) since then. The most important difference between two figures is that the negative causality is more significant and stronger in Figure 3. Hence, the results suggest that the merit-order effect is more evident when wind penetration instead of raw wind generation data is used.

According to the results so far, there exists strong evidence of merit-order effect of wind penetration in Turkish day-ahead electricity market. Thus, increasing share of wind in total electricity generation decreases the day-ahead market clearing prices. The analyses so far were conducted using the data set covering the whole period. Yet, as evident from Figure 1, there has been a strong structural break in wind generation, and hence in wind penetration data, occurred in 2016. Because of the fact that this structural break would lead to biased deductions on the causality dynamics, CWT Granger-causality tests are conducted using two sub-period data sets, i.e., pre- and post-2016, and the results are provided on Figures 4 and 5, respectively.[11]

Figure 4. CWT Granger-causality between price and windshare based on daily data covering the pre-2016 period, i.e., from January 2011 to December 2015.

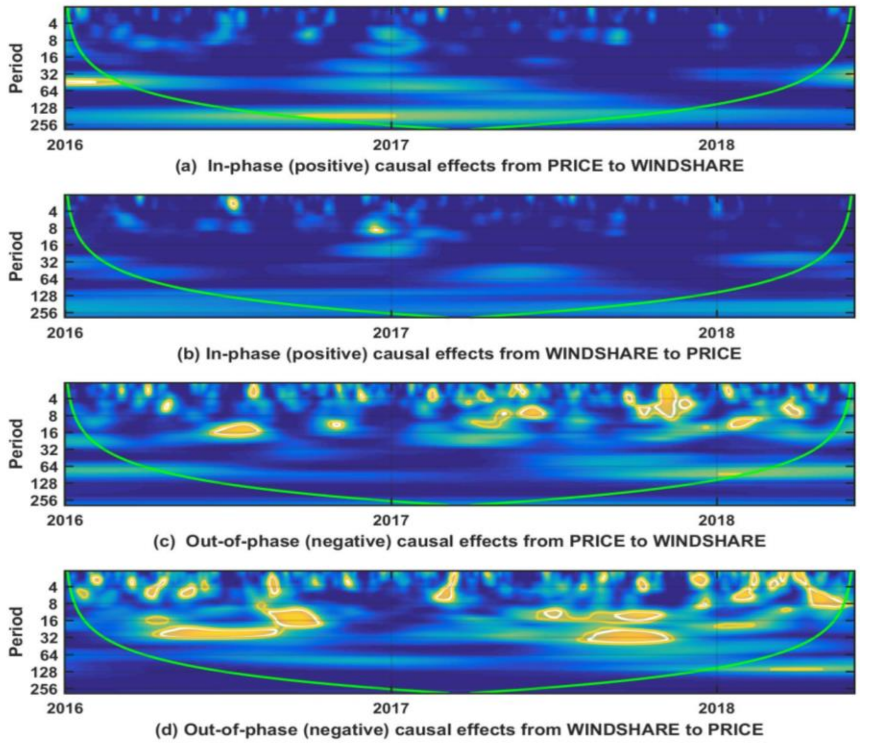


The CWT Granger-causality test results for the pre-2016 sub-period suggest negative, significant and mostly short-term and intermittent bi-directional causality between windshare and price. Similar to the whole period analyses, the negative causality from windshare to price seems to be extended over a longer time period (64 days of frequency) during the second half of 2015. Although, quite a long-term of negative causality (128–256

[11] For the sub-period analyses we use windshare data since both wind and windshare data yield highly similar results for the whole period. We also included the sub-period results using wind data in the Appendix for the purpose of comparison.

days of frequency) is also observed during the first half of 2011, the result is not reliable as it lies outside of the COI.

Figure 5. CWT Granger-causality between price and windshare based on daily data covering the post-2016 period, i.e., from January 2016 to May 2018.



Finally, Figure 5 illustrates the results for the post-2016 sub-period. Negative and significant bidirectional causality between windshare and price could easily be observed over the sub-period. The negative causality from price to windshare is in relatively short term (0–16 days of frequency) while from windshare to price is in relatively longer term (up to 32 days of frequency). On the other hand, significant positive causality over 128–256 days of frequency from price to windshare could be spotted for the period between last quarter of 2016 and first quarter of 2017. Yet, this causality is quite close to the COI hence would be less reliable. As mentioned above, a similar yet stronger and more significant positive causality was found in the whole period analyses (Figures 2 and 3) for almost all 2016. We already have attributed this positive relation to the structural break occurred in the wind and windshare data, which was the reason to employ sub-period analyses.

As evident from Figure 5, the positive causality from price to wind is way closer to COI hence less reliable when sub-period analysis is conducted.

