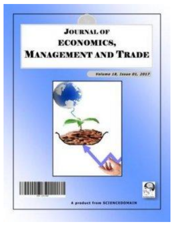

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Growth, Electric Power Consumption Externalities and Patterns of Localisation of Emissions

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Authors' contributions

This work was carried out in collaboration between all authors. Author SK designed the study, authors CA and TM performed the statistical analysis and wrote the first draft of the manuscript. Author SK wrote the protocol. Authors SK, CA and TM managed the analyses of the study. Author TM managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Aims: To elaborate on dimensions of Electric Consumption and patterns of localization.
Study Design: Investigate spatial, economic, electric and environmental spillovers.
Place and Duration of Study: Chicago, USA. Department of Finance, between September 2017 and September 2018.
Methodology: This paper examines the causality relationship between the electric power consumption externalities and economic growth in 89 countries using data from the period 1990 to 2014. The spatial econometric approach is employed to identify neighbouring relationships.
Results: Results with estimated spatial, economic and environmental weights present a potential comparison among the effects of different types of spillovers relative to the geographical clusters. In other words, they examine the role of externalities across countries in the process of energy consumption by estimating the empirical counterpart models.
Conclusion: The effect of regional externalities of energy consumption pattern on GDP growth is verified through spatial, economic and environmental channels.

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Keywords: Energy consumption; economic growth; spatial econometrics; patterns of spillovers.

1. INTRODUCTION

Climate change and global warming are the greatest causes of environmental pollution. Carbon dioxide (CO_2) is the main source of the greenhouse impact because of the consumption of fossil fuels. The last three decades the CO_2 emissions have almost doubled their ratio from 17,8Gt in 1980 to 32,1Gt in 2015 according to International Energy Agency (IEA). The threat of increased CO_2 emissions is an imperative issue, which concerns the countries' governments universally. World Bank (Fig. 1) verifies that the largest countries have the biggest energy consumption per capita in 2017. Furthermore, exhaustible natural resources put in danger the future of the energy market and the turn in renewable energy sources is incumbent in the following years. In 1997, the international treaty "Kyoto Protocol" was signed by 37 industrialised countries and the European Community with specified national emissions targets for each country to deteriorate the greenhouse gases. Fig. 2 depicts the top 20 countries in the highest electricity generation in 2014. As expected, this specific concern became subject of intense research in economic literature and show that increased CO_2 emissions are related to the global rapid industrialisation to achieve economic growth. However, results show that there is an improvement in energy efficiency for fuel and electricity use in all sectors; energy intensity is not an appropriate proxy for energy efficiency [1].

Generally speaking, the relationship between electricity consumption and economic growth can be categorised into four testable causal hypotheses: 1) Growth hypothesis assumes that electricity is a necessary factor of economic growth. 2) Conservation hypothesis postulates a causality running from economic growth to electricity consumption. Yildirim & Aslan [2] used data for 17 highly developed OECD countries, and Narayan [3] uncovered the conservative hypothesis for 90 developing countries in a set of 135 countries during 1984-2010. 3) Feedback hypothesis emphasises the interdependence between electricity consumption and economic growth. 4)

Neutrality hypothesis assumes no causal link. Karanfil and Li [4] considered 160 countries for 1980-2010 and found no evidence for growth hypothesis in any one income level. In the long run, the majority of samples provide feedback hypothesis, and in short run the conservation and the neutrality hypothesis are implied depending on the region group. Omri [5] surveyed 48 papers related to Energy Growth (EG) and Energy Consumption (EC) nexus and claimed that 29% support growth hypothesis, 27% feedback hypothesis, 23% conservation hypothesis and 21% neutrality hypothesis. Payne [6] categorised 99 papers into these four hypotheses and concluded that there is no homogeneity in a group of countries due to various factors.

