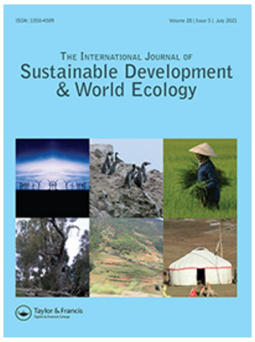

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Sustainable electricity generation: the possibility of substituting fossil fuels for hydropower and solar energy in Italy

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ABSTRACT

Electricity remains the most important form of end-use energy consumption and an important factor for economic growth and development. However, electricity generation also constitutes a great source of concern for global warming and climate change with threats to sustainable development as fossil fuels dominate electricity generation fuel mix for most economies of the world. This is exactly the case for Italy with fossil fuels dominating electricity generation fuel mix over the last couple of decades. Thus, there is a need to reverse this trend by increasing the shares of renewable energy sources in the fuel mix. This study, therefore, investigates the potentials for renewable energy sources of hydropower and solar energy to substitute the fossil fuels of coal and natural gas in electricity generation for Italy. Adopting the ridge regression procedure to obtain the parameter estimates, the results provide evidence that substitution is possible among all fuels. While both hydropower and solar energy are found to be substitutable for the fossil fuels, solar energy is found to provide more substitutability than hydropower. This implies that Italy has the potential to gradually move away from the carbon-intensive fossil fuels of coal and gas to more environmental-friendly solar energy and hydropower in the process of generating electricity.

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Interfuel substitution; electricity; solar energy; hydropower; translog production function; Italy

1. Introduction

Electricity generation is one of the main sources of emission across the globe. According to the International Energy Association (2020), electricity and heat production generated 13 billion tonnes of carbon dioxide emissions or 41% of the total carbon dioxide emissions from fuel combustion in the globe in 2017. The major reason for this situation is because fossil fuels dominate the electricity mix. About 16,947 terawatt-hours or 63% of the total electricity was generated through fossil fuel sources. Only 4,222 terawatt-hours or 16% of the total electricity was generated through hydropower and 724 terawatt-hours or 3% of the total electricity was generated through solar energy (British Petroleum 2020). In addition to the fact that the use of these two sources of electricity will lead to less pollution, they also have several advantages. Unlike fossil fuels such as gas, coal or oil, hydropower is environmental-friendly as it releases very small amounts of greenhouse gases (GHG). Beyond its function of promoting energy security and decreasing a country's reliance on fossil fuels, hydropower provides the prospects for poverty alleviation. The development of hydropower infrastructures is intimately associated with local and global development policies. Its quick response storage and capacity features are beneficial in meeting abrupt changes in electricity demand and to augment supply from inflexible sources of electricity. The water stored in reservoirs of dams can be utilized as a key source of providing water for diverse purposes such as irrigation for agricultural products (Sachdev et al. 2015).

The use of solar energy confers several advantages in the economy. For instance, the cost of solar energy is usually negligible, beyond the initial cost outlay. The operational labour requirement of solar energy is enormously lower than the conventional power plant. Since it is a locally sourced form of energy, solar power can improve energy security. Therefore, solar energy plays a crucial role by supporting the economy of a nation. Energy security ensures that a nation is less susceptible to external events that might raise the price of domestic energy products. A particularly advantageous and relevant characteristic of solar energy production is that it generates employment opportunities. In 2018, the solar photovoltaic industry was able to support more than over 3.6 million jobs globally (International Renewable Energy Agency 2019).

In order to reap the benefits of these two sources of electricity, their usage must be increased and to successfully increase their usage, these two sources of electricity should have the potential to substitute the fossil fuels, which are currently dominant in the electricity sector. The

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feasibility of such substitution can be examined within the inter-fuel substitution framework as exemplified in Berndt and Wood (1975). However, interfuel substitution studies that incorporate hydropower and solar energy into the analyses are rare with most studies focusing on examining the substitutability relationships between the four popular energy sources of coal, gas, oil and electricity. Besides, these studies have also been largely conducted within the framework of the aggregate energy sector with limited attention on the electricity sector and interfuel substitution studies on Italy as a country has not been adequately considered.

The aim of the paper is, therefore, to contribute to the existing literature by investigating the potential of substituting the fossil fuels – coal and gas for both hydropower and solar energy in the process of generating electricity in Italy. We have selected Italy because of several reasons. Firstly, with a real GDP of US$2.1 billion (constant 2010 prices), Italy was fourth largest economy in Europe after Germany, United Kingdom and France in 2019 (World Bank Group 2020). Secondly, by consuming 6.37 exajoules of energy, the country accounted for 7.6% of the total energy consumed in the continent and was the fifth in the continent after Germany, France, United Kingdom and Turkey (British Petroleum 2020). Thirdly, by generating 283 terawatt-hours of electricity in 2019, Italy was the fifth largest electricity generator in Europe, after Germany, France, United Kingdom and Turkey. Fourthly, by producing 325 million tonnes of carbon dioxide in 2019, the country has the fourth biggest carbon dioxide in Europe, after Germany, United Kingdom and Turkey and accounts for 8% of the total carbon dioxide emitted in the continent (British Petroleum 2020). Fifthly, similar to the situation in several nations, fossil fuels dominate both the energy mix and electricity mix in the country (Güney and Kantar 2020; Smith and Archer 2020; Sudsawasd et al. 2020). Hence, this has made the electricity sector as one of the major causes of the country's emissions. According to the International Energy Association (2020), electricity and heat production generated 109 million tonnes of carbon dioxide emissions or 34% of the total carbon dioxide emissions from fuel combustion in the country in 2017. Lastly, the use of hydropower and solar energy account for 16% and 9% of the total electricity (British Petroleum 2020).

