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Assessment of the supply and demand function of hydropower energy industry: Fresh empirical evidence from the EU region

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Assessment of the supply and demand function of hydropower energy industry: Fresh empirical evidence from the EU region

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Abstract: The hydropower industry is a crucial catalyst for improving the National Renewable Energy Action Plans (NREAPs) and mitigating greenhouse gas (GHG) emissions in line with the Renewable Energy Directive of the European Union. Hydropower has been described as one of the most scalable electricity generations, enabling the incorporation of variable production for wind and solar energy systems. Nonetheless, despite ensuring that hydropower production securely matches demand in the real-time market, uncertainty about investment cost and concession rights continue to impede the achievement of the goal. The study used the supply and demand functions to analyse the market hydropower energy industry in the EU from 1990-2018. The research employed two-stage least square (2SLS) and autoregressive integrated moving average (ARIMA) models for the analyses. The outcomes of the supply side indicated that an increase in input resource (precipitation) and hydropower price are essential factors influencing the growth in hydropower supply in the EU region. By contrast, the result reveals that a rise in input cost discourages more hydropower energy production in the EU. As for the demand side, statistical findings have shown that income is directly associated with the demand for hydropower. Whereas an increase in the price of hydropower energy causes reductions in demand. More importantly, we find solar energy to be a substitute for hydropower in the EU region. The results of the forecasted hydropower market demonstrate that supply would be enough to cater to hydropower consumption in the European Union region until 2030. A typical pumped-hydro for supply-push is needed for managing prices during off and peak load situations. There is also a need to streamline the variable cost of topology and geography when constructing a Dam. This study recommends that the EU expand and make hydropower transmission from the grid a national project to be easily accessible for consumption.

1. Introduction

The movement for sustainable energy sources, such as hydropower, wind, solar, and bioenergy facilities, has been regarded as clean and sustainable [1]. Several factors have driven these interests, including but not limited to oil price volatility and ever-increasing environmental concerns, particularly those related to CO2 emissions [2, 3]. Hydropower is a renewable energy source derived from moving water at force through dams and reservoirs to generate large amounts of electricity [4]. Several studies have characterised hydropower development as capital-intensive, clean, cheap, reliable and flexible [5]. The industry has also been described as one of the vital participants in the European Commission's new green deal [6]. Figure 1 displays the production and consumption of hydropower energy in the EU region from 1990-2018. It excludes Cyprus and Malta due to the unavailability of data. It indicates that hydropower energy generation experienced a significant increase in the years 2001 (408 GWh), 2010 (408 GWh) and 2014 (407 GWh), compared to the year 1990 level (308 GWh). About 76 GWh decreased in hydropower energy generation between 2014 and 2017. In 2018, hydropower returned to an upward trend in power production.

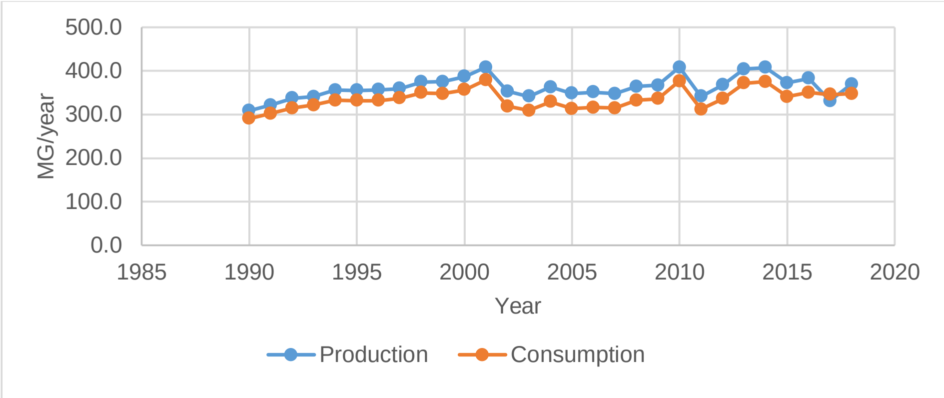

Figure 1. Chart of Hydropower Energy in the EU region. Source: IEA [7].