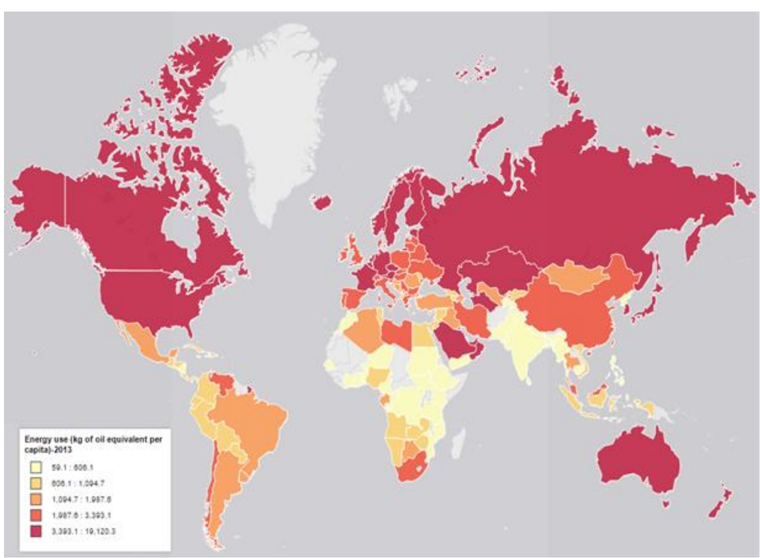

Fig. 1. World energy consumption per capita based on 2013

To make proper policy suggestions, it is necessary and essential to clarify the relationship and the direction of causality between them. The purpose of the present paper is to complement and extend the previous literature that has investigated the causal relationship between economic growth and electricity consumption, which has so far provided conflicting results. To do so, the cross-sectional dimension is added to increase the power of various tests in a multivariate framework, which addresses the problem of omitted variable bias and accounts for different characteristics across countries. A spatial econometric framework is employed to measure the above dimensions.

As a result of this, many researchers published a large number of empirical studies to explain the causal relationship between economic growth and energy consumption. However, the results varied due to different variables, countries and econometric methodologies. More specifically, several studies proposed the existence of an inverse U-shaped relationship between economic activity and the environmental quality, the well-known Environment Kuznets Curve (EKC) as described at Azam and Khan [7]. The EKC proposed that economic development at the beginning leads to a decline in the environment, but after a specific point of economic growth, a society begins to enhance its relationship with the environment and levels of environmental degradation mitigates. The existence of any direction of this relationship plays a significant role for countries because it can demonstrate policies for the CO_2 emissions and development of the economy depending on the stage and the characteristics of it.

The purpose of this paper is to examine the relationship and the causality between the energy consumption, CO_2 emissions and economic growth in 89 countries categorised by region and by income criteria for the 1990 - 2014 period by using spatial econometric model. The decision to estimate our empirical model using a spatial econometric approach is supported by the results of several statistical tests on the presence of either a spatially lagged dependent variable and/or spatially lagged residuals. For instance, we used several Lagrange multiplier tests proposed by Baltagi et al. (2003) and Baltagi and Long (2008). The results of these tests confirm the presence of both spatial effects.

The main contribution of this paper is to elaborate on the dimensions of Electric Power Consumption (EPC) and the patterns of localisation. More specifically, consumption patterns are decomposed among of geographical and economic effects. The organisational structure of the paper is divided into four sections: Section 2 summarises the theoretical and empirical literature on economic growth models. Section 3 provides the data and the methodology. Section 4 discusses the empirical results, and Section 5 provides the conclusions and policy implications.

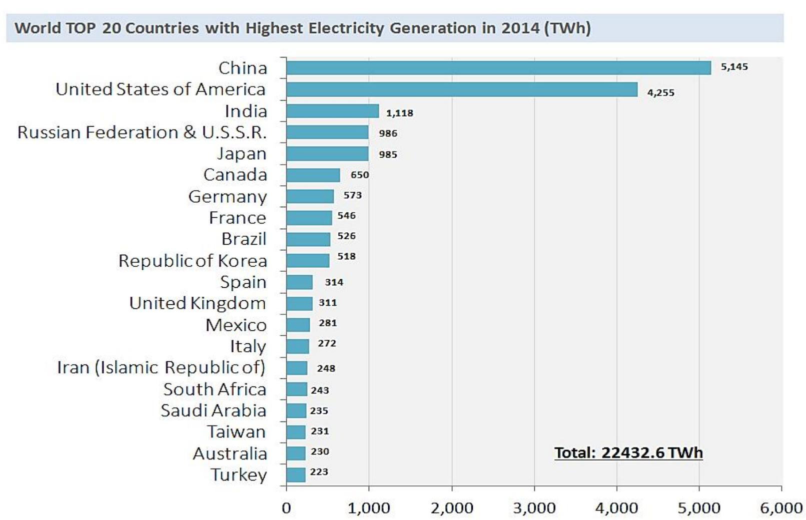

Fig. 2. World top 20 countries with the highest electricity generation in 2014

2. ECONOMIC GROWTH MODELS THROUGH ENERGY CONSUMPTION WITH RESPECT TO GEOGRAPHICAL AND ECONOMIC EFFECTS

The theoretical literature most closely related to our work lies within the relationship and the causality between energy consumption (EC) and economic growth (EG). Fuinhas and Marques [8] suggested bidirectional causality for PIGST countries (Portugal, Italy, Greece, Spain, Turkey) for 1965-2009 between EG and EC in both short run and long run applying ARDL bounds. Dergiades et al. [9] pointed out the significant unidirectional both linear and non-linear causality running from EC to EG in Greece during 1960-2008 using time series data. Esseghir and Khuni [10], Mahadevan and Asafu-Adjaye [11], Ciaretta and Zarraga (2010), Omri [12] applied vector error correction model (VECM). Mahadevan and Asafu-Adjaye [11] used data for 20 net energy importers and exporters for 1971-2002 and found EC causes EG in short run in developing countries. Moreover, Esseghir and Khuni [10] revealed bidirectional causality for 38 UFM (Unions for the Mediterranean) in short and long run in developed and developing countries from 1980 to 2010.