The other parts of the paper include Section 2 that involves the existing literature, while Section 3 contains the methodology used in this study. Section 4 presents the empirical findings and Section 5 involves the conclusion of the paper.

2. Literature review

Research into the substitutability relationships between different energy fuels has a rich history. It dates back to the end of the first post-oil shock of the 1970s. Prior to this period, oil dominated the energy consumption profiles of the major economies of the world- a scenario that meant that most countries were adversely affected by the sudden oil glut of the 1973 to 1974 period. This development awakened the interest of stakeholders including policymakers and researchers on exploring the possibility of substituting oil for other alternative sources of energy. Consequently, Berndt and Wood (1975) produced a novel paper on the subject. Generally speaking, the research efforts are of two strands, namely, inter-factor substitution and inter-fuel substitution. Inter-factor substitution deals with investigating the possibility of substituting energy for other primary factors of production such as labour and capital while inter-fuel substitution investigates the substitution possibilities among competing energy fuels. Berndt and Wood (1975) paper was essentially an inter-factor substitution exploration as it investigated the substitution possibility between energy and the primary factors of labour and capital. Their study, which focused on the US manufacturing sector for the period 1947–1971, found substitutability relationships between energy and labour and complementary relationships between energy and capital.

Since then, majority of the interfuel substitution studies have focused on investigating the relationships between the four main energy fuels of oil, natural gas, electricity and coal. Some of the notable studies in this regard include Lin et al. (2016) on Ghana, Ma and Stern (2016) on Chinese provinces, Lin and Atsagli (2017) on Nigeria, Lin and Tian (2017) on China, Wesseh and Lin (2018) on Egypt and Considine (2018) on the US. However, in more recent times, authors are expanding the scope of analysis by exploring other areas of research in interfuel substitution. For instance, Li et al. (2019) examined the underlying dynamics in the coal market in China. The study also reveals that inter-fuel substitution is a major issue in the coal market in China.

Contributing to the research, Serletis and Xu (2019) employed the Markov Switching Minflex Laurent demand system to investigate interfuel substitution in the United States for the period 1919 to 2012. Their results provided strong evidence in support of substitutability relationships between all energy pairs. Lin and Abudu (2020) estimated a translog production function with the ridge regression approach to measure energy intensity and inter-fuel substitution for Ghana for the period spanning 2000 to 2015. They also provided evidence for substitution among the energy resources.

However, due to the exacerbating problem of global warming and the concerns for resource sustainability, several variants of renewable energy sources are increasingly being included in the analyses. For instance, Jones (2014), introduced biomass as the fifth fuel alongside the traditional fuels of coal, natural gas, oil and electricity for the US into the analysis and found substantial evidence that biomass can substitute natural gas in US energy profile. In a similar study for the US, Suh (2016) was also able to establish substitutability between coal and biomass and between natural gas and biomass while a complementary relationship between biomass and electricity was established. Kumar et al. (2015), in a study involving 12 designated industries from the countries belonging to the Organisation for Economic Cooperation and Development (OECD), examined the nature of the substitutability relationships between the renewable and the non-renewable energy sources. The result produced a negative substitution elasticity estimate which supports the complementarity relationship between the two energy sources.

In another study conducted by Wesseh and Lin (2016), to investigate the relationships between renewable and non-renewable energy sources in the economic community for West African countries (ECOWAS) member countries, the ridge regression procedure was employed to obtain the parameters of a translog production function. Their results provided evidence in support of substitutability between renewable and non-renewable energy for ECOWAS member countries. Focusing on a component of renewable energy, Bello et al. (2018) introduced hydropower in a study on three transition economies, namely, Malaysia, China and Thailand. Using the ridge regression procedure, the results show evidence of strong substitution between renewable energy represented by hydropower and non-renewable energy represented by coal, gas and oil that are employed for generating electricity in those countries. A similar study was also conducted by Bello et al. (2020) on Malaysia using the translog cost function framework where hydropower was found to be substituted for the fossil fuels of coal, and natural gas used in the generation of electricity for the country. The study also showed that trading off the fossil fuels for hydropower in electricity has the potential to reduce carbon dioxide emissions.

Contributing to the research while also factoring in the dynamics of renewable energy source, Suh (2019) examined the interfuel substitution impacts of biofuel usage on carbon dioxide emissions in the transportation sector of the US. Using a dynamic linear logit approach, the results reveal substitutability relationships between ethanol and petroleum, complementary relationships between ethanol and natural gas, while natural gas has the potentials to substitute petroleum. Lin and Ankrah (2019) incorporated the dynamics of renewable energy into the analysis for Nigeria. Using the ridge regression procedure, the authors found the existence of substitutability relationship between renewable and non-renewable energy while noting that output is primarily driven by capital and labour with both renewable and non-renewable playing insignificant roles in output generation. In a somewhat different study, Solarin and Bello (2019) extended the analysis by further introducing the concept of sustainable development in a study that investigate possibilities of substitution between biomass and fossil fuels in Brazil for the period 1980–2015. The study provided strong evidence of substitutability between biomass and fossil fuels and that sustainable development index can reveal some of the inherent negative effects of fossil-fuel consumption in the economy.

