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STATISTICAL APPROACH TO EVALUATE POWER GENERATION SOURCES' INFLUENCE ON ELECTRICITY MARKET PRICE: LITHUANIA CASE

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ABSTRACT. ***This article introduces a statistical approach that helps to evaluate different power generation sources' influence on electricity market prices. The methodology involves certain regions' electricity market and power grid data time series analysis. The two-stage correlation analysis method is used to determine electricity sources that meaningfully influence electricity prices and do not correlate with electricity load. Those electricity generation sources are selected for the linear regression where the dependent variable is electricity market price and independent variables are identified generation sources. The regression equation is a final methodology tool that assesses different power generation sources' impact on electricity market price. Coefficient value, besides each independent variable, identifies the magnitude of the impact, while***

positive and negative signs determine if the electricity market price would increase or decrease if an average monthly generation of a certain source would be increased. The proposed approach allowed us to estimate different electricity sources' influence on electricity prices in Lithuania. Run-of-river generation and electricity import are identified as two variables meaningfully influencing electricity market prices in Lithuania. Regression analysis showed that a 1 MW increase in an average monthly run-of-river generation could decrease electricity price by 0.131 € while a 1 MW increase in average monthly electricity import could increase electricity price by 0.017 €.

KEYWORDS: electricity market price, power generation sources evaluation, methodology, correlation, regression.

JEL classification: C10, C20, Q47.

Introduction

With new environmental policies and electricity market liberalisation taking place, the energy generation mix is rapidly changing in many countries around the world. More strict environmental regulations significantly increase electricity generation from renewable energy sources such as wind and solar. As a result, marginal electricity prices are decreasing, and liberal market conditions cause conventional power plants to become less competitive.

To be able to develop a sustainable and feasible electricity system with certain generators and necessary infrastructure it is important to understand their possible effect on electricity market price (Tvaronavičienė *et al.*, 2020). Several scholars believe that renewable energy generation will continue to dominate the economics of energy markets in the future. This will create a challenge and need for quantifying the price effects of renewables (Westgaard, *et al.*, 2021; Radavičius, *et al.*, 2021). It is expected that renewable energy will lead to a reduction in electricity market prices, however, scholarly literature is scarce and there is a need for new methods (Csereklyei, *et al.*, 2019; Yasmeen, *et al.*, 2021; Raghutla, Chittedi, 2021).

The expansion of various energy generation sources installed power might have a different effect on the electricity price in different countries. Some countries might have rich fossil fuel resources which would make coal, oil, or natural gas the cheapest generation option. However, if fuels must be imported to the country and their market price increase it will also influence electricity price (Masood *et al.*, 2019). For example, Spanish electricity prices are dependent on coal, oil, and natural gas import (Ramos, *et al.*, 2019). Besides commodities costs, the electricity market price can be highly influenced by renewable energy generation (Rabe *et al.*, 2021; 2022; Kostikova *et al.*, 2022; Alsaleh, Abdul-Rahim, 2021; Yilanci, Gorus, 2021). Several studies show that wind power generation might not only decrease electricity prices on average but also highly increase its volatility (Ketterer, 2014). In 2009 there were 130 intervals of negative electricity prices in the Texas power grid caused by wind power plants but in 2010 it did not happen even once (See Tao, *et al.*, 2012). Significant growth of wind power plants installed power might cause a strong temporary electricity price fluctuation but in the long term, the problem is solved. Solar capacity growth is pushing electricity market prices down during daylight hours, but prices might increase during non-daylight hours (Bushnell, *et al.*, 2018). Similarly, solar generation influences electricity prices during the summer when the daytime is longer and during the winter when the daytime is shorter. Finally, the market price can be influenced by electricity imports from neighbouring countries. From 2011 to 2015 electricity market price in Germany roughly dropped by 38% and it was partly caused by additional electricity links (Bublitz, *et al.*, 2017). At the same time, if a country is not able to generate enough energy with local power plants and electricity is more expensive in neighbouring areas, import might increase the electricity market price.

Electricity system models can be classified into game theory, simulation, and time series analysis (Aggarwal, *et al.*, 2009). Game theory models concentrate on the market players' strategy, simulation models try to replicate energy system, and time series analysis concentrate on historical values and their relations. Electricity pricing schemes to shift energy consumption from on-peak hours to off-peak hours are an example of a game theory model (Khalid, *et al.*, 2019). Simulation models can be used to identify operating system status in different wind penetration, forecasts, and curtailment scenarios (Martinez-Anido, *et al.*, 2016). Among all these three models time series analysis is the most widely used method to determine a connection between electricity market price and possible influencing factors. For example, time series and regression analysis were used by different scholars to weigh renewable energy resources' influence on electricity prices in the Dutch region (Mulder, Scholtens, 2013), as well as to analyse electricity price volatility because of solar and wind generation in Germany (Kyritsis, *et al.*, 2013). Correlation can provide insightful results when a relation between variables in the long term needs to be identified, while regression analysis can quantify those relations and provide practical results.