Many researchers have intensively analysed the nexus economic growth (EG), environment (EN), energy consumption (EC) reporting ambiguous results. The majority of their studies dealt with the referred nexus in a bivariate framework. Lütkepohl [13] and Zachariadis [14] referred to the possibility of omitted variable bias due to bivariate analysis. In addition, Zachariadis [14] applied bivariate energy-economy causality tests for G-7 countries concluding that large samples and multivariate models are preferred to provide reliable and consistent results. Following that, we have considered significant to involve in our study variables as urbanisation, CO_2 emissions, urban population, energy investments with private participation and Foreign Direct Investments (FDI).

Taking into account income level as economic and geographical criteria for causal difference Huang et al. [15], Ozturk et al. [16], Kahsai et al. [17] focused on it. Huang et al. [15] revealed no causal relationship for 82 countries between the variables for low-income level, positive unidirectional causal relationship for below middle and upper-middle income level from EG to EC but the negative single direction for high-income level during 1970-2002. Ozturk et al. [16] found evidence based on 51 countries over 1971-2005 that there is long-run unidirectional causality from GDP to EC for low-income and bidirectional causality for middle-income but no strong relation for all income groups. Kahsai et al. [17] highlight the differentiation of income levels for 44 Sub-Saharan Africa countries using country-level time series data during 1980-2007, proving the existence of strong causality in both directions in the long run and no causality in short-run in low-income level.

Narayan and Narayan [18], and Azam and Khan [7] examined the Environmental Kuznet's Curve (EKC) based on the EC-EG relationship. Back in 2010, Pao and Tsai tried to find the outcomes on the long run and the short run equilibrium, and at the same time, they examined BRIC countries for 1971-2005 (except Russia for 1990-2005). Narayan and Narayan [18] examined the EKC for 43 developing countries based on the short and run-long income elasticity in five regions during 1980-2004. They revealed considerable variation and the long-run income provided less to CO_2 emissions for 35 % of the countries. Azam and Khan (2016) used time-series data for 1975-2014 in four countries (Tanzania, Guatemala, China and the USA) which represent each income level (low, lower middle, upper middle, high). Especially, they examined the long and short run elasticity and confirmed the validity of EKC hypothesis for low and lower-middle-income level.

Increasingly studies examined the relationships between CO_2 emissions, energy consumption and economic growth. Chang [19] found a bidirectional causality running from GDP to CO_2 emissions and electricity consumption in China for 1981-2006. Wang et al. [20] used panel data for 28 provinces in China for 1995-2007. They proved bidirectional causality between CO_2 emissions and energy consumption together with energy consumption and economic growth suggesting the existence of a U-shaped curve between economic growth and CO_2 emissions. Wei et al. (2015) used linear and nonlinear tests in China providing evidence of unidirectional causality from CO_2 emissions to GDP and bi-directional causality between energy consumption and CO_2 emissions for both tests during 1978-2012. Soytas & Sari (2007) concluded that carbon emissions cause energy consumption in Turkey over 1960-2000. Yang et al. (2011) stated also that there is a strong bi-directional causality between output, energy use and emissions in Russia in 1990-2007 while output exhibits a negative significant impact in emissions and does not support EKC hypothesis. Filis et al. (2017) examined 106 countries categorised by income level using PVAR over the period 1971-2011. They found the existence of bidirectional causality between economic growth and energy consumption. On the contrary, Fillis claimed that there was no evidence that renewable energy consumption is conducive to economic growth and that developed countries may actually grow-out of environmental pollution.

The inclusion of additional variables to the tripartite nexus presents an interesting subject for discussion, especially regarding economic and environmental development. Hossain [21] added trade openness and urbanisation for newly industrialised countries (NIC) from 1971-2007. He showed that when EC increases, CO_2 emissions also are increasing, polluting the environment. Narayan and Smyth [22] included capital formation in G7 countries and revealed that capital formation and EC caused real GDP in the long run. Cheng & Zhang [23] included capital and urban population and revealed unidirectional causality running from GDP to energy consumption and from energy consumption to carbon emissions in the long run in China during 1960-2007. Narayan and Smyth [22] used annual time series data for Middle East countries for the period 1974-2002 including exports. According to Poumanyvong & Kaneko [24], Li & Lin [25] applying the STIRPAT model revealed that urbanisation affects energy consumption and CO_2 depending on the income level of each country. Urbanisation decreased EC in low and below income category with significant results. Poumanyvong & Kaneko [24] used a panel dataset of 99 countries over the period 1975-2005 while Li & Lin [25] introduced a panel dataset of 73 countries during 1971-2010.