Given the statistics of hydropower energy (Figure 1), it is evident that consumption and production follow the same trend, slightly from 1990-2001. The market trend remains relatively lower in 2009 compared with the 2002 level. Generally, hydropower production has marginally remained higher than consumption, except in 2017. Therefore, this study aims to assess the supply and demand function empirically and forecast the hydropower energy industry in the EU region. Birkedal and Bolkesjø [8] evaluated the determinants of hydropower supply in Norway and statistically demonstrated that the price of hydro significantly determines supply. [9] noted that price increase reactions are heterogeneous among household classes. [10] found that per capita income substantially increases energy consumption in G7 countries. [11] discovered that an increase in annual precipitation in the range between 2% and 6% with more extensive changes in winter and autumn would significantly impact hydropower output in Italy.

The motivation for this research is that the empirical assessment of the supply and demand function of hydropower energy in the EU is relatively scarce. Therefore, this study aimed to provide additional empirical evidence on how supply and demand's essential economic functions influence the EU's hydropower energy industry. The significant vital contribution of this study is the forecast of hydropower supply and demand until the end of 2030. The estimates will serve an essential purpose to policymakers in planning, optimisation and maintaining a reasonable balance between demand and supply of hydropower. The rest of the study is organised as follows: Section (2) provides material and method, (3) is about results and discussion, and (4) presents the conclusion and policy recommendations.

2. Materials and methods

A two-stage least square (2SLS) approach was employed to empirically assess hydropower energy's supply and demand function in the EU. This study used an autoregressive integrated moving average (ARIMA) framework to select appropriate models for the market forecast. In a multivariate regression model, there is a general presumption that at least one of the explanatory variables is endogenous or suffers from a measuring malfunction; thus, Ordinary Least Squares (OLS) cannot produce a consistent parameter in such a framework [12]. Besides, [13] stated that simultaneous equation models permit a feedback relationship between variables. For example, a reduced-form market function from simultaneous equations is a feedback model, where the price can determine supply and vice-versa. This feedback could create a dilemma of simultaneity, causing OLS to be unsuitable for assessing the consistency of each equation. More so, [14] proposed that the 2SLS could solve the puzzle of endogenous regressors. Meanwhile, [15] said that 2SLS helps classify instrumental variables unrelated to the error term.

Table 1. Variable description and sources

Supply function	Coefficient sign	Source
Input resource (rainfall in volume)	(+)	[16]
Hydropower price (USD/kWh)	(+)	[7]
Input cost (dam capacity per capita)	(-)	[16]
Pumped-hydro-instrumental variable		[17]
Installed capacity- instrumental variable		[17]
Demand function		
Hydropower price (USD/kWh)	(-)	[17]
Solar energy price (USD/kWh)	(+)	[17]
Income (GDP per capita)	(+)	[18]
Investment –instrumental variable		[19]
Consumer price index- instrumental variable		[18]

2.1 Empirical models

Following the previous studies [8, 10, 20], we specified the hydropower energy industry as $Q_{i,t}$, and it is decomposed into $q^s_{i,t}$ and $q^d_{i,t,}$ denoting quantity supplied and demanded, respectively.

The supply function in region *i* is expressed as follow:

$$q^s_{i,t} = A^s_i \cdot (IR^s_{i,t})^{ß s_i} \cdot (P^s_{i,t})^{\delta s_i} \cdot (IC^s_{i,t})^{\lambda s_i} \cdot (Z_{i,t}) \cdot \varepsilon^s_{i,t} \quad (1)$$

Let $q_{i,t}$ denote the corresponding quantity of hydroelectricity supplied in country *i* at year *t*. $ß^s_i$, $\delta^s_{i,}$ and λ^s_i are the parameters to be examined, which suggest the supply elasticities of input resource, own price, and input cost, while $Z_{i,t}$ represent the instrumental variables. A^s_i and $\varepsilon^s_{i,t}$ is the constant and $\varepsilon^s_{i,t}$ disturbance term.