In scientific articles related to electricity price analysis, correlation is often used as one of the tools to determine connections between variables. Several articles with a neural network-based day-ahead electricity price forecasting approach use the correlation method to determine similar electricity prices and load days (Mandal, *et al.*, 2007, Cerjan, *et al.*, 2019, Cerjan, *et al.*, 2014). This method helps to identify similar electricity price/load pairs in different time moments which later can be used to train an artificial intelligence model. This approach allows the provision of a price forecast based on historical data and selected period parameters. Since the artificial intelligence model delivers value arrived from complicated non-linear relations it is hard to identify exact factors which influenced one or another forecasted value. Regression models are based on linear relationships and indicate connections between dependent and independent variables. Linear relationships can be useful when direct relation between different electricity generation sources and electricity price needs to be identified.

There are very few scientific articles covering Lithuanian electricity market price research. In one of the articles, the author explores the Monte Carlo simulation method for 5 months electricity price forecasting period (Ngujen Tat, 2018). Another publication concentrates on day-ahead electricity price forecasting using seasonal naïve, exponential smoothing, and artificial neural network methods (Beigaitė, Krilavičius, 2018). Both mentioned articles focus on future electricity price forecasts but do not look for a direct relation between influencing factors and electricity price.

This research aims to introduce a statistical method that allows an evaluation of electricity sources' influence on the electricity price. Due to the lack of similar research, Lithuania's case is selected as an example. The methodology provides guidance on how to identify electricity sources that meaningfully affect electricity prices and quantify that effect using correlation and regression analysis. The suggested methodology can bring benefit to government institutions when planning future policies, as well as electricity market participants when planning generation and suggesting wholesale electricity prices to the consumers.

1. Theoretical Background

The literature analysis conducted in this paper is based on articles that explore different electricity market price forecasting models. Academic literature rarely concentrates on the relationship between electricity prices and influencing factors as a separate topic. The common way is to include influencing factors determination as a part of the electricity price forecasting model creation process. Electricity price forecasting models that are covered in this paper's literature analysis are divided into two groups: research that concentrates on Lithuania and research that concentrates on other countries. Wide geographical electricity price forecasting models' coverage gives a good understanding of possible electricity price influencing factors.

1.1 Research on Lithuanian electricity price

Eight different articles were identified while looking for papers on Lithuanian electricity price research. The earliest article was published in 2012, and the latest one – was in 2021 while there were no articles published in 2022. V. Bobinaitė, I. Konstantinavčiūtė, R. Beigaitė, and T. Krilavičius were the four authors that had two associated articles. *Table 1* presents the list of articles, publishing year, and influencing factors used in the electricity price forecasting models related to Lithuania research.

Table 1. Articles related to electricity price research in Lithuania

Title	Year	Influencing factors
Electricity Price Forecasting in Lithuania (Kvietkauskaitė, 2021)	2021	Calendar days, coal price, hydropower in Sweden, actual load in Lithuania, natural gas price, temperature, wind power in Lithuania
Lithuanian Electricity Market Price Forecasting Model Based on Univariate Time Series Analysis (Česnavičius, 2020)	2020	Historical electricity price
Electricity Price Forecasting for Nord Pool Data Using Recurrent Neural Networks (Beigaitė, Krilavičius, 2018)	2018	Historical electricity price
Electricity Price Forecasting Using Monte Carlo Simulation: the Case of Lithuania (Nguyen Tat, 2018)	2018	Electricity consumption, electricity generation, electricity import, electricity export
Electricity Price Forecasting for Nord Pool Data (Beigaitė, Krilavičius, 2017)	2017	Historical electricity price
Future of Lithuanian energy system: Electricity import or local generation? (Norvaiša, Galinis, 2016)	2016	Energy system parameters, commodity prices, investment costs
Does Electricity from Renewable Energy Sources Reduce Electricity Market Price in Lithuania? (Bobinaitė, Konstantinavčiūtė, 2014)	2014	Electricity consumption, trade with Latvia, trade with Belarus, trade with Russia, wind generation
Theoretical Model For Electricity Market Price Forecasting (Bobinaitė, Konstantinavičiūtė, Lekavičius, 2012)	2012	Macroeconomic indicators, electricity demand, electricity generation, weather conditions, commodity prices, CO_2 prices, wind speed, currency exchange rates, changes in electricity import/export

Source: compiled by authors.