The above survey of the related literature reveals two important points. First, most of the studies on interfuel substitution have been conducted within the context of aggregate energy sector with little attention being accorded to the electricity sector despite its important not only to the energy sector but also to the aggregate economy. For instance, while other sub-sectors, such as the manufacturing, transportation, iron and steel and chemical sectors, have been given much attention to in the literature, as far as we know, only few studies such as Bello et al. (2018), (2020) have specifically focused on interfuel substitution solely within the electricity sector and none of these studies has simultaneously considered two renewable energy sources such as hydropower and solar energy. Secondly, with specific reference to Italy, there is a dearth of empirical study on interfuel substitution. While Italy has been included in several studies such as Griffin (1977), Hall (1986), Jones (1996), Renou-Maissant (1999), Morana (2000), and Serletis et al. (2010), (2011), that focus on OECD countries, single country-specific studies with Italy as the main focus is rare. As far as we know, Bardazzi et al. (2015) is perhaps the only study to have singularly conducted a full single-country specific interfuel substitution study focusing on Italy. It is important to conduct a single-country specific study of interfuel substitution on Italy as such a study is likely to generate a more accurate policy inference by taking into considerations the distinctive characteristics of the country. This present study is a departure from Bardazzi et al. (2015) in the sense that it is more comprehensive as it conducted within the context of the aggregate economy while Bardazzi et al. (2015) was essentially a firm-level analysis. Thus, we attempt to fill this gap in the literature by obtaining the estimate of substitution elasticities for Italy using macro-level data while incorporating variants of renewable energy sources into the analysis.

3. Methodology: model, data and estimation technique

3.1 Model

A linear production function relating output to input is specified as follows:

$$Q = q(K, L, E). \tag{1}$$

where output level Q is dependent on the amount of total capital stock, numbers of labours employed and the quantity of energy resources. The energy input is weakly separable and homothetic in its different forms of coal energy (C), natural gas (G), hydropower (H) and solar energy (S). Thus, Equation (1) is further re-specified as:

$$Q = q(K, L, E(C, G, H, S)). \quad (2)$$

Equation (2) is then transformed into a twice differentiable transcendental logarithm (translog) production function of the form:

$$Log(Q_t) = \beta_0 + \sum_i \beta_i Log(X_{it}) + 0.5 \sum_i \sum_j \beta_{ij} Log(X_{it}) Log(X_{jt}). \quad (3)$$

where Q is the output and the X_s are the various units of input combinations capital stock, labour, coal, natural gas, hydropower and solar energy with subscripts i and j representing such combinations. Period, which is annual in this instance, is denoted by subscript t and the β_s are the estimable parameters.

Equation (3), expressed in the logarithm form, is the general form of a second order Taylor Series approximation. The specific form of the model is specified as follows:

$$\begin{aligned} Log(Q_t) = {} & \beta_0 + \beta_K Log(K_t) + \beta_L Log(L_t) + \beta_C Log(C_t) + \beta_G Log(G_t) + \beta_H Log(H_t) \\ & + \beta_S Log(S_t) + \beta_{CG} Log(C_t) Log(G_t) + \beta_{CH} Log(C_t) Log(H_t) + \beta_{CS} Log(C_t) Log(S_t) \\ & + \beta_{GH} Log(G_t) Log(H_t) + \beta_{GS} Log(G_t) Log(S_t) + \beta_{HS} Log(H_t) Log(S_t) + \beta_{CC} Log(C_t)^2 \\ & + \beta_{GG} Log(G_t)^2 + \beta_{HH} Log(H_t)^2 + \beta_{SS} Log(S_t)^2. \end{aligned} \quad (4)$$

As the core aim of this paper is to investigate the substitutability between the energy inputs, we have only included their translog terms in Equation (4) to prevent over-parameterization. Using the parameter estimates in Equation (4), it is feasible to compute the estimate of the output of elasticity which is required to obtain the substitution elasticity estimates between the energy pairs. The output elasticity estimate of each of the energy series is obtained as follows:

$$\eta_{it} = \frac{\partial Log(Q_t)}{\partial Log(X_{it})} = \beta_i + \sum_j \beta_{ij} Log(X_{jt}) > 0, \quad (5)$$

where $\eta_{it}$is the output elasticity of an input i at time t. Thus, for each of the energy series coal, natural gas, hydropower and solar energy, the output elasticities are calculated, respectively, as follows:

$$\begin{aligned} \eta_{Ct} &= \frac{\partial Log(Q_t)}{\partial Log(C_{ct})} \\ &= \beta_C + \beta_{CG} Log(G_t) + \beta_{CH} Log(H_t) + \beta_{CS} Log(S_t) \\ &\quad + 2\beta_{CC} Log(C_t), \end{aligned} \quad (6)$$

$$\begin{aligned} \eta_{Gt} &= \frac{\partial Log(Q_t)}{\partial Log(G_{gt})} \\ &= \beta_G + \beta_{CG} Log(C_t) + \beta_{GH} Log(H_t) + \beta_{GS} Log(S_t) \\ &\quad + 2\beta_{GG} Log(G_t), \end{aligned} \quad (7)$$