The additive log form of both left and right sides in Equation (1) can be rewritten as follow:

$$lnq^s_{i,t} = lnA^s_i + ß^s_i \cdot lnIR^s_{i,t} + \delta^s_i \cdot lnP^s_{i,t} + \lambda^s_i \cdot lnIC^s_{i,t} + lnZ_{i,t} + \varepsilon^s_{i,t} \quad (2)$$

Similarly, demand function in region is expressed as follow:

$$q^d_{i,t} = A^d_i \cdot (P^d_{i,t})^{ß d_i} \cdot (SP^d_{i,t})^{\delta d_i} \cdot (Y^d_{i,t})^{\lambda d_i} \cdot (Z_{i,t}) \cdot \varepsilon^s_{i,t} \quad (3)$$

Let $q_{i,t}$ denote the corresponding quantity of hydropower demanded in country *i* at year t. $ß^d_i$, $\delta^d_{i,}$ and λ^d_i are the parameters to be assessed, which suggest the demand elasticities of own price (P), substitute price (SP) and income (Y). At the same time, $Z_{i,t}$ represents the instrumental variables. A^d_i and $\varepsilon^d_{i,t}$ is the constant and unobservable error term. The logarithm for the demand function in equation (4) can be rewritten as follow:

$$lnq^d_{i,t} = lnA^d_i + ß^s_i \cdot lnP^d_{i,t} + \delta^s_i \cdot lnSP^d_{i,t} + \lambda^s_i \cdot lnY^d_{i,t} + lnZ_{i,t} + \varepsilon^d_{i,t} \quad (4)$$

This section forecast the historical data on the supply and demand of hydropower using the time series technique of autoregressive integrated moving average (ARIMA) developed by [21]. ARIMA uses a historical data series to decide the best-fit model based on stationarity and low standard error. The required model was selected based on four criteria; the Akaike criterion, Schwarz Bayesian criterion, maximum likelihood and the standard error.

A typical ARIMA model is characterised by *(p, d, q),*

where *p* is the number of autoregressive series, d refers to the number of differences, and *q* signifies the number of moving averages. Following the specification of Fattah et al. [22], this study presents the autoregressive model as:

$$Y_t = \alpha 1 Y_{t-1} + \varepsilon_t \quad (5)$$

Where Y_t is the linear function of the hydroelectricity supply or demand in the preceding year, $\alpha 1$ is the autoregressive coefficient, and the series is assumed to be associated with the disturbance error term ε_t. The moving average is expressed as:

$$Y_t = \varepsilon_t - \theta_1 \varepsilon_{t-1} \quad (6)$$

ARIMA requires three-stage processes (identification, estimation and diagnostic review) to evaluate the suitability of a proposed model [23].

3. Results and discussion

Table 2 displays the result of the empirical assessment of the supply and demand function of hydropower energy in the EU from 1990-2018. In the supply function of hydropower energy, results show that a 1% increase in the volume of rainfall will cause a 3.425% increase in hydropower supply. This result is consistent with [11], who found that geographical growth trends in hydropower production depend highly on future precipitation levels. The outcome in (Table 2) reveals that a 1% rise in the price of hydropower will cause a 1.2% increase in hydropower energy supply in the EU between 1990 and 2018. The result of hydropower input cost demonstrates that a 1% point increase will cause a 0.587% reduction in the quantity of hydropower energy in the EU over the study period. The result aligns with [4].

Table 2. Regression results assessing supply and demand functions of hydropower energy in the EU region (1990-2018).

Supply function	EU Region	EU Developed	EU Developing
lnIR	3.425*** (0.179)	2.685***(0.178)	7.273***(0.732)
lnP	1.20***(0.127)	0.739***(0.164)	3.457***(0.416)
lnIC	-0.587***(0.060)	-0.577***(0.108)	-0.819***(0.135)
Intercept	-30.074***(2.020)	-21.034***(1.781)	-6.525***(7.521)
Sargan test	1.301[0.2540]	1.543[0.214]	0.168[0.681]
Observation	754		
Demand function			
lnP	-0.936***(0.336)	-3.769***(0.189)	-4.310**(2.019)
lnSP (solar energy)	0.466***(0.085)	0.622***(0.193)	0.974***(0.176)
lnY	0.046**(0. 023)	0.010(0.064)	0.001(0.030)
Intercept	4.243***(0.788)	-2.344(0.572)	6.124(0.503)
Sargan test	3.353[0.067]	0.008[0.928]	10.759[0.031]
Observation	748	435	313
Country	26	15	11

Note: ***, ** denotes significance at the 1% and 5% level, respectively. The parentheses (.) are standard errors and [...] are p-values. In addition, IR is the input resource, P refers to the price, IC is the input cost, SP means substitute price, and Y is income.