Five out of eight identified scientific publications researched factors influencing the

Lithuanian electricity market price. Kvietkauskaitė (2021) in her Master's thesis and Bobinaitė, Konstantinavčiūtė (2014) used statistical electricity price forecasting models where commodity prices, electricity generation, electricity consumption, commodity prices, and electricity/import-export were used as influencing factors. Ngujen Tat (2018) used the Monte Carlo simulation method where electricity consumption, generation import, and export were the selected factors. Norvaiša, Galinis (2014) wrote a paper on Lithuania's electricity system modelling where marginal electricity price was one of the outputs while inputs were energy system parameters, commodity prices, and investment costs. Bobinaitė, Konstantinavičiūtė, Lekavičius (2012) published a theoretical electricity price forecasting methodology where various electricity system parameters, commodity prices, weather conditions, and macroeconomic indicators were discussed as potential influencing factors. Česnavičius (2020) and Beigaitė, Krilavičius (2018, 2017) made research on Lithuanian electricity price forecasting models but did not include any external factors to construct the model.

A scarce number of scientific publications exploring factors influencing Lithuania's electricity price proves that the topic is uncovered, and additional academic research could have a meaningful contribution. From a scientific point of view, the main influencing factors identification allows carrying further research such as electricity price forecasting models where identified factors could be independent variables. From a practical point of view, understanding different factors weighing electricity price allow one to plan energy system and resources in a way that there would be no dependence on one source and energy price would be affordable for the users.

1.2 Research on Global Electricity Price

To identify electricity price influencing factors used in the electricity price forecasting models outside of Lithuania, twenty articles with a 2015–2022 publication period were reviewed. *Table 2* presents the list of articles and electricity price influencing factors.

Table 2. Articles related to electricity price research in other countries

Title	Country/region	Year	Influencing factors
Modeling and Forecasting Electricity Demand and Prices: A Comparison of Alternative Approaches (Shah, Iftikhar & Ali, 2022)	Nord Pool	2022	Electricity demand and seasonality
Electricity Spot Price Forecast by Modelling Supply and Demand Curve (Pinhão, Fonseca, Covas, 2022)	Iberia	2022	Electricity demand, wind generation
Data-driven Structural Modeling of Electricity Price Dynamics (Mahler, Girard, Kariniotakis, 2021)	France	2021	Fuel price, emission price, electricity demand/supply
Short- to Mid-Term Day-Ahead Electricity Price Forecasting Using Futures (Ziel & Steinert, 2019)	Germany & Austria	2019	Electricity price futures
A Linear Regression Pattern for Electricity Price Forecasting in the Iberian Electricity Market (Ramos, Ferreira & Fernandes, 2019)	Iberia	2019	Electricity demand, heating/cooling degree days, industrial production index, oil price, oil import per capita, renewable energy production and balancing energy per capita,
Deregulated Electric Energy Price Forecasting in Pool Market Using Regression Techniques (Johannesen, Kolhe & Goodwin, 2019)	Nord Pool	2019	Historical electricity price
Forecasting of Electricity Price Through a Functional Prediction of Sale and Purchase Curves (Shah & Lisi, 2019)	Italy	2019	Historical electricity price, electricity demand
Probabilistic Mid- and Long-Term Electricity Price Forecasting (Ziel & Steinert, 2018)	Germany & Austria	2018	Weather, wind, solar, nuclear, lignite, coal, natural gas, hydropower generation, electricity load, auction data,

Table 2 (*continuation*). Articles related to electricity price research in other countries

Forecasting Electricity Spot Price for Nord Pool Market With a Hybrid K-factor GARMA-LLWNN Model (Ben Amor, Boubaker & Belkacem, 2018)	Nord Pool	2018	Historical electricity price
Recent Advances in Electricity Price Forecasting: a Review of Probabilistic Forecasting (Nowotarski & Weron, 2017)	General methodology	2017	Historical electricity prices and seasonality
Mid-Term Electricity Market Clearing Price Forecasting With Sparse Data: A Case in Newly-Reformed Yunnan Electricity Market (Cheng, Luo, Miao & Wu, 2016)	China	2016	Thermal, hydro, solar, wind power plants production, electricity export and demand, number of electricity market participants
Long-Term Spanish Electricity Market Price Forecasting With Cointegration and VEC Models (Marcos, Reneses & Bello, 2016)	Spain	2016	Electricity price futures, oil prices, oil futures, electricity demand, wind generation
Medium-Term Probabilistic Forecasting of Electricity Prices: a Hybrid Approach (Bello, Bunn, Reneses & Muñoz, 2016)	Spain	2016	Electricity demand, hydro conditions, wind generation, coal prices, natural gas prices, emission prices, power plants availability
Evolutionary Extreme Learning Machine for Energy Price Forecasting (Chakravarty, Mohapatra & Dash, 2016)	US several states, Nord Pool, Spain	2016	Historical electricity price
Medium-Term Probabilistic Forecasting of Extremely Low Prices in Electricity Markets: Application to the Spanish Case (Bello, Reneses & Muñoz, 2016)	Spain	2016	Coal prices, natural gas prices, emission prices, power plants availability
A Combined Seasonal ARIMA and ANN Model for Improved Results in Electricity Spot Price Forecasting: Case Study in Turkey (Ozozen, Kayakutlu, Ketterer & Kayalica, 2016)	Turkey	2016	Daily average electricity price, hourly profile value
Mid-Term Electricity Price Forecasting Using SVM (Mohamed & El-Hawary, 2016)	New England	2016	Calendar day, fuel prices, electricity demand, weather conditions, electricity import/export
Short- and Mid-Term Forecasting of Baseload Electricity Prices in the U.K.: The Impact of Intra-Day Price Relationships and Market Fundamentals (Maciejowska & Weron, 2016)	UK	2016	Electricity demand, coal prices, natural gas prices, emission prices
Neural Network Models for Electricity Prices and Loads Short and Long-Term Prediction (Kotur & Žarković, 2016)	Uk, Serbia	2016	Historical electricity price
Probabilistic Forecasting of Hourly Electricity Prices in the Medium-Term Using Spatial Interpolation Techniques (Bello, Reneses, Muñoz & Delgadillo, 2015)	Spain	2015	Electricity demand, wind generation, hydro conditions, coal prices, natural gas prices, emission prices, power plants availability