The objective of this paper is to investigate the causality relationship between the electric power consumption externalities and economic growth trying to discover patterns of localisation of CO_2 emissions.

3. DATA AND SPATIAL ECONOMETRIC MODELLING

Our data source is World Bank's database (2016) and includes 89 countries according to data availability for the 1990-2014 period. All variables are employed with their natural logarithms form to reduce heteroscedasticity. This study examines these countries under four income groups and four regions (Europe, Australia, North & South America, and Asia). According to the World Bank country classification[1], these 89 countries are classified as low-income countries (Nepal), lower middle income countries (Armenia, Bangladesh, Bolivia, Georgia, India, Indonesia, Moldova, Pakistan, Philippines, Syrian Arab Republic, Ukraine, Uzbekistan, Vietnam, Yemen Rep.), upper middle income countries (Albania, Azerbaijan, Belarus, Bosnia and Herzegovina, Brazil, Bulgaria, China, Colombia, Costa Rica, Ecuador, Iran Islamic Rep., Iraq, Jamaica, Jordan, Kazakhstan, Lebanon, FYROM, Malaysia, Mexico, Mongolia, Panama Paraguay, Peru, Romania, Thailand, Turkey) and high income (Argentina, Australia, Austria, Bahrain, Belgium, Canada, Chile, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hong Kong SAR, Hungary, Iceland, Ireland, Israel, Italy, Japan, Korea Rep., Kuwait, Latvia, Lithuania, Luxembourg, Malta, Netherlands, New Zealand, Norway, Poland, Portugal, Qatar, Russian Federation, Saudi Arabia, Singapore, Slovak Republic, Slovenia, Spain, Sweden, Switzerland, United Arab Emirates, United Kingdom, United States, Uruguay and Venezuela RB). Table 1 provide descriptive statistics of the variables employed in each estimation method, while Table 3 and 4 show level estimations and include all regions and countries to study both local and country neighbouring effects.

In Table 2 we use several estimation methods for the model to check robustness and to see if there is a different sign or magnitude depending on each estimation method.

In this paper, we explicitly address the effect of regional externalities of energy consumption pattern on the GDP growth. The reasoning behind such externalities is basically the consumption or production patterns between countries caused by energy consumption as well as emissions. The externalities compensate the mechanisms of decreasing returns to scale to capital accumulation within each economy. Concretely, final energy consumption (captured

[1] https://datahelpdesk.worldbank.org/knowledgebase/articles/906519-world-bank-country-and-lending-groups

Table 1. Summary statistics

Variables	No of observations	Mean value	Standard deviation	Min	Max
Energy use	1992	4.911	0.494	3.704	6.818
Electric Power Consumption	2044	7.975	1.201	3.569	10.882
CO2 emissions	1835	-1.196	0.580	-3.567	0.804
Energy investments pp	506	19.752	1.824	13.122	24.357
GDP pc 2011	2126	9.632	0.957	7.089	11.807
Urban population	2225	4.161	0.360	2.181	4.605
FDI out	1712	-0.732	2.415	-16.937	4.962
High Income	2225	0.539	0.499	0.000	1.000
Upper Middle	2225	0.292	0.455	0.000	1.000
Lower Middle	2225	0.157	0.364	0.000	1.000
Europe	2225	0.461	0.499	0.000	1.000
South America	2225	0.112	0.316	0.000	1.000
Asia Australia	2225	0.360	0.480	0.000	1.000

by FEC in our model) in a given economy may be affected by energy consumption in neighbouring economies regarding geographic or economic criteria. We focus on spatial and economic externalities by using the following equation as described in Huang et al. [15], Ozturk et al. [16] and Kahsai et al. [17]:

$$logGDP_{i\tau} = \eta_i + \lambda \sum_{\substack{j=1 \\ j\neq i}}^{m} w_{ij} GDP_{j\tau} + \mu \sum_{\substack{j=1 \\ j\neq i}}^{m} c_{ij} FEC_{j\tau} + \nu \sum_{\substack{j=1 \\ j\neq i}}^{m} c_{ij} EM_{j\tau} + \nu X_{i\tau} + \omega_{i\tau} \quad (1)$$

where $i = 1, \ldots, m$ denotes a region, and $m = 1, \ldots, k$ a time-period [26]. Spatial weights[2] are denoted by *w* and economic weights by *c*. Therefore, *W* and *C* constitute the respective weight matrices and *X* is a vector of independent variables that include, electric power consumption (kWh per capita), CO_2 emissions (kg per 2011 PPP$ of GDP), Foreign Direct Investments (% of GDP), investment in energy with private participation (current US$), urban population (% of total).