5. Conclusions and Policy Implications

This paper aims at analyzing the effects of increasing wind-based electricity generation on day-ahead electricity prices in Turkey. For this purpose, we employ a novel non-parametric causality methodology, namely Continuous Wavelet Transform Granger-causality test, on daily electricity generation planning from wind, the share of wind in total planned generation and market clearing prices in day-ahead electricity market. Our dataset covers the period from January 3, 2011 and May 31, 2018, during when extensive subsidies have been given to wind-based electricity generation sector within the context of Renewable Energy Sources Supporting Mechanism, designed by Turkish government.

The results mainly suggest that there exists a negative and significant causality from wind penetration to market clearing prices. In the energy economics literature, increasing share of renewable energy sources in electricity generation is supposed to decrease the electricity prices, which is known as the merit-order effect. Hence, our results confirm the existence of wind merit-order effect in Turkish electricity market. In addition to the whole period analysis, we conducted our methodology to cover two sub-periods, i.e., pre- and post-2016, due to the fact that in 2016 there has been a strong structural break in the data of electricity generation from wind. Sub-period analyses suggest that the negative causality from wind penetration to electricity prices is more significant in the post-2016 era.

The results, depicted in this study, give an insight on how successful the electricity market re-structuring policies, particularly renewable subsidies, have been in increasing consumer welfare by decreasing the prices in Turkey. Electricity market reform, initiated by 2001 Electricity Market Law and extended by 2005 Law on the Utilization of Renewable Sources, created a suitable economic environment for wind penetration. Yet, as suggested by many researchers, subsidies were not high enough to attract investment in wind generation until 2011, when Turkish government introduced the Renewable Energy Sources Supporting Mechanism. Our analyses suggest that during this recent supporting mechanism, wind penetration in electricity generation significantly decreased the electricity prices, showing the success of governmental policies towards renewables. The analyses in this paper would be extended by conducting a further research to assess the causality between other modern renewables, such as solar and geothermal, and electricity prices.

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Appendix: CWT Granger-causality test results of pre-2016 and post-2016 sub-periods using price and wind data

Figure A1. CWT Granger-causality between price and wind based on daily data covering the pre-2016 period, i.e., from January 2011 to December 2015.

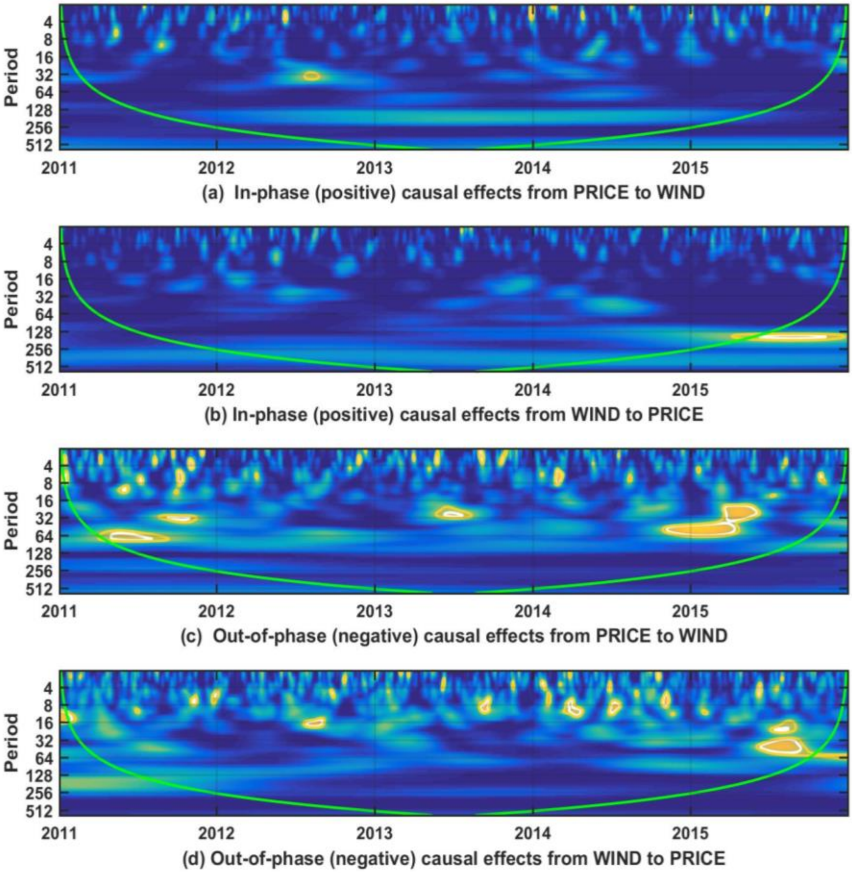

Figure A2. CWT Granger-causality between price and wind based on daily data covering the post-2016 period, i.e., from January 2016 to May 201