# Open Data in Electrical Energy Balancing of Ukraine: Green Deal and Security Aspects

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**Abstract.** The implementation of The European Green Deal is a modern driver of changes in the energy sector for transition to a clean economy and energy security. Access and sustained consumption of clean energy sources, reduction of greenhouse gas emissions and environmental pollution are important initiatives for overall socio-economic development. This all implies the need to develop models for the analysis the state of the energy system in real time as well as predict general energy consumption based on available open data and balance databases. In this manuscript, we investigate the importance of open data for energy security and the development of effective energy policy and institutional frameworks. Analysis of the electrical energy balance of Ukraine (the 2019 calendar year) on the base of the open data shows the existence of volatility between the production of electricity from renewable energy sources and its consumption, which may directly affect the country's security.

**Keywords:** open data in energy sector, electrical energy balancing, energy security in Ukraine.

## 1 Introduction

In order to analyze the state of the energy system in real time, to predict internal process, and, especially, to develop energy policies at all levels of governance, the availability of open energy data is important. Currently, energy systems in most countries are being modernized and developed based on the concept of deep integration of electric power grids and computer information and communication networks. Developing access to modern energy database for users is not a main challenge, but also strongly multidisciplinary linked to other aspects such as geography, health, education and equality. Using Open data gives fresh perspectives for scientific community and policy-makers to create efficient energy systems. Furthermore, extension of Open data, grids databases such as electricity generation capacities, consumption, electrical loads, geo-referenced data promote to fill knowledge gaps and contributes to energy SDG targets and Green Deal agenda [1]. Ukraine also have obligations in several environmental, energy and climate partnerships [2].

Special attention in the research made on interconnection among availability of Open electrical energy data and credibility of research for energy systems development based on energy balancing methodology. The electrical energy balance lets to study the domestic electrical energy situation, to monitor effects of national electrical energy policy of a country [3] and to compare balancing activities at the international energy market.

# 2 Recent Research Analysis

## 2.1 Related Works on Energy Balancing

The problem of energy balance has been studied extensively for the past decade. Actually, there are many theoretical and practical approaches developed in the field of electric energy balance. Fig. 1 shows the number of publications with TITLE-ABS-KEY "Open Data&Energy" per year in accordance with Scopus database of peer-reviewed literature. The exponentially growing number of publications per year proves that the open data in the context of electric energy balance is currently a trendy topic of research.

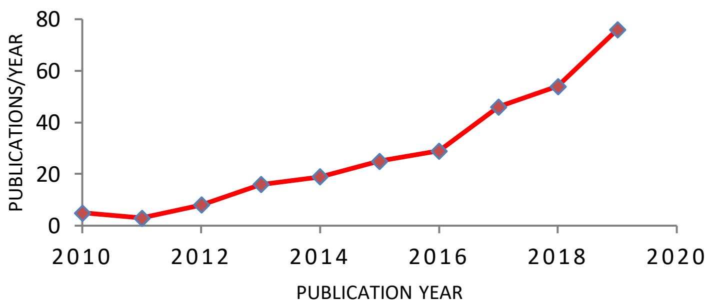



**Fig. 1.** Number of publications per year under the topic "Open Data&Energy" listed in the source index of the Scopus (Source: Conducted by authors based on Scopus database [4])

However, the peculiarities of application open data in electrical energy balancing faces a lack of methodological approaches. This is mainly because of significant complexity of the problem. Researchers as well as policy makers in energy sector generally emphasizes the importance and urgency of the issue, but also its multiplicity and difficulty. Pfenninger et al. [1] prove the need of open and high-quality big data to develop quantitative energy models, which is the basis of well-thought-out energy policy at all levels of government. In Wiese et al. [6] the lack of transparency of energy models as well as lack of an open source energy system for developing a sustainability strategy are discussed. The author emphasizes the importance of expertise from different fields on technical, economic, environmental, and social issues for modeling a complex system as renewable energy pathways simulation system.