Consequently, we allow for economic spillovers, in addition to standard geographic ones, and in particular the elements c_{ij}, to depend on the similarity of their economic characteristics regarding GDP per capita [27]; [28]. The GDP connectivity matrix differs from any distance matrix in two notable ways. First, the GDP matrix consists of weights where the importance of another country *j* for country *i* is given by the relative magnitude of GDP per capita. Second, the GDP connectivity matrix weighs high-type partners much more heavily than low-type partners, whereas, in the distance matrix, any neighbour of *i* must always have *j* as a non-trivial neighbour [29]; Fotis et al. [30]. Therefore, the elements of the GDP per capita connectivity matrix are defined as

$$c_{ij} = 1 - \left|\frac{GDP_j - GDP_i}{GDP_j + GDP_i}\right| \quad (2)$$

and by construction, this index ranges from 0 to 1. If GDP per capita is the same between two countries, then $c_{ij} = 1$. The elements of the GDP connectivity matrix take the value of 0 if the magnitude of GDP per capita of country *j* is dissimilar with country *i,* should the difference in GDP values is really significant. Moreover, the elements of the economic weight matrix, c_{ij}, are not constants but an estimable function of economic distance. In particular, we assume that $c_{ij} \propto e^{-\theta c_{ij}}$ where c_{ij} is the economic distance between distance regions *i* and *j* and *θ* is an unknown parameter. Thus, our general specification framework includes more parsimonious specifications or specifications with alternative weights for the border effects. A negative (zero) value of the parameter would imply that characteristics of a region have a bigger spillover effect the further away they are (are independent of distance). Hence, this parameter is or should be, positive for significant spatial effects. Finally, our model involves the Maximum Likelihood (ML) estimation[3] of the parameters and asymptotic standard errors to account for the possibility of spatial correlation in

[2] *For alternative specifications of weight matrices see Anselin et al. (1996).*

[3] *For further details, see Brueckner (2003).*

the error structure. The use of an estimated θ for the calculation of the weight matrix understates the ML standard errors. It is necessitated by the fact that the standard ML estimation procedures for spatial models consider fixed weight matrices, but it has the incidental benefit that it sidesteps the issue of the confidence intervals for θ possibly covering zero [31].

4. EMPIRICAL FINDINGS

This section presents the estimates of each method we studied. Table 2 presents 10 different estimation methods on 89 countries to examine the impact of neighbouring GDP growth on regional externalities of energy consumption pattern, using spatial neighbouring criteria. The impact of electric power consumption is significantly positive in all estimation models in line with the literature [32]. Ordinary Least Squares (OLS) and Weighted Least Squares (WLS) both present the higher estimate of 0.568 and Arellano-Bond dynamic panel-data estimation (Arellano-Bond1) with one lag appears the lowest at 0.365. Energy use of oil per capita has a negative impact in all methods. As pointed out by Yang [33] the negative impact may be due to the variable used to measure real gross domestic product. Apart from WLS all methods create significant results at the 1% level. OLS exhibits the weakest impact (-0.23) while feasible Generalized Least Squares (fGLS) and fGLS with robust present the strongest impact (-0.88). Foreign Direct Investment out (FDIo) has a significantly positive impact on GDP growth using all methods. At the same time, FDIo presents the lowest impact on Arellano-Bond1, Arellano-Bond2 and GMM methods. Hansen & Rand [34] also revealed the positive relationship between FDIo and GDP growth even though there was ambiguity concerning the direction of causality. Investment in energy with private participation has a significantly negative influence on GDP growth applying fGLS and fGLS with robust methods at the 1% level of significance. While using Arellano-Bond1 and Arellano-Bond2 the investment in energy appears significant at the 0.10 level, FE and Random effects (RE) reach the 0.05 level moreover the rest of the methods set significant results at the 0.01 level. CO_2 emissions (kg per 2011 ppp $ GDP) has a significantly positive impact for fGLS and fGLS with robust estimation methods [35] while OLS, FE, robust FE, RE and GMM turn up significantly negative coefficients. The sign of CO_2 emissions usually depends on the developing phase or income level [36,37,38].

Finally, the variable urban population (% of total) has a positive impact on OLS, WLS, fGLS, fGLS with robust, FE and RE method. Deng et al. [39] explained this positive result might be associated with the fact that when the economy increases, the size of the urban core and population rise too, accompanied with important indirect effects. The estimated coefficient of the variable urban population ranges from 0.425 (fGLS/fGLS with robust) to 0.123 (Arellano-Bond1).