$$\begin{aligned} \eta_{Ht} &= \frac{\partial Log(Q_t)}{\partial Log(H_{ht})} \\ &= \beta_H + \beta_{CH} Log(C_t) + \beta_{GH} Log(G_t) + \beta_{HS} Log(S_t) \\ &\quad + 2\beta_{HH} Log(H_t), \end{aligned} \quad (8)$$

$$\begin{aligned} \eta_{St} &= \frac{\partial Log(Q_t)}{\partial Log(S_{st})} \\ &= \beta_S + \beta_{CS} Log(C_t) + \beta_{GS} Log(G_t) + \beta_{HS} Log(H_t) \\ &\quad + 2\beta_{SS} Log(S_t). \end{aligned} \quad (9)$$

The calculated output elasticity estimates are then used to generate the substitution elasticity estimates between two energy pairs using the following formula:

$$\beta_{ij} = \left[1 + 2\left[\beta_{ij} - \beta_{ii}(\eta_j/\eta_i) - \beta_{jj}(\eta_i/\eta_j)\right] \cdot \left[\eta_i + \eta_j\right]^{-1}\right]^{-1}, \quad (i \neq j; = C, G, H, S). \quad (10)$$

Equation (10) gives the symmetric substitution elasticity between two energy pairs, that is the elasticity estimates are symmetry, i.e. ($\beta_{ij} = \beta_{ji}$). Thus, the substitution elasticity estimate between the respective energy pairs is obtained as follows:

$$\text{Coal and Natural Gas}: \sigma_{CG} = [1 + 2[\beta_{CG} - \beta_{CC}(\eta_G/\eta_C) - \beta_{GG}(\eta_C/\eta_G)] * [\eta_C + \eta_G]^{-1}]^{-1}, \quad (11)$$

$$\textit{Coal and Hydropower}: \sigma_{CH} = [1 + 2[\beta_{CH} - \beta_{CC}(\eta_H/\eta_C) - \beta_{HH}(\eta_C/\eta_H)] * [\eta_C + \eta_H]^{-1}]^{-1}, \quad (12)$$

$$\text{Coal and Solar Energy}: \sigma_{CS} = [1 + 2[\beta_{CS} - \beta_{CC}(\eta_S/\eta_C) - \beta_{SS}(\eta_C/\eta_S)] * [\eta_C + \eta_S]^{-1}]^{-1}, \quad (13)$$

$$\text{Gas and Hydropower}: \sigma_{GH} = [1 + 2[\beta_{GH} - \beta_{GG}(\eta_H/\eta_G) - \beta_{HH}(\eta_G/\eta_H)] * [\eta_G + \eta_H]^{-1}]^{-1}, \quad (14)$$

$$\text{Gas and Solar Energy}: \sigma_{GS} = [1 + 2[\beta_{GS} - \beta_{GG}(\eta_S/\eta_G) - \beta_{SS}(\eta_G/\eta_S)] * [\eta_G + \eta_S]^{-1}]^{-1}, \quad (15)$$

$$\text{Hydro and Solar Energy}: \sigma_{HS} = [1 + 2[\beta_{HS} - \alpha_{HH}(\eta_S/\eta_H) - \beta_{SS}(\eta_H/\eta_S)] * [\eta_H + \eta_S]^{-1}]^{-1}, \quad (16)$$

In Equations (11) to (16), the decision rule is that positive estimates imply substitutability while negative estimates suggest complementarity between two energy inputs.

3.2 Data

The dataset entails annual time series data of Italy's real gross domestic product (GDP), gross fixed capital formation (GFCF), labour, coal, natural gas, hydropower and solar energy consumption for the period 1989 to 2018. Data on real GDP and GFCF series were generated from the World Bank Group (2020)' *World Development Indicators* at constant 2010US$ to control for inflationary trend. The labour series, calculated as a number of persons employed (in thousand per persons), were obtained from The Conference Board (2020). The British Petroleum (2020)'s *Statistical Review of World Energy* provided the data on the energy series and are stated in million tonnes of oil equivalent (MTOE). In order to prevent double counting and data overstatement, we have only included only the volume of coal, natural gas, hydropower and solar energy used in the generation of electricity for Italy.

3.3 Estimation technique: Ridge regression

Translog models involving squared polynomial terms such as the one specified in Equation (4) are susceptible to severe multicollinearity problem can cause a serious problem in model estimation. In cases of extreme multicollinearity, model estimation is severely marred by deflated t-statistics due to exaggeration of the standard errors, thereby leading to not only non-significant probability values but also misleading parameter estimates. Under this circumstance, the adoption of the usual ordinary least squares estimates is no longer consistent.

Thus, we commence the analysis by first testing for the extent of multicollinearity in the model by examining the variance inflation factors (VIFs) of the regressors and the condition number of the eigenvalues of correlation of the variables. The outputs of the multicollinearity analysis, available in Table 1, show that not only is the variance inflation factors for each of the regressors significantly exceed 10 but also the condition number of the eigenvalues of correlation of some variables exceeds 100 thereby establishing the existence of an extreme multicollinearity problem and rendering the application of the OLS technique unsuitable in this circumstance.