This study examined the price substitution of solar Photovoltaic (PV) on the quantity demanded hydropower energy in the EU. In this model, the coefficients of the explanatory variables produced expected signs, which agree with economic theory. The outcome shows that a 1% change in the price of hydropower will cause a 0.936% reduction in the quantity demanded. This finding is compatible with the economic theory, which suggests that demand is inelastic when a change in demand for production is proportional to a change in price. However, the result indicates that when solar price increases by 1%, the quantity demanded hydropower energy increases by 0.466% over the period studied. This result suggests that hydroelectricity and solar power are substitutes and are not complements in consumption. It means that electricity users consume hydro and solar differently. The relationship between hydropower quantity demanded and the income level is positive and significant, implying that income is a crucial determinant for hydropower demand function in the EU. The empirical outcome is consistent with [10].

3.1. Analysis of the assessment of supply and demand function of the hydropower industry in the EU15 (developed) and EU13 (developing) countries

As mentioned in the previous section, this study considers two homogenous subpanels constructed based on the economic classification of sample countries (developed and developing EU countries). The nature of the subpanels empirically unravelled the group-specific characteristics. As shown in Table (2), the outcomes of the supply side are in tandem with the economic theory of the supply function. The result unravels that a 1% increase in input resources will enhance a 2.685% increase in hydropower energy supply in the EU-developed countries. At the same time, a 1% increase in input resources will be the reason for a rise in hydropower supply by 7.273% in the EU developing countries. The result further indicates that a 1% increase in the price of hydropower would cause the supply to rise by 0.739% and 3.457% in the subpanels, respectively. The result lends consistency to the one [24] reported. Also, the empirical outcomes of this study suggest that a 1% increase in input cost will cause a 0.577% decrease to supply in the developed countries and a 0.819% reduction in the EU developing countries over the period studied. There is numerous socio-environmental problem that could increase the input cost of the hydropower industry, which will, in turn, cause hydroelectricity output to experience slow growth. Among the socio-environmental obligations of the hydropower industry are; reducing disruption to natural ecological conditions, which could have significant negative implications for the river flow, ensuring dispersal and migration of species, control natural sediment dynamics that are affected by weirs or dams. The result also reveals that as price increases by 1% and 5%, hydropower energy quantity demanded would decrease by 3.769% and 4.31%, respectively, in the EU15 and EU13 [25]. The result of solar energy demonstrated that a 1% change in the price of solar would cause a 0.622% and 0.974% shift in demand for hydropower energy in the EU15 and EU13 countries, respectively. By contrast, the coefficient of income carries a positive but insignificant impact on demand for hydropower in the sub-panel EU. [9] argued that reactions to an increased price defer among household classes. [15] also stressed the difficulty in determining income as a deciding criterion for quantity demand because it is associated with social and demographic factors such as household size, education, health and economic well-being.

3.2. Forecasting analysis of the domestic market of the hydropower industry in the EU region

It is worth noting that highlighting the future expectation of hydropower energy production and consumption would provide an insight for policymakers, investors, and operators on planning and optimisation. More importantly, the forecast would serve a significant purpose for the EU recast objective on the renewable energy directive established for 2030. Table 3 displays the actual (2005-2018) and forecasted (2019-2030) values of hydropower energy production and consumption in the EU region. The study used the Augmented Dickey-Fuller unit root test to investigate the stationarity of the historic data from 1990-2018. Table 3 shows the ADF result, indicating that both supply and demand series are stationary at I(0) and statistically significant at 1% and 5%, respectively.

Table 3. Augmented Dickey-Fuller (ADF) unit root test

Variable	Level	
	Without trend	With trend
Supply	-3.806***	-3.928**
Demand	-3.572**	-3.730**

Note: ***, ** denotes significance at the 1% and 5% level, respectively.

Subsequently, we use the ACF and PACF correlograms to determine AR and MA for the supply series. We, therefore, tested several models to identify the most suitable one. Initially, the best-fitted model for the supply data was ARIMA 6,1,1 because it has low volatility, high adjusted r-squared, low Akaike information criterion (AIC) and Schwartz Bayesian information criterion (SBIC) compared with ARIMA 1,0,1 and 1,0,6. Moreover, we noticed from the ACF and PACF correlograms that there is still uncaptured information in the series. Following the parsimonious condition suggested by Box-Jenkins, we selected the least series with uncaptured details to ascertain an appropriate model.