It should be noted about some ethical and security concerns around open data. Collecting data, formulating models might encounter problem with access to sensitive commercial data or to data containing individual households' information. Costs of security failures in smart grid deployments have analyzed by McDaniel and McLaughlin [7]. Simmhan et al. [8] note that security and privacy concerns inherent in an information-rich Smart Grid environment. Such situation can be exacerbated by their deployment smart grid software architectures on clouds.

Energy security and current transformations in the economy are highlighted in the literature. Effects of energy convergence are analyzed for example in Rui et al. [9]. Authors in [10, 11] shows importance of balanced resource allocation at all levels of governance. Vasylyeva and Pryymenko in [12] focused on the concept of "energy dependence" through energy security of all types of energy resources by using Jewell model. In addition, authors in [13] develop methodical approach that allows to assess the overall level of energy security of the country with further minimization of integral specific discounted environmental and economic costs. By using IEA Model of short-term energy security, the energy security of Ukraine is assessed. Karakasis in [14] focus on policy paradigms for energy security matters. By conducting open-ended interviews with the opinion-makers, author come to conclusion that there is difference between the academic and the policy world in energy fields.

Many authors in their papers [15] confirm that biogas is the most perspective alternative resources and expected to bring benefits for the environment and economy [16]. Effects that take place through reduction of the natural gas consumption and replacement by alternative fuel types are analyzed for example in [17], which finds additional budget stimulation for local energy market transformation. From a different perspective, a methodological approach to electricity pricing on local level is developed by Mentel et al. [18] in the form of accounting a balance of electricity production and its consumption by the population of a particular territory. It is important to highlight the implementation of the Net-zero building concept to gain energy security. In [19] researchers make the economic assessment of the different power of solar collectors and energy consumption by the households taking into account principles of Net-zero building.

Several empirical studies indicate that green investments have a positive effect on economy and energy security. Lyeonov et al. in [19] estimates that green investment could provoke the growth of GDP per capita by 6.4% and the increase of renewable energy by 5.6% in the total final energy consumption. Similar arguments are presented by Marcel in [21]. Author by using Stationery and Johansen cointegration tests, VAR model, and Granger causality determines relationship between electricity consumption and economic growth. In manuscript, bidirectional causality is empirically proven. Some authors [22, 23] emphasize on impotence of green bonds as incentive instrument for realizing green and renewable projects.

### 2.2 Open Data for Quality of Science in Energy Fields and Energy Policy

According to European data portal [24], "Open data" is data that anyone can access, use and share. In other words, it's a tool for the digital age that brings social, economic and environmental benefits. The Open Knowledge Foundation [25] specify Open data on two characteristics to openness: legal openness (legal to build on and to share it - open license, placing into the public domain, etc.) and technical openness (no technical barriers to using data - machine readable, available in bulk, etc.). Moreover, Foundation defines principles of Open data: availability and access; re-use and redistribution; universal participation.

Importance of open data for energy security are determined by the following factors:

- the constantly growing demands both on environmental friendliness and on improving the efficiency of energy systems and networks;
- the unstable nature of wind and solar power generators that increases the requirements for efficient and fast load management in power systems;
- the need for effective management of distributed generation systems with a large number of sources;
- the need for accurate load energy forecasting and efficient management of network elements to save energy and prevent congestion.

Increasing the relevance of the topic of the energy balance and the availability of open data requires creation of a specific online collaboration platform across science and policy. The interconnected factors that influence quality of science in energy fields and energy policy are presented in Fig. 2.