The next task is to examine Table 2 vertically presenting the results of each estimation method. OLS and fGLS both present the lower p-value (below 0.01) for all variables. FE and RE estimation methods have exactly the same impact on each variable with almost all of them to be significant at the 0.01 level. fGLS with robust errors estimates each variable at 0.01 significant level apart from investment in energy with private participation which appears significant at the 0.10 level. FE with robust errors gives CO_2 emissions significant at the 0.10 level, FDI_out at the 0.05 level and for the rest significant ones at the 0.01 level. Arellano-Bond1 and Arellano-Bond2 produce almost the same results regarding the direction and the significance of each variable. Finally, applying GMM estimation method, it reveals FDI_out and CO_2 emissions significance at the 0.10 level while electrical power consumption, energy use of oil and investment in energy with private participation turn also significant at the 0.01 level. This particular estimation method exhibits greater coefficients in contrast with Arellano-Bond1 and Arellano-Bond2.

In Table 3 we examine the relationship between geographical, electric and environmental neighbouring effects. In column 2, we exclude geographical and environmental neighbouring effects, so that we can identify electric's proximity unique impact. Columns 3-5 mix both spatial and electric as well as environmental effects. These specifications assume that neighbouring regions with similar electric or environmental structure are closely linked with each other through e.g. energy investments, urban population, foreign direct investments. In column 6, geographical, electric and environmental criteria are included simultaneously, and we may identify their distinctive influence and provide insight into their contribution to economic growth.

Table 2. Baseline models

Model	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Variables	**OLS**	**WLS**	**Feasible GLS**	**Feasible GLS (robust)**	**Fixed Effects**	**Fixed Effects (robust)**	**Random Effects**	**Arellano-Bond (1,2)**	**Arellano-Bond (2,2)**	**GMM**
GDP(pc)_2011 lag1								0,406*** (0,36)	0,504*** (0,57)	
GDP(pc)_2011 lag2									-0,103* (0,45)	
Electric_consumption(pc)	0,568*** (0,31)	0,568*** (0,32)	0,483*** (0,25)	0,483*** (0,49)	0,472*** (0,29)	0,472*** (0,74)	0,494*** (0,27)	0,365*** (0,3)	0,367*** (0,31)	0,562*** (0,73)
Energy_use	-0,235*** (0,69)	-0,235 (0,17)	-0,881*** (0,6)	-0,881*** (0,78)	-0,496*** (0,57)	-0,496*** (0,112)	-0,433*** (0,54)	-0,267*** (0,36)	-0,261*** (0,38)	-0,476*** (0,19)
FDI_out	0,027*** (0,7)	0,027*** (0,7)	0,031*** (0,4)	0,031* (0,12)	0,017*** (0,2)	0,017** (0,5)	0,018*** (0,2)	0,004* (0,1)	0,003* (0,1)	0,003* (0,1)
Energy_inv(pp)	0,039*** (0,8)	0,039*** (0,11)	-0,038*** (0,6)	-0,038*** (0,9)	0,007** (0,2)	0,007 (0,3)	0,008** (0,2)	0,003* (0,1)	0,003* (0,1)	0,006*** (0,1)
CO_2 emissions	-0,242*** (0,61)	-0,242 (0,149)	0,451*** (0,58)	0,451*** (0,68)	-0,234*** (0,5)	-0,235* (0,92)	-0,263*** (0,49)	-0,010 (0,29)	-0,013 (0,3)	-0,134* (0,65)
Urban_population	0,313*** (0,69)	0,313*** (0,62)	0,425*** (0,5)	0,425*** (0,76)	0,328*** (0,87)	0,328 (0,273)	0,280*** (0,82)	0,123 (0,95)	0,154 (0,1)	0,286 (0,342)
constant	3,751*** 0,52	3,751*** 1,12	9,619*** 0,43	9,619*** 0,49	6,268*** 0,42	6,268*** 0,99	5,962*** 0,41	3,466*** 0,37	3,342*** 0,38	- -
N	354	354	306	306	354	354	354	261	260	262
F	251,418	459,060	612,811	917,384	541,475	82,134				
R squared	0,812	0,812	0,924	0,924	0.912	0,912				

*Notes: Standard errors are given in parentheses; p-values for the tests. Standard errors are robust to heteroscedasticity and are clustered by year to allow for spatial-serial correlation in the errors [35]. Also, *, **, and ***, respectively, indicate statistical significance at the 0.10, 0.05, and 0.01 levels.*