To remedy this problem, Hoerl (1962) developed a special regression procedure known as the ridge regression procedure. The procedure is a slight modification of the ordinary least squares regression estimate with the introduction of a ridge parameter called a biasing constant (p). Therefore, the original matrix for the OLS coefficient estimate $\beta_{\mathbf{OLS}} = (\mathbf{X}'\mathbf{X})^{-\mathbf{1}}\mathbf{X}'\mathbf{Y}$is modified into a ridge specification as $\beta_{\mathbf{R}} = (\mathbf{X}'\mathbf{X}+p\mathbf{I})^{-\mathbf{1}}\mathbf{X}'\mathbf{Y}$where p is the penalty parameter with a range of values from zero to unity and $\mathbf{I}$is an identity matrix. The ordinary least squares estimates correspond to the ridge regression estimates with a penalty parameter of zero. The target is to select an optimum p value for which the mean squared error of the ordinary least squares estimator is more than ridge regression estimator, implies a lesser bias in the estimation.

To achieve this, Hoerl and Kennard (1970) proposed the use of the ridge trace as a systematic way of determining the optimum value of p. The ridge trace plots the ridge regression parameters as a function of p and the value of p for which the regression parameters stabilize is selected as the optimum. A penalty parameter of 0.874 has been chosen as the optimum value of p based on the ridge trace plot shown in Figure 1 as the parameter estimates seem to stabilise around this value.

Furthermore, Table 2 is also used to show the effect of the ridge regression procedure on the variance inflation factors. As can be seen, varying the penalty parameters reduces the variance inflation factors. The zero value of the penalty parameter corresponds to the variance inflation factors for the OLS estimates which are very large, but gradual increment in the penalty parameter continues to decrease the variance inflation

Table 1. Least squares multicollinearity test result.

Independent Variable	Variance Inflation Factors	Eigenvalues	Condition Number
Log (K)	50.929	10.292	1.0000
Log (L)	71.2276	3.32031	3.1000
Log (C)	9949.142	1.431199	7.1900
Log (G)	23,600.59	0.713818	14.420
Log (H)	8229.186	0.120297	85.560
Log (S)	18,418.81	0.089578	114.90
Log (C)*Log (G)	31,826.77	0.026957	381.83
Log (C)*Log (H)	9973.269	0.00204	5046.6
Log (C)*Log (S)	3292.604	0.001658	6206.39
Log (G)*Log (H)	7526.564	0.000485	21,232.23
Log (G)*Log (S)	5169.585	0.000403	25,570.43
Log (H)*Log (S)	5110.836	0.000162	63,536.7
Log (C)*Log (C)	15,464.56	0.000081	126,515.81
Log (G)*Log (G)	17,655.13	0.00006	171,827.6
Log (H)*Log (H)	7396.401	0.000018	579,516.26
Log (S)*Log (S)	20.1889	0.000015	685,464.84

Multicollinearity is severe as the variance inflation factors exceed 10 and some condition numbers of the eigenvalues of correlations of some variables are more than 100.

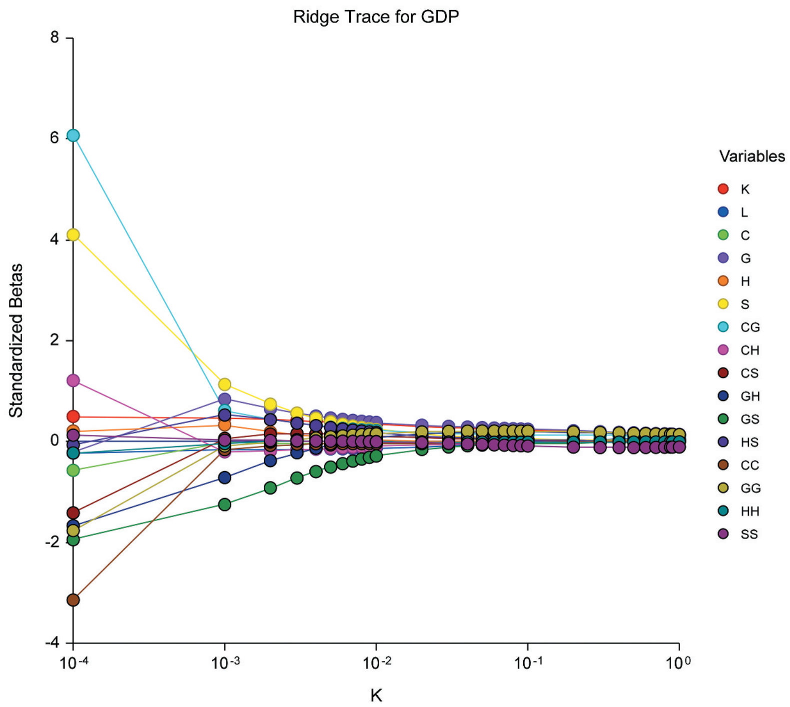

Figure 1. The ridge trace plot for the selection of optimum penalty parameter.

factors until the value of 0.874 where the variance inflation factors for all variables have come under 10 and multicollinearity effectively addressed.

4. Result and discussion

Following the determination of the optimum *p* value, the results of the ridge regression procedure are presented in Table 3 which also displays the variance inflation factors along with the parameter estimates. We now present the results of the parameter estimates of the ridge regression procedure in Table 3. The table displays the values of the variance inflation factor for each of the parameters and as can be seen these values are below 10 thereby establishing the fact that the problem of multicollinearity has been effectively solved. In addition to this, the f-ratio is significant at 1% level with an R-squared of 83.4% indicating a strong goodness of fit and explanatory power of the parameters in the model. This is also reflected in the significance levels of the parameters with the majority being significant at the 1% level.