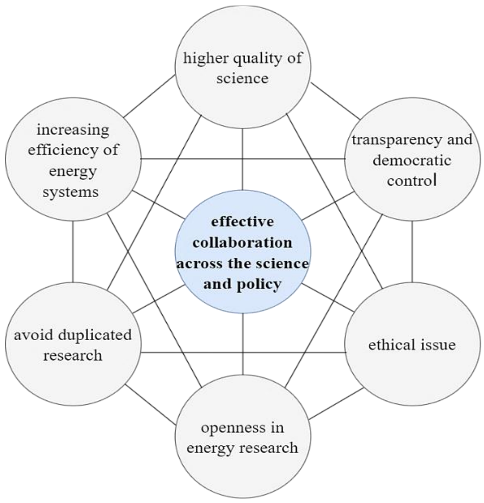



**Fig. 2.** The importance of open data for quality of science in energy fields and energy policy (Source: Conducted by authors)

The role played by Open Data and Big data as a tool for research in different fields of science has been intensely debated in the academic literature over the last years [26, 27, 28, 29]. In Beyi [30], the link between the individual and the digital network is explained through new market mediator tools for creating global social dialogue.

Summarized literature review on place of Open and Big data in the contemporary world is discussed in [31].

# 3 Data and Methodology

## 3.1 Data

Our research based on the course of the hour-by-hour electrical energy balance of the Integrated power system (IPS) of Ukraine. The data were upload from the Open data portal of Ukraine (that fully integrated into the European data portal). The electrical energy balance databases on the portal available from the 2016 year, but we used electrical energy statistics refer to the 2019 calendar year only (from January to December on the hour-by-hour basis). The daily cycle of electrical energy balance stats at 01:00 a.m. and ends at 12:00 p.m. The data in electrical energy balances were presented in megawatt-hours (MW). The accuracy of the electrical energy balance data in some cases not very good. Firstly, in the 2019-year database, we found missing data for two observation hours (see Fig. 3). For the purpose of research, we had to make corrections of empty cells with the values above (empty cells at 4:00 p.m., 17.12.2019) and below (at 5:00 p.m., 17.12.2019). Secondly, we observed some errors in volumes of computed index '*Used for the internal market'* electrical energy. The "statistical difference" in energy balance not high but indicates "that some reported elements are inaccurate (or alternatively, some elements are not reported)" [3]. Thirdly, this database has two different names on the portal ('*Hour-by-hour balance of the IPS capacity of Ukraine*' and '*Electrical energy production and consumption balance (forecast and actual)*').

## 3.2 General Model

The electrical energy statistics collected by the National power company 'Ukrenergo' [32] according to the statistical methodology of Ukraine. The presented approach not fully harmonized with Eurostat's energy statistics approaches. We tried to apply definitions of Regulation (EC) No 1099/2008 on energy statistics [33], but not all data were covered. 'Ukrenergo' does not report these data points: geothermal, wind power production (but publish the value of renewables); total fuel consumption in main activity producer plants. Electrical energy balance of Ukraine possible to describe by following equations (1-6):

$$E_{TEP\ i} = E_{NPP\ i} + E_{THPP\ i} + E_{TPP\ i} + E_{other\ renewables\ i} + \varepsilon_{ld\ i} \quad (1)$$

$$E_{THPP\ i} = E_{HPP\ i} + E_{CHPP\ i} + E_{PSP\ i} + \varepsilon_{ld\ i} \quad (2)$$

$$E_{TNEP\ i} = E_{TEP\ i} - E_{Consumption\ i} + \varepsilon_{ld\ i} \quad (3)$$

$$E_{UIM\ i} = E_{TNEP\ i} + E_{TNEI\ i} - E_{usedPSP\ i} + \varepsilon_{ld\ i} = 0 \quad (4)$$

$$E_{TNEI\ i} = E_{TEI\ i} - E_{TEE\ i} + \varepsilon_{ld\ i} \quad (5)$$

$$E_{TNEI\ i} = E_{NEI\ EU\ i} + E_{NEI\ R\text{-}B\ i} + E_{NEI\ M\ i} + \varepsilon_{ld\ i} \quad (6)$$