Source: compiled by authors.

The majority of the reviewed articles included historical electricity prices, energy demand, and commodity prices as electricity price influencing factors. Pinhão, Fonseca *et al.* (2022), Marcos, Reneses *et al.* (2016), Bello, Bunn *et al.* (2016), and Bello, Reneses *et al.* (2015) also included wind generation to electricity price explanatory variables. Only two papers, Ziel, Steinert (2018) and Cheng, Luo *et al.* (2016), considered a wider range of generation sources such as thermal, solar, coal, hydro, nuclear, and natural gas power plants. Seven out of twenty articles were making forecasts for Spain or Iberia energy markets. Shah, Iftikhar *et al.* (2022), Johannesen, Kolhe *et al.* (2019), Ben Amor, Boubaker *et al.* (2018), and Chakravarty, Mohapatra *et al.* (2016) explored the Nord Pool energy market with their forecasting models. Notably, all four articles introduced machine-learning electricity market price forecasting methods that did not explore generation sources' influence.

The lack of articles exploring a wider range of electricity generation sources' influence on electricity market price and the scarce number of recent research conducted on the Nord

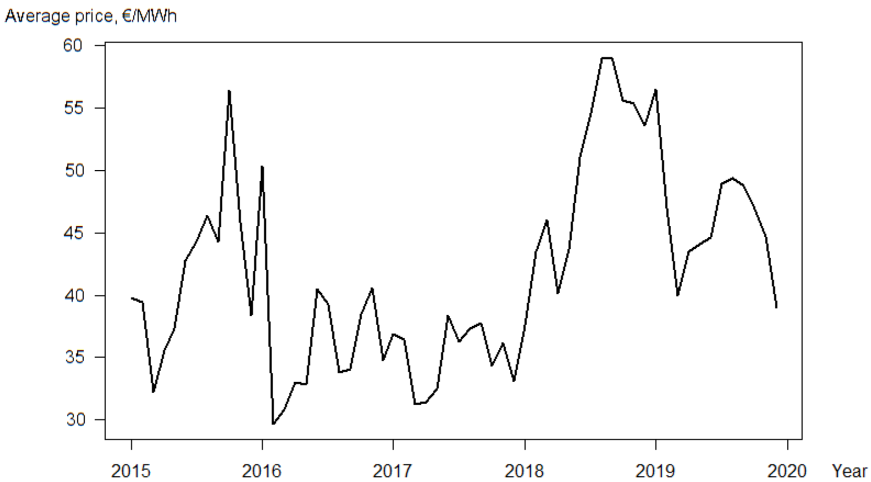
Pool energy market proves that there is a need for additional research. This paper aims to explore energy generation sources' influence on electricity market prices in Lithuania (which is a participant in the Nord Pool market) and fill the research gap.

2. Methodology

The method of this research consists of three parts: data collection, correct variables selection, and regression analysis. In the first part electricity system data is collected and a primary inspection with general observations about time series is made. The second part introduces correlation-based methodology which identifies the strength of the relation between electricity price and independent variables. Finally, the third part concentrates on linear regression construction with selected variables.

2.1 Variables

The research is based on Lithuanian electricity system data. The collected dataset contains three-time series groups: electricity market price, electricity load, and electricity consumption from different sources. Each time series represents the average hourly value for each month from January 2015 to December 2019, which results in 60 values per one time series. Electricity market price data is gathered from Nord Pool, a Northern Europe electricity exchange market operator where Lithuania is one of the 14 most active power exchange participants. *Figure 1* represents the plotted electricity market price time series that are used in the research.