From the parameter estimates of the ridge regression available in Table 3, the output elasticities of each of the energy inputs are obtained using Equations (6), (7), (8) and (9), respectively, for coal, natural gas, hydropower and solar energy and the results are presented in Table 4. The result shows that the average output elasticities, over the sample period, for all energy series are positive thus satisfying the positivity condition imposed by Equation (3). It is also noted that both fossil fuels of coal and natural gas have higher output elasticities than the renewable energy sources of hydropower and solar energy considered in the study. This is probably due to the fact that the non-renewable sources currently dominate Italy electricity sector. Among the four fuels considered in this study, the non-renewable energy sources of coal and natural gas accounted for more than 70% of the fuel mix over the course of the sample period. It is also noted that solar energy has the least output elasticity amongst all the energy input considered, a possible reflection of the fact that it has the least share in the electricity generation fuel mix, about 2.5%, over the course of the sample period.

From the estimates of the output of elasticity, the estimates of the substitution elasticities between the energy pairs are calculated and the resulted are presented in Table 5. The results show that all energy pairs considered are substitutes. The highest substitutability estimate occurred between hydropower and solar energy, followed by between coal and solar energy and then between gas and solar energy. This implies that the highest substitution estimate occurs between solar energy and each of the energy input.

The plausible logic for this outcome is seen in her economic strategic drive for increase and sustainable energy as the energy inputs show a positive relationship with output (GDP). This result further gives credence to the energy-induced growth hypothesis, which is indicative for Italy economy given that her energy mix is currently driven by fossil fuel. However,

Table 2. Effect of penalty parameter (*p*) on the variance inflation factor.

p	Log (K)	Log (L)	Log (C)	Log (G)	Log (H)	Log (S)	Log (C)*Log G)	Log (C)*Log H)	Log (C)*Log (S)
0.000	50.903	71.228	9949.142	23,600.590	8229.186	18,418.808	31,826.770	9973.269	3292.604
0.001	23.1341	13.9012	64.1715	56.8151	60.0758	90.8676	67.581	56.488	125.074
0.002	20.5174	12.0711	23.3704	21.5744	21.631	33.4558	29.117	21.821	55.278
0.003	18.8021	11.2322	12.7099	12.1443	11.6209	17.8725	17.245	12.400	32.743
0.004	17.4512	10.6485	8.2021	8.1812	7.4148	11.3317	11.684	8.212	22.0226
0.005	16.3099	10.1757	5.8378	6.1136	5.2221	7.9419	8.5636	5.9293	15.9686
0.006	15.3125	9.7673	4.4323	4.8837	3.9256	5.9464	6.6167	4.5329	12.1832
0.007	14.4245	9.4029	3.5241	4.0836	3.0922	4.6658	5.3114	3.6113	9.6463
….	….	….	….	….	….	….	….	….	….
….	….	….	….	….	….	….	….	….	….
0.874	0.0943	0.1053	0.0748	0.0465	0.1064	0.0377	0.0189	0.0703	0.0415

(contd.)

p	Log (G)*Log (H)	Log (G)*Log (S)	Log (H)*Log (S)	Log (C)*Log (C)	Log (G)*Log (G)	Log (H)*Log (H)	Log (S)*Log (S)
0.000	7526.564	5169.585	5110.836	15,464.556	17,655.128	7396.401	20.189
0.001	128.542	135.511	150.378	74.820	91.185	63.037	9.046
0.002	51.001	71.698	68.257	31.842	35.048	20.989	8.460
0.003	28.425	45.135	39.894	18.544	19.491	10.709	8.110
0.004	18.545	31.2958	26.3987	12.3984	12.8544	6.6194	7.8478
0.005	13.2752	23.1281	18.8593	8.996	9.3642	4.5741	7.6299
0.006	10.1084	17.8882	14.2014	6.8988	7.2797	3.4018	7.4374
0.007	8.0455	14.3165	11.115	5.5087	5.9223	2.6658	7.2618
….	….	….	….	….	….	….	….
….	….	….	….	….	….	….	….
0.874	0.0408	0.0501	0.0384	0.0753	0.0417	0.106	0.133

The first row where *p* is the OLS's Variance Inflation Factors. The last row where *p* is 0.874 gives the optimal VIF values for the ridge regression where the problem of severe multicollinearity has been corrected.

Table 3. Ridge regression parameter estimates.