where $E_{TEP\,i}$ – total electricity production (MW) in the *i*-balance ($i$ = 1, …, $N$), $E_{NPP\,i}$ – nuclear power production (MW), $E_{THPP\,i}$ – total hydro power production (MW), $E_{TPP\,i}$ – conventional thermal power production (MW), $E_{other\ renewables\ i}$ – other renewables (not including hydro power production, MW), $\varepsilon_{ld\,i}$ – losses (transformation, distribution and transmission losses) and statistical difference (MW) in the *i*-balance, $E_{HPP\,i}$ – hydro power production (MW), $E_{CHPP\,i}$ – combined heat and power plant production (MW), $E_{PSP\,i}$ – part of hydro produced from pumped storage (MW), $E_{TNEP\,i}$ – total net electricity production (MW), $E_{Consumption\,i}$ – electricity consumption (MW), $E_{UIM\,i}$ – used for the internal market (MW), $E_{TNEI\,i}$ – total net electricity imports (MW), $E_{usedPSP\,i}$ – electricity used for pumped storage (MW), $E_{TEI\,i}$ – total electricity imports (MW), $E_{TEE\,i}$ – total electricity exports (MW), $E_{NEI\,EU\,i}$ – net electricity imports to EU (MW), $E_{NEI\,B\text{-}R\,i}$ – net electricity imports to Belarus and Russia (MW), $E_{NEI\,M\,i}$ – net electricity imports to Moldova (MW).

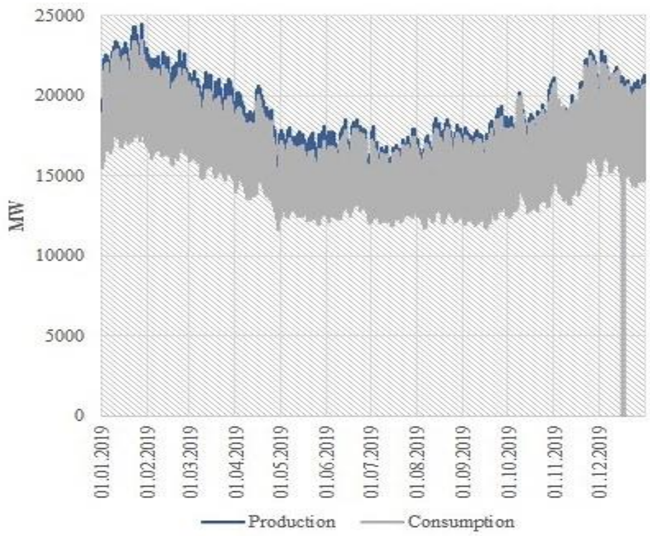



**Fig. 3.** Hour-by-hour electrical energy balance of the IPS of Ukraine in 2019 (Source: Conducted by authors based on the data of the Open data portal (ODP) of Ukraine [32])

The general regression model of electrical energy balance based on equations (1-6) is as follow (7):

$$Y_i = f\,(X_i) + \varepsilon_{ld\,i} \tag{7}$$

where $Y_i$ – dependent variable, $X_i$ – independent variables in the *i*-balance ($i$ = 1, …, $N$).

To test differences between electricity consumption and renewables power production, we set the hypothesis is as follows:

*H0*: No difference between means of electricity consumption and renewables power production.

*Ha*: Difference between means (means of electricity consumption and renewables power production is not equal to another).