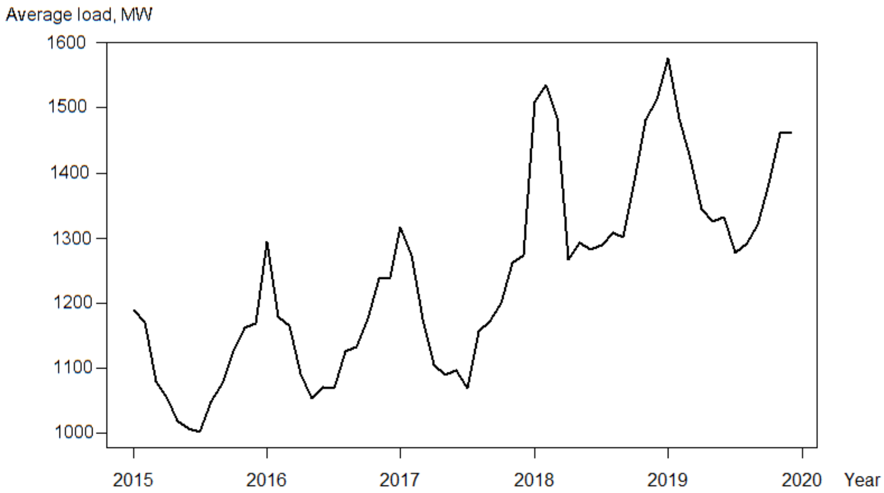


Source: data source Nord Pool "Day-ahead Prices".

Figure 1. **Historical Average Monthly Electricity Market Price in Lithuania**

The graph shows constant average electricity price movements from a lower to a higher value. The highest electricity price in the observed period is 59.11 €/MWh, while the lowest value is 29.65 €/MWh, and almost a double price difference can be noticed. The average electricity price in the observed period is equal to 41.93 €/MWh. Seasonality can be identified due to significantly lower prices at the beginning of each year.

Electricity load data is gathered from "Litgrid", a Lithuanian electricity transmission system operator which is responsible for electricity demand and supply balance. *Figure 2* represents the plotted electricity load time series.



Source: data source Litgrid "Faktinis nacionalinis elektros energijos suvartojimas".

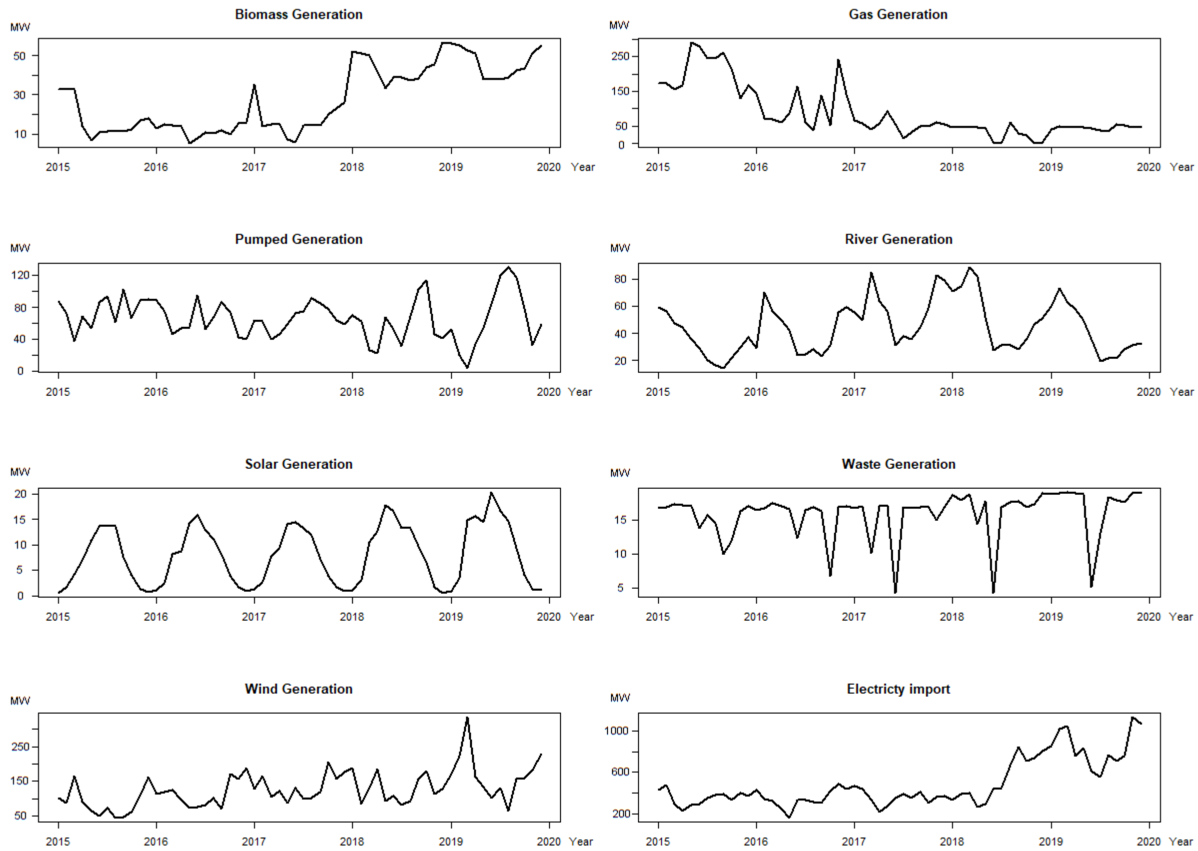
Figure 2. **Historical Average Monthly Electricity Load in Lithuania**