Table 3. Spatial, electric, environmental neighboring effects

	Types of weights					
	Spatial No Electric and No Emissions	**No spatial, Electric and No Emissions**	**No Spatial, No Electric and Emissions**	**Spatial, Electric and No Emissions**	**Spatial, No electric and Emissions**	**Spatial, Electric and Emissions**
Model	(1)	(2)	(3)	(4)	(5)	(6)
λ lngdp	0,021			0,009	0,115	0,095
	(1,453)			(1,934)	(1,472)	(1,043)
μ lnelectric		0,731*		0,504*		*0,474**
		(0,316)		(0,284)		(0,228)
v lnemissions			0,112*		0,086*	0,102*
			(0,051)		(0,046)	(0,055)
GDP(pc)_2011 (spatial)	0,08			0,07	0,08	
	(1,223)			(0,841)	(0,931)	
GDP(pc)_2011 (energy)		0,775*		0,705*		0,675*
		(0,310)		(2,140)		(1,990)
GDP(pc)_2011			0,539*		0,494*	0,384*
(emissions)			(0,298)		(1,950)	(1,820)
Electric_consumption(pc)	0,311**	0,405*	0,388*	0,396*	0,462*	0,441*
	(0,110)	(1,760)	(0,210)	(1,950)	(1,750)	(1,690)
Energy_use	-0,119*	-0,135*	-0,109*	-0,108*	-0,107*	-0,114*
	(0,081)	(1,890)	(2,010)	(1,740)	(1,820)	(1,690)
FDI_out	0,009	0,003	0,216	0,457	0,592	0,288
	(0,887)	(1,045)	(0,996)	(1,235)	(0,741)	(1,425)
Energy_inv(pp)	0,015	-0,078*	-0,068*	-0,048*	-,059*	-0,073*
	(1,456)	(0,039)	(0,035)	(0,022)	(0,031)	(0,038)
CO_2 emissions	-0,034	-0,338	-0,772	-0,759	-0,534	-0,428
	(0,994)	(0,155)	(1,781)	(1,342)	(1,422)	(1,228)
Urban_population	0,552*	0,197*	0,096*	0,217*	0,164*	0,138*
	(0,221)	(0,089)	(0,049)	(0,104)	(0,086)	(0,068)
constant	1,069	1,431	0,961	1,195	1,536	1,459
	(1,337)	(1,523)	(1,112)	(1,237)	(1,069)	(1,942)
N	354	354	306	306	262	245
F-test	704,11	689,75	831,42	715,1	914,4	588,3

*Notes: Standard errors are given in parentheses; p-values for the tests. Standard errors are robust to heteroscedasticity and are clustered by year to allow for spatial-serial correlation in the errors [35]. Also, *, **, and ***, respectively, indicate statistical significance at the 0.10, 0.05, and 0.01 levels.*

Table 4. Economic, electric, environmental neighboring effects

	Types of weights					
	Economic, No Electric and No Emissions	**No economic, Electric and No Emissions**	**No economic, No Electric and Emissions**	**Economic, Electric and No Emissions**	**Economic, No electric and Emissions**	**Economic, Electric and Emissions**
Model	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
λ lngdp	0,082*			0,247*	0,198*	0,175*
	(0,043)			(0,102)	(0,103)	(0,835)
μ lnelectric		0,731*		0,352*		0,309*
		(0,316)		(0,173)		(0,161)
v lnemissions			0,112*		0,163*	0,077*
			(0,051)		(0,085)	(0,036)
GDP(pc)_2011 (economic)	0,041*			0,031*	0,723	
	(0,021)			(0,017)	(1,639)	
GDP(pc)_2011 (energy)		0,775*		0,642*		0,353*
		(0,310)		(0,340)		(0,162)
GDP(pc)_2011 (emissions)			0,539*		0,245*	0,205*
			(0,298)		(0,125)	(0,117)
Electric_consumption(pc)	0,167*	0,405*	0,388*	0,095*	0,069*	0,058*
	(0,085)	(1,760)	(0,210)	(0,045)	(0,037)	(0,034)
Energy_use	-0,058*	-0,135*	-0,109*	-0,108*	-0,082*	-0,049*
	(0.032)	(1,890)	(2,010)	(0,055)	(0,044)	(0.027)
FDI_out	0,009	0,003	0,216	0,788	1,002	1,329
	(1,553)	(1,045)	(0,996)	(1,741)	(1,172)	(1,859)
Energy_inv(pp)	2,442	-0,078*	-0,068*	-0,076*	-0,043*	-0,038*
	(2,004)	(0,039)	(0,035)	(0,035)	(0,024)	(0,018)
CO_2 emissions	-0,022	-0,338	-0,772	-1,442	-1,684	-1,003
	(0,741)	(0,155)	(1,781)	(0,995)	(1,935)	(1,641)
Urban_population	0,431*	0,197*	0,096*	0,055*	0,082*	0,074*
	(0,211)	(0,089)	(0,049)	(0,022)	(0,041)	(0,037)
constant	0,884	1,431	0,961	1,893	1,968	1,244
	(1,707)	(1,523)	(1,112)	(1,971)	(2.452)	(1,404)
N	354	354	306	306	262	245
F-test	502,75	689,75	831,42	654,2	743,2	495,4