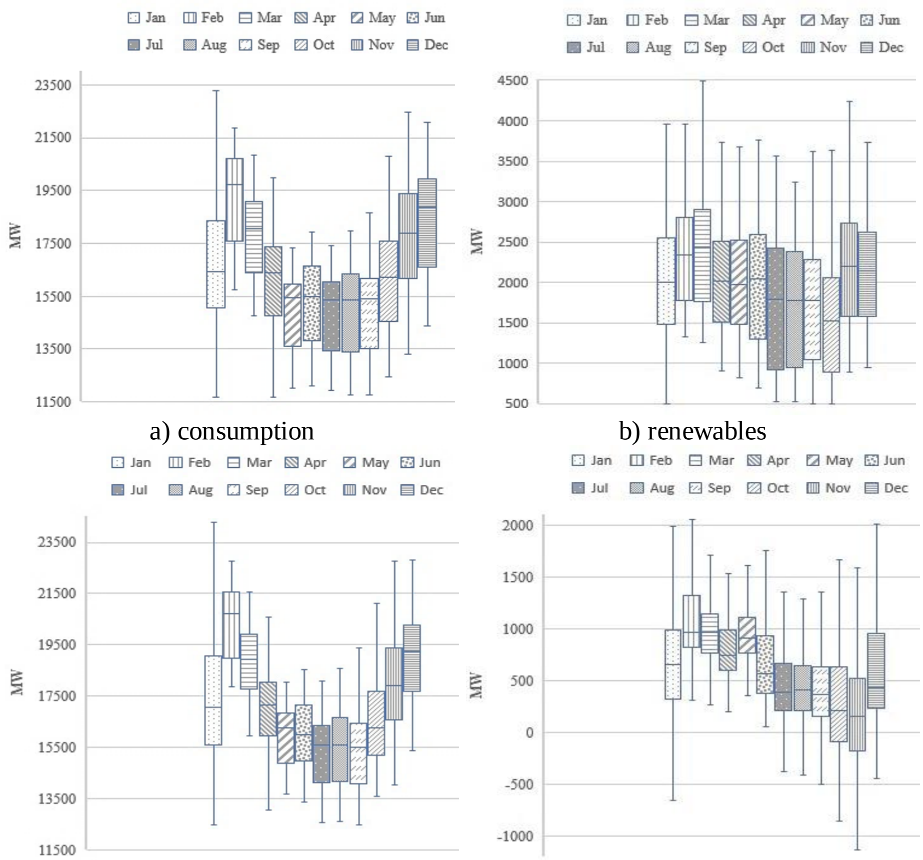
The data set of electrical energy balance has a high range of values. To apply statistical testing, we used a normalization procedure in Python to change the values to a common scale. The general statistics were computed in Python with Pandas, SciPy, the Scikit-learn, Statsmodels modules.

## 4 Results

Ukrainian electricity production generally orients on the internal market. The peak and the most significant variation values of electrical energy production and consumption were observed in January 2019. But the highest mean values of production and consumption were in February 2019. The lowest level of electrical energy production and consumption occurred during the warmest seasonal period in Ukraine: from May to October. But if we look at renewable power production, are visible differences between electrical energy consumption and renewable power production (see Fig. 4). This situation arises in connection with the production of electricity from new renewable energy sources (other renewables in Ukrainian case). Operators and agents in the energy market balance the production and consumption of electricity not only through pumped storage but within combined heat and power plant production ($E_{CHPP}$, Table 1). Export-import operations are not the main source of the electricity market balancing in Ukraine due to existing restrictions in this area. The Ukrainian electricity market is only by 6 % synchronized with the EU market. The rest of the energy is flowing between Ukraine and Belarus, as well as between Ukraine and Russia, although Russia is proclaimed a military adversary of Ukraine. And therefore, the uncontrolled and unsystematic production of electricity from new renewable energy sources strengthens Ukraine's dependence on Russia through the problem of balancing the production and consumption of electricity. And may worsen the energy security of Ukraine.

The OLS regression on electrical energy balance analysis results on following as:

- the total hydro power production is explained by 54,2 % of the variation in electrical energy consumption (Table 2); the 94,7 % of the variation in electrical energy consumption is explained by total electricity production (Table 3);
- there is a significant difference in means (Table 2 and Table 3), so we should reject the *H0* hypothesis, and accept the *Ha* hypothesis;
- The F-statistic = 1.036 for the total electricity production and F-statistic = 1.559 for the total hydro power production, which is indicating that there is a significant effect of electrical energy production on consumption; this indicates that the overall regressions are meaningful.




a) consumption

b) renewables

c) total electricity production

d) total net electricity production

**Fig. 4.** Box and Whisker charts of electrical energy balance of Ukraine in 2019 (Source: Conducted by authors based on the data of the ODP of Ukraine [32])