Plotted data indicates constant electricity load fluctuation from higher to lower value and a long-term upwards trend. The highest average monthly electricity load is equal to 1577 MW, while the lowest value is 1002 MW. The average electricity load in the observed time period is equal to 1002 MW. Similarly, as with electricity price, seasonality in electricity load can be noticed. Demand sharply increases at the end of the year and heavily decreases at the beginning of the year. However, while electricity load has a long-term upwards trend, electricity price does not share this feature.

Electricity supply data from different energy sources is gathered from the ENTSO-E transparency platform. ENTSO-E represents a European network for electricity transmission system operators, and Lithuania is one of the member states. The transparency platform stores hourly electricity generation data from different energy sources. Lithuania receives electrical energy from 8 energy sources:

1. Biomass power plants.
2. Natural gas power plants.
3. Hydro-pumped storage power plant.
4. Run-of-river power plants.
5. Photovoltaic solar power plants.
6. Waste fuel power plants.
7. Wind power plants.
8. Electricity imports from neighbouring countries.

Electricity sources listed above were continuously supplying electrical power throughout the research period. *Figure 3* represents the plotted time series data for all electricity sources in Lithuania.



Source: data source ENTSO-E Transparency Platform "Generation, LT".

Figure 3. **Historical Average Monthly Electricity Generation by Different Energy Sources**

Plotted graphs illustrate several different time series behaviours. Biomass generation and electricity import plots show a long-term upwards trend. Contrary to gas generation which has a long-term downward trend. Run-of-river and photovoltaic solar power have a very clear seasonal trend while pumped storage and wind power plants fluctuate but a clear trend cannot be noticed. Waste fuel power plants generate almost constant power with seasonal breaks. MW power generation scale indicates that most of the electricity is supplied by import, wind power, pumped storage, and run-of-river generation. Biomass, solar, and waste fuel generation have a relatively small part in the overall generation mix. Gas generation had a considerable part in the past years but in recent years it decreased.

2.2 Two-stage Correlation and Regression

The goal of the proposed methodology is to identify electricity generation sources that have a strong relationship with electricity market price but at the same time do not have strong relationships with electricity demand fluctuations. If the generation source has a strong relationship with both electricity market price and electricity demand it is considered that price change is influenced not by the generation source type but by demand and supply laws. In other words, it is considered that a particular generation source is mostly used for electricity supply and demand balancing and is not a preferred generation source in the long term. To determine the electricity generation source's influence on electricity market price both variables' relation at the same period must be measured and repeated along the all-time interval. Possible relation between two variables is identified using Pearson's correlation coefficient formula:

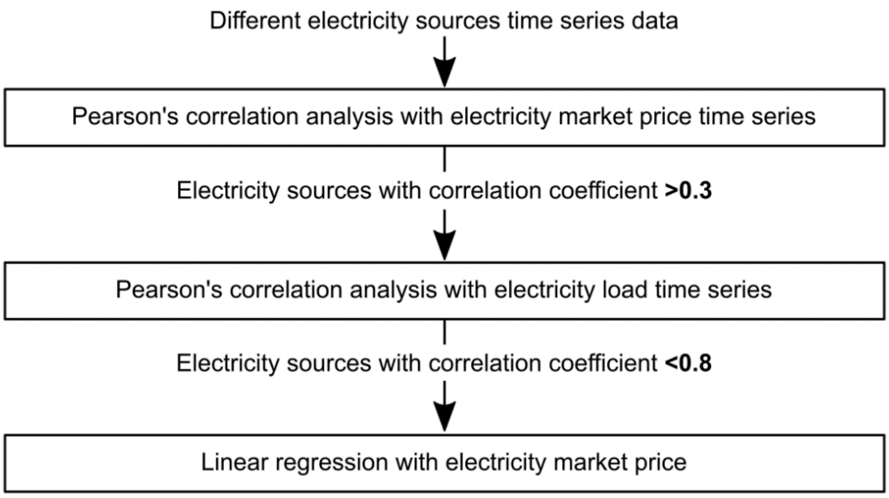
$$r = \frac{\sum(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum(x_i - \bar{x})^2 \sum(y_i - \bar{y})^2}} \quad (1)$$