Independent Variable	Parameter Estimates	t-Stat	Variance Inflation Factor
Constant	23.985		
Log (K)	0.092a***	4.023	0.094
Log (L)	0.094*	1.661	0.105
Log (C)	0.008	0.992	0.075
Log (G)	0.021***	6.101	0.047
Log (H)	0.003	0.140	0.106
Log (S)	0.0005	0.978	0.038
Log (C)*Log (G)	0.0027***	6.819	0.019
Log (C)*Log (H)	0.0014	0.723	0.070
Log (C)*Log (S)	0.00008	0.557	0.042
Log (G)*Log (H)	0.0045***	5.663	0.041
Log (G)*Log (S)	−0.00005	−0.342	0.050
Log (H)*Log (S)	0.0001	0.755	0.038
Log (C)*Log (C)	0.0012	0.965	0.075
Log (G)*Log (G)	0.0024***	6.184	0.042
Log (H)*Log (H)	−0.0005	−0.197	0.106
Log (S)*Log (S)	−0.00103***	−2.685	0.133
R Squared: 0.834			
F-ratio: 4.0834 (0.007)			

***implies 1% level of significance, * implies 10% level of significance.
Figures in parenthesis are probability values.

the current energy-induced growth is not sustainable as it is depleting the quality of the environment from plants with a combustion engine that emits carbon dioxide emissions. Additionally, the United States Energy Information Administration Agency (Energy Information Administration 2018) alluded to the pivotal role of energy in driving economic growth. The unanswered puzzle of alternative, clean and sustainable energy sources still applies to Italy.

Interestingly, our empirical results reveal that both hydropower and solar energy can substitute other non-renewable energy sources like (coal and natural gas energy). The possible intuition for this is due to the clean nature and its environmental advantage derived from the consumption of solar and hydropower energy. This outcome resonates with the study of Gyamfi et al. (2020) for emerging (E7) countries, where hydropower energy significantly contributes to E7 economies. Furthermore, in our empirical analysis, it is seen that the reported elasticity of output estimates and elasticity of substitution estimates are insightful, where we see a substantial degree of sustainability among the different sources of energy investigated. Interestingly, renewable energy from hydropower and solar energy shows strong evidence to substitute fossil-fuel energy over the examined period. It is clear that the substitutability of solar energy is greater than hydropower energy in Italy. For instance, the substitutability between natural gas

Table 4. Elasticity of output estimates.

Year	$\eta\varepsilon_C$	$\eta\varepsilon G$	$\eta\varepsilon H$	$\eta\varepsilon S$
1989	0.030	0.064	0.014	0.014
1990	0.031	0.064	0.014	0.012
1991	0.031	0.065	0.014	0.012
1992	0.030	0.064	0.013	0.011
1993	0.030	0.064	0.013	0.010
1994	0.030	0.065	0.014	0.010
1995	0.031	0.065	0.015	0.010
1996	0.031	0.066	0.015	0.010
1997	0.031	0.066	0.016	0.010
1998	0.032	0.067	0.017	0.010
1999	0.033	0.069	0.017	0.009
2000	0.033	0.070	0.018	0.009
2001	0.034	0.071	0.019	0.009
2002	0.034	0.070	0.019	0.009
2003	0.034	0.071	0.020	0.009
2004	0.035	0.072	0.020	0.008
2005	0.035	0.072	0.021	0.008
2006	0.036	0.072	0.021	0.008
2007	0.036	0.072	0.022	0.008
2008	0.036	0.073	0.022	0.004
2009	0.036	0.073	0.021	0.002
2010	0.036	0.073	0.021	0.000
2011	0.036	0.073	0.021	−0.004
2012	0.036	0.072	0.021	−0.005
2013	0.035	0.072	0.020	−0.005
2014	0.035	0.071	0.019	−0.005
2015	0.035	0.071	0.020	−0.005
2016	0.035	0.071	0.021	−0.005
2017	0.035	0.070	0.021	−0.006
2018	0.035	0.071	0.020	−0.006
Average	0.034	0.069	0.018	0.005

Table 5. Elasticity of substitution estimates.

Year	σ_{CG}	σ_{GH}	σ_{CS}	σ_{GH}	σ_{GS}	σ_{HS}
1989	1.018	0.913	1.005	0.853	0.902	0.891
1990	1.017	0.918	0.978	0.859	0.888	0.883
1991	1.017	0.913	0.981	0.855	0.883	0.879
1992	1.018	0.911	0.965	0.852	0.867	0.868
1993	1.018	0.912	0.955	0.853	0.861	0.864
1994	1.018	0.914	0.953	0.855	0.861	0.864
1995	1.017	0.919	0.936	0.861	0.855	0.861
1996	1.017	0.920	0.932	0.862	0.853	0.859
1997	1.017	0.924	0.922	0.867	0.850	0.857
1998	1.016	0.927	0.914	0.872	0.847	0.855
1999	1.016	0.931	0.906	0.876	0.845	0.853
2000	1.016	0.934	0.899	0.880	0.842	0.851
2001	1.015	0.935	0.896	0.882	0.840	0.849
2002	1.015	0.935	0.891	0.882	0.837	0.846
2003	1.015	0.938	0.880	0.885	0.831	0.841
2004	1.015	0.939	0.870	0.888	0.823	0.834
2005	1.015	0.942	0.863	0.890	0.820	0.830
2006	1.014	0.942	0.857	0.891	0.814	0.825
2007	1.014	0.944	0.849	0.893	0.809	0.820
2008	1.014	0.943	0.724	0.893	0.695	0.710
2009	1.014	0.941	0.488	0.890	0.474	0.484
2010	1.014	0.942	−0.184	0.891	−0.186	−0.184
2011	1.014	0.942	2.591	0.891	2.256	2.833
2012	1.014	0.941	1.973	0.890	1.773	2.179
2013	1.014	0.938	1.914	0.886	1.713	2.156
2014	1.015	0.936	1.912	0.883	1.702	2.190
2015	1.014	0.939	1.871	0.886	1.682	2.107
2016	1.015	0.940	1.877	0.888	1.692	2.098
2017	1.015	0.942	1.816	0.889	1.649	2.020
2018	1.015	0.940	1.856	0.888	1.673	2.082
Average	1.016	0.932	1.143	0.878	1.042	1.164

and solar is higher than between natural gas and hydro-energy source. This suggests the need for more investment into solar energy plants and photovoltaic energy in the country to drive clean energy targets and environmental sustainability. This position aligns with the findings of Serletis et al. (2011) for OECD countries.