**Table 1.** Correlation matrix between electricity consumption ($E_{Consumption}$) and other electrical energy aggregates (Source: Conducted by authors based on the data of the ODP of Ukraine [32])

| $E_{NPP}$ | $E_{HPP}$ | $E_{CHPP}$ | $E_{PSP}$ | $E_{THPP}$ | $E_{TPP}$ | $E_{other\ renewables}$ | $E_{TEP}$ | $E_{TNEP}$ | $E_{NEI\ R\text{-}B}$ | $E_{NEI\ M}$ | $E_{NEI\ EU}$ | $E_{TNEI}$ | $E_{usedPSP}$ | $E_{UIM}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.658 | 0.496 | 0.748 | 0.422 | 0.736 | 0.699 | 0.035 | 0.973 | -0.239 | -0.044 | -0.498 | -0.034 | -0.107 | 0.448 | -0.005 |

**Table 2.** OLS Regression results: E_Consumption and E_THPP in 2019 (Source: Conducted by authors based on the data of the ODP of Ukraine [32])

| Dep. Variable: | E_Consumption | R-squared: | 0.542 |
|---|---|---|---|
| Model: | OLS | Adj. R-squared: | 0.542 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Method: | | Least Squares | | F-statistic: | | 1.036e+04 |
| No. Observations: | | 8759 | | Prob (F-statistic): | | 0.00 |
| Df Residuals: | | 8757 | | Log-Likelihood: | | -77454. |
| Df Model: | | 1 | | AIC: | | 1.549e+05 |
| Covariance Type: | | nonrobust | | BIC: | | 1.549e+05 |
| | coef | std err | t | P>\|t\| | [0.025 | 0.975] |
| Intercept | 1.283e+04 | 41.960 | 305.836 | 0.000 | 1.28e+04 | 1.29e+04 |
| E_THPP | 2.3577 | 0.023 | 101.788 | 0.000 | 2.312 | 2.403 |

**Table 3.** OLS Regression results: E_Consumption and E_TEP in 2019 (Source: Conducted by authors based on the data of the ODP of Ukraine [32])

| | | | | | | |
|---|---|---|---|---|---|---|
| Dep. Variable: | | E_Consumption | | R-squared: | | 0.947 |
| Model: | | OLS | | Adj. R-squared: | | 0.947 |
| Method: | | Least Squares | | F-statistic: | | 1.559e+05 |
| No. Observations: | | 8759 | | Prob (F-statistic): | | 0.00 |
| Df Residuals: | | 8757 | | Log-Likelihood: | | -68023. |
| Df Model: | | 1 | | AIC: | | 1.360e+05 |
| Covariance Type: | | nonrobust | | BIC: | | 1.361e+05 |
| | coef | std err | t | P>\|t\| | [0.025 | 0.975] |
| Intercept | -740.9104 | 44.577 | -16.621 | 0.000 | -828.291 | -653.530 |
| E_TEP | 1.0022 | 0.003 | 394.872 | 0.000 | 0.997 | 1.007 |

## 5 Conclusions

Our study showed a significant interest increase in the energy sector, especially in renewable energy matters. Open data should help researchers conduct analysis. But the presented databases in the energy sector are not always available, relevant, and meet the requirements for the quality of research. All these shortcomings correspond to Ukrainian open data in the energy sector. The data in the energy sector is published only by 18 percent on the Ukrainian open data portal; the same databases have several names; some data are absent in the databases, and there are errors in the calculations.

However, open data is quite necessary for balancing electrical energy. An analysis of the production and consumption of electricity allows us to see the problems of balancing, which can affect the energy security of the country as a whole and individual contractors in particular.

The data test displays that stimulating the electricity production from renewable sources in Ukraine not only leads to green energy consumption but also significantly increases the volatility between production and electricity consumption, the dependence on neighboring countries to balance the electrical market. And since one of the neighboring countries is Russia, the current situation causes the need for electrical energy balancing therapy in a short period and conceptual changes the source of renewable power production in a long period in Ukraine.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