In the presented formula dependent variable is either electricity market price or electricity demand and the independent variables are the above-listed electricity generation sources. A strong correlation between the price and generation source is considered once the correlation coefficient is more than 0.3. The selected coefficient value does not represent a strong correlation but considering that electricity price is influenced by a number of factors moderate correlation from one source can have a noticeable impact. A strong correlation between the electricity load and generation source is considered once the correlation coefficient is more than 0.8. The selected coefficient value indicates a strong correlation since the methodology aims to identify more expensive electricity sources which might be used only under increased demand conditions.

Variables that fulfil correlation requirements, strong correlation with electricity market price, and lack of strong correlation with electricity load, are selected to be included in the regression. The linear regression model is presented in the following formula:

$$y_j = \beta_o + \beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_j x_i + \varepsilon_i \quad (2)$$

In the linear regression model dependent variable is the electricity market price while the independent variables are all previously identified electricity generation sources. Constant intercept identifies the average electricity market price which would be achieved if all selected independent variables would be zero. The coefficient value next to the independent variable shows how much the price would change if an average monthly generation of electricity source would be increased by 1 MW. The coefficient plus or minus sign determines if the electricity market price would increase or decrease. Error term indicates differences between regression-fitted dependent variable values and actual values. *Figure 4* presents a methodology summary for electricity source selection.



Source: created by authors.

Figure 4. **Scheme for Regression Analysis Electricity Sources Selection**

3. Results of the Analysis

This paper section introduces previously described methodology results using data gathered for Lithuania's energy system. First, a correlation analysis between Lithuania's electricity market price and electricity sources is performed. Secondly, a correlation analysis between electricity load and electricity sources is executed. The first two steps allow the selection of sources with meaningful influence on electricity market price. Finally, selected variables are included in linear regression with electricity prices. After each step respective conclusions and observations are made.

3.1 Correlation Analysis

Table 3 presents the results of the first correlation analysis between electricity market prices and eight electricity sources in Lithuania.

Table 3. Correlation values between electricity market price and electricity sources

Generation source	Correlation coefficient
Biomass	**0.512**
Natural gas	-0.126
Hydro pumped storage	0.185
Run-of-river	**-0.369**
Photovoltaic solar	0.077
Waste fuel	0.001
Wind power	-0.053
Electricity import	**0.538**

Notes: Bolded values represent correlation values higher than 0.3.

Source: own calculations.

The first correlation analysis identified that natural gas, run-of-river, and wind power generation have a negative effect on electricity prices while biomass, pumped storage, solar, waste fuel generation and electricity import have a positive one. Only three out of eight electricity sources have a higher than 0.3 correlation coefficient. Biomass generation, run-of-river generation, and electricity import can be considered as having a meaningful impact on electricity prices. These three energy sources are checked on the second correlation analysis with electricity load.

Table 4. Correlation values between electricity load and electricity sources

Generation source	Correlation coefficient
Biomass	**0.897**
Natural gas	-0.584
Hydro pumped storage	-0.252
Run-of-river	0.360
Photovoltaic solar	-0.314
Waste fuel	0.321
Wind power	0.556
Electricity import	0.710

Notes: bolded values represent correlation values higher than 0.8.

Source: own calculations.

Table 4 presents the results of the second correlation analysis between the Lithuanian electricity system load and eight electricity sources in Lithuania.

The second correlation analysis identified that all energy sources, except pumped storage, have at least a weak link with electricity demand. Out of three previously determined generation sources, biomass generation has a correlation coefficient above 0.8 value. This shows evidence that even though biomass generation has a relatively strong correlation with electricity market price it is used at the time moments when the electricity price is driven by the demand but not by the generation source. The conclusion allows us to exclude biomass generation from further analysis. Based on both correlation analysis results run-of-river generation and electricity import are selected for final regression analysis.

3.2 Regression Analysis

Table 5 presents linear regression results between run-of-river generation and electricity import as independent variables and electricity market price as a dependent variable.

Table 5. Regression analysis results and important statistics

Regression statistics				
Number of observations	60			
Multiple R	0.631			
R square	0.398			
Adjusted R square	0.377			
Standard error	6.164			
Variables				
	Coefficient	Standard error	t stat	p-value
Intercept	39.563	2.680	14.760	**<2e-16**
Run-of-river	-0.131	0.041	-3.213	**0.002**
Electricity import	0.017	0.003	4.981	**6.2e-06**

Notes: bolded values represent variables with a higher than 1% significance level in the regression.