The results of the possibility of substitutability among these highlighted variables have its environmental implication in Italy's economy energy mix. This assertion is timely and worthy of further exploration by stakeholders, energy experts, practitioners who design and formulate energy strategies in Italy. As outcomes offer policy insights for the need for more alternative and clean energy sources is encouraged. Given that the current county's (energy) electrification is seen as a key driver for sustainable growth due to its ability to drive other sectors of the economy like industrial layout and small and medium enterprise. However, there is a trade-off for the quality of the environment as non-renewable energy drives by environmental pollution.

Given the aforementioned dynamics of Italy energy sector and her energy portfolio mix, it is imperative for fuel interchange to cleaner electrification sources. Italy's is reputed as the fourth largest energy consumer in the European blocs, where the bulk of her energy consumption comprises petroleum and natural gas sources. Interestingly, the government of Italy has had deliberate strides to increase her share of renewable energy consumption from hydroelectricity. For instance, in 2005 hydroelectricity consumption increased from a record of less than 2% to approximately 10% over a decade. Furthermore, commitment of the government includes reinforcing the fourth national efficiency action plans (NEEAP) to foster national energy innovation, efficiency and energy security without trade-off for quality of the environment in the economic growth trajectory.

5. Conclusion and policy implications

United Nations Sustainable Development Goals (UN-SDGs) that address pertinent issues across the globe by 2030 motivate this country-specific study. More specifically this study focuses on access to clean and responsible energy interfuel consumption (SDGs-7, 12) and climate change mitigation (SDG-13), on the need for substituting fossil-fuel base energy sources for renewable energy mix for the case of Italy for annual frequency data from1989-2018. This study thereby explores the possibility of substitutability of coal, natural gas energy option for hydropower, and solar energy sources using a translog production function framework. To this end, we employ the use of ridge regression procedure and circumvent for possible multicollinearity among the investigated variable parameter.

This study also ameliorates for omitted variable bias by the inclusion of renewable energy sources (hydroenergy and solar energy sources) to model framework. Empirical evidence gives credence to the possibility of substitution between non-renewable energy sources and renewable energy sources. Furthermore, we observe that both hydropower and solar energy are found to be substitutable for fossil fuels, solar energy is found to provide more substitutability than hydropower. Interestingly, from the ridge regression, while most of the variables are statistically insignificant under consideration of their isolated forms, they became statistically significant when each variable interacts with one of the other variables in the model. Specifically, the interaction of coal energy with natural gas and the interaction of natural gas with hydropower has a positive and significant impact on economic growth.

From a policy perspective, our analysis for Italy has insightful outcomes for policymakers and stakeholders in terms of her energy mix. We observe a significant relationship between growth drivers (capita and labour and energy sources both renewable and non-renewable energy). This study thus validates the energy-induced growth hypothesis. However, the concern for policymakers is that economy driven by fossil-fuel energy sources, which are dirty and not environmentally sustainable as seen in Italy where over 70% of her electrification (energy) is driven from fossil-fuel sources. These non-renewable forms of energy produce carbon dioxide emissions. Thus, it is imperative for Italy to adopt the expansion of both solar and hydropower generation plants to avoid pollutant emissions in the economy. This also establishes the need for a paradigm shift in Italy's energy portfolio mix from non-renewable to renewables, which also includes the construction of clean energy infrastructures. For instance, given that hydropower and photovoltaic (solar) energy shows substitutability for fossil fuel. This necessitates the need to increase government increasing energy investment (renewables) on a gradual basis not to jeopardize her economic growth, which is currently based on fossil-fuel sources.

Conclusively, this study suggests there is a need for a gradual transition from conventional energy sources (fossil-fuel base) to renewable (clean) energy sources in Italy for electricity generation. These clean energy sources are known to be more environmentally and ecosystem friendly especially in an era where there are serious concerns for green or clean energy. The Italian governments, both central and regional, have made several efforts to improve the share of renewable energy sources, not only in electricity generation but also in the overall energy profile of the country. Such initiatives include the feed-in tariff for all renewable energy producers, the feed-in premium for electricity produced by photovoltaic plants, and the award of green certificates to the producers of renewable energy resources. However, these initiatives are mostly targeted to encourage and promote the use of renewable energy resources. For maximum results, efforts should also be made in regards to the discouragement of fossil fuels through the introduction and implementation of deterrent policies in the form of imposition of carbon tax to the producers of fossil fuels. This will serve the dual purpose of providing additional source of revenue to the government and importantly, a source of disincentive to produce more fossil fuels. This will go a long way in complementing the incentive programs and policies on renewable energy and help in the process of increasing the share of renewable energy not just in electricity generation but in the overall energy profile of the country.

Disclosure statement

No potential conflict of interest was reported by the authors.

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