The forecasts span from 2019-2030 from time-series data between 2005 and 2018. The forecasted values indicate a steady-state upward trend in hydropower, which the industry will sustain until 2030. This prediction is consistent with the aggressive approach of the EU renewable energy development strategy towards 2030.

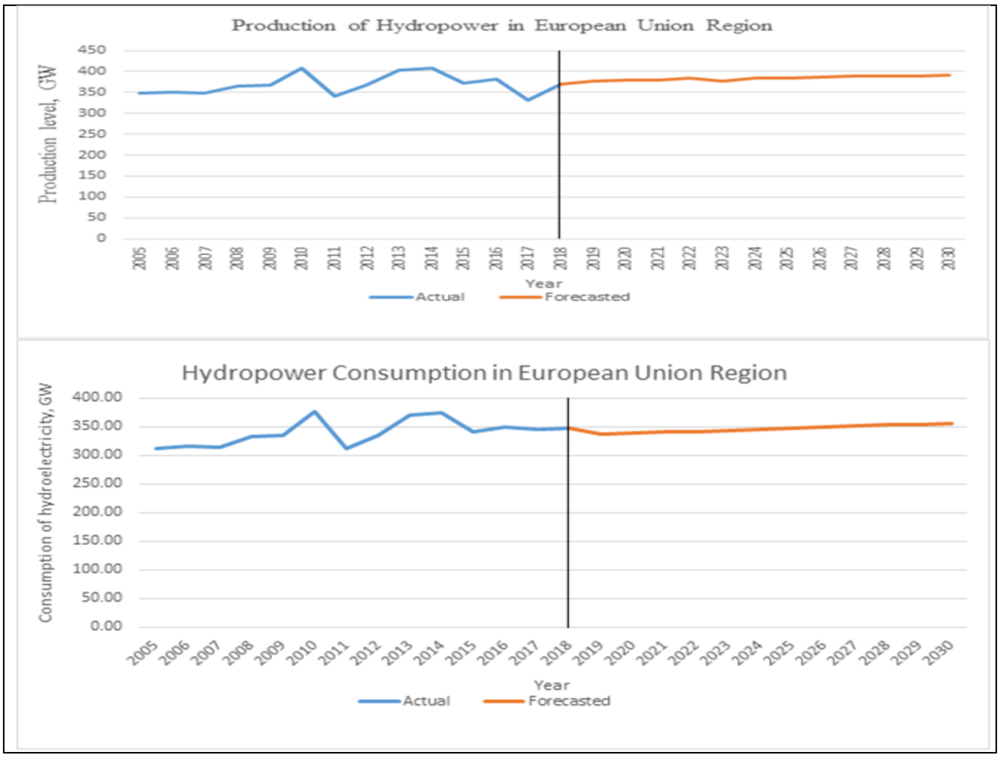

Figure 2. Actual and forecasted values of production and consumption of hydropower energy in the EU region. The vertical lines indicate the threshold.

4. Conclusion

The study has analysed the empirical assessment of supply and demand functions of hydropower energy in the EU region from 1990-2018. We also forecasted based on the historical time-series data of production and consumption of hydropower, using ARIMA models. From the analytical results of the supply side of hydropower, the report concluded that input resource, price and cost are statistically significant for the supply of hydropower in the European Union zone and its sub-regions. As for the demand side of the market, statistical findings permit us to conclude that income and substitute price (solar energy) has a direct relationship with the demand for hydropower in the EU region. Whereas, for the sub-regions, we conclude that income does not determine the need for hydropower. However, the price and quantity of demanded hydropower energy indicated an inverse relationship. From the forecasted results of the hydropower market, we conclude that supply would continue to variably cater to the demand for hydropower year-on-year in the EU region until 2030. Although, despite the absence of a shortage, the industry still needs to reduce the imbalance between supply and demand, to assure market efficiency. This research is limited to the hydropower industry in the EU region, excluding Cyprus and Malta. This research is limited to the domestic market of the hydropower industry in the EU due to unavailable information about the international hydropower market. To our knowledge, hydroelectricity import and export transactions are not available for all EU member countries. Future research may focus on the determinants of importing and exporting hydroelectricity in selected EU member countries. This kind of research will help understand how monetary policy and economic policy uncertainty is shaping the future of the hydropower industry in key economies in the EU region.

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