Source: own calculations.

Linear regression results indicate that around 40% of electricity market price fluctuations can be explained by run-of-river generation and electricity import variations. 6.1% standard error value shows a relatively small mismatch between fitted and actual dependent variable values. All selected independent variables have a small p-value which indicates that their influence on the regression is significant. Regression results refer that model was built correctly and selected variables can be used to partly explain electricity market price movements. To understand the independent variables' magnitude on electricity price, coefficients are taken, and a regression equation is built:

$$Electricity\ market\ price = 39.563 - 0.131\ Run\ of\ river + 0.017\ Electricity\ Import \qquad (3)$$

The equation shows that without any run-of-river generation and electricity import electricity market price in Lithuania is around 40 €/MWh. This price is similar to the previously indicated average electricity market price for all research periods. With each 1 MW of average monthly run-of-river generation electricity price decreases by 0.131 €. Contrary to 1 MW of average monthly electricity import which increases the electricity price by 0.017 €.

4. Discussion

Presented research method and results explore only electricity generation sources' influence on the electricity price. In reality, electricity price is affected by many additional factors such as electricity demand/supply, commodities prices, weather conditions, electricity grid operation costs, government subsidies for certain generation sources, and others. Grid operation costs and subsidies represent electricity increase that depends on maintenance costs and political decisions. These factors increase electricity prices by a flat rate for a longer period and cannot be evaluated using statistical methods. However, electricity demand/supply, oil and natural gas prices, wind speed, and solar radiation would vary at all time periods and affect electricity prices. These factors' effect on electricity prices can be evaluated using statistical methods. Additional variables in the methodology and regression analysis could help to better explain electricity price fluctuations and deliver more robust research results.

Further research is planned towards regression analysis expansion by including other electricity price influencing factors. Electricity flow through the links with neighbouring countries, foreign power plants generation, and commodities market prices are a few of the variables' examples that are planned to be included in future analysis to improve the model.

Conclusions

Changing the electricity generation mix have a significant effect on electricity market price. Renewables are expected to be a key influencing driver in the future. Time series analysis methods can help to evaluate variable generation sources' impact on the electricity market price on a long-term horizon.

The proposed two-stage correlation analysis methodology allows for determining electricity sources that meaningfully influence electricity prices and do not depend on demand fluctuations. The first stage selects energy sources that have a strong correlation with electricity market price while the second stage eliminates energy sources that have a strong correlation with electricity load.

Identified electricity sources are used for linear regression where their influence magnitude on electricity price is determined. Regression coefficients indicate how much electricity price would increase or decrease in 1 MW average monthly generation would be added to the electricity source.

Research demonstrates methodology results on Lithuania's energy system data. After performing a two-stage correlation analysis, run-of-river generation and electricity import is identified as two variables meaningfully influencing electricity market price in Lithuania. Regression analysis showed that a 1 MW increase in an average monthly run-of-river generation could decrease the electricity price by 0.131 € while a 1 MW increase in average monthly electricity import could increase the electricity price by 0.017 €.

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STATISTINIS TYRIMAS, KURIUO SIEKIAMA ĮVERTINTI ELEKTROS ENERGIJOS GAMYBOS ŠALTINIŲ ĮTAKĄ ELEKTROS ENERGIJOS RINKOS KAINOMS: LIETUVOS ATVEJIS

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SANTRAUKA

Šiame straipsnyje pateikiamas statistinis tyrimas, kuris leidžia įvertinti skirtingų elektros energijos gamybos šaltinių įtaką elektros energijos rinkos kainai. Metodika apima tam tikrų regionų elektros energijos rinkos ir elektros energijos tinklų duomenų laiko eilučių analizę. Dviejų pakopų koreliacijos analizės metodas taikomas siekiant nustatyti elektros energijos šaltinius, kurie reikšmingai veikia elektros energijos kainas ir nėra susiję su elektros energijos apkrova. Galutinė metodinė priemonė yra regresijos lygtis, kurią pasitelkus vertinama skirtingų elektros energijos gamybos šaltinių įtaka elektros energijos rinkos kainai. Pasiūlytas metodas leido įvertinti skirtingų elektros energijos šaltinių įtaką elektros energijos kainoms Lietuvoje. Nustatyta, kad upės hidroenergijos gamyba ir elektros energijos importas yra du kintamieji, reikšmingai veikiantys elektros energijos rinkos kainas Lietuvoje.

REIKŠMINIAI ŽODŽIAI: elektros energijos rinkos kaina, elektros energijos gamybos šaltinių įvertinimas, metodologija, koreliacija, regresija.