*Notes: Standard errors are given in parentheses; p-values for the tests. Standard errors are robust to heteroscedasticity and are clustered by year to allow for spatial-serial correlation in the errors [35]. Also, *, **, and ***, respectively, indicate statistical significance at the 0.10, 0.05, and 0.01 levels*

When only electric proximity is employed (Column 2), the electric impact is strongly positive and significant (0,731). When environmental proximity is used (Column 3), the CO_2 emissions effect is also positive and significant (0,112). In addition, when geographical and electric criteria are included (Column 4), then the electric effect seems statistically significant with less magnitude than the case of column 3 (0,731), while geographical proximity has no effect at all. If the neighbouring environmental effect is applied instead of electric together with geographic (Column 5), then geographical proximity does not affect significantly while environmental proximity is positive and significant (0,086). In the case, where environmental and electric criteria in conjunction with geographical proximity are involved (Column 6), the electric effect is once again strongly positive than the environmental one (0,474 vs. 0,102) which strengthens compared to the previous case (0,086), indicating the importance of the electric effect.

Furthermore, urban population boosts in Column 1 in which only geographical proximity is applied and has a significant impact in the whole sample ranging from 0,096 to 0,552, while Foreign Direct Investments and CO_2 emissions do not affect at all in all possible models. Moreover, energy use affects negatively neighbouring countries in all cases as their coefficients lie from -0,107 to -0,135). This confirms the results of the country-level estimations, although the range of estimates is once narrower. Given baseline estimations, energy investments with private participation range from -0,003 to 0,039, while when we use spatial, electric and environmental effects, the contribution ranges from -0,078 to -0,043. Therefore, the variable has a negative contribution when using spatial, electric, environmental, economic effects as Tables 3 and 4 show.

In Table 4, we replace geographical proximity with economic in all possible models. When only economic proximity is applied (Column 1), the economic effect of neighbouring countries is positive and significant (0,082). When electric proximity is only employed (Column 2), the electric effect of adjacent countries is strongly positive and also significant (0,731). In the last combination with a unique proximity, the environmental effect is estimated (Column 3), showing that this particular effect is also positive and significant. When economic and electric criteria are used (Column 4), the economic effect of neighbouring countries triple its power while the electric effect is more than halved (0,352). If the environmental effect is applied instead of electric together with economic proximity (Column 5), the economic correlation weakens a bit (0,198) compared to the previous case (0,247) while environmental neighbours appear to have positive and significant influence (0,163).

Urban population boosts in all cases but especially when the economic efficiency is only employed (0,431). As Table 3, Foreign Direct Investments and CO_2 emissions do not affect at all in all possible combinations of weights of Table 4. If we take a closer look in baseline estimations for the variable of energy use, it ranges from -0,235 to -0,881. However, when we use economic, electric and environmental effects, the contribution narrows from -0,049 to -0,135. Thus, we may conclude that energy use has a negative impact when using spatial, economic, electric and environmental effects as Table 3 and 4 show. Moreover, energy investments with private participation in Table 4 have the same behaviour as Table 3. Energy consumption and its patterns are related with the empirical papers at the literature such Mahadevan and Asafu-Adjaye [11] who used data for 20 net energy importers and exporters for 1971-2002 and found EC causes EG in short run in developing countries. Moreover, our results verify the analysis of Esseghir and Khuni [10] who revealed bidirectional causality for 38 UFM (Unions for the Mediterranean) in short and long run in developed and developing countries from 1980 to 2010.

Results with estimated spatial, economic and environmental weights are presented in Tables 5 and 6. Table 5 presents a potential comparison about the effects of different types of spillovers relative to the geographical clusters. In other words, it examines the changes in the sign and magnitude of our estimates should we do not define any a priori weights and allow their impact to vary along the distance. In this section, we present evidence that supports our hypothesis on the role of externalities across countries in the process of energy consumption by estimating the empirical counterpart presented above. We use energy consumption and some explanatory variables to capture the fundamental considerations of the models presented before. It should be stressed that when selecting the aforementioned conditioning variables with estimated weights, we do not allow observations to differ markedly across nearby countries so that their inclusion can be considered as a test of robustness for our hypothesis on the role of externalities. As pointed out by Hossain [21] who added trade openness and urbanisation for newly industrialised countries (NIC) our estimates show that when EC increases, CO_2 emissions also are increasing, polluting the environment. Narayan and Smyth [22] also included capital formation in G7 countries and revealed that capital formation and EC caused real GDP in the long run.

Spatial and economic (or electric/environmental) level estimations allow us to study neighbouring effects and provide evidence concerning the dynamics of each country separately (Deltas and Karkalakos, 2013). Finally, spatial econometric estimations include all countries and present combinations of neighbouring effects (Table 6) to verify the robustness of our results.

Summarising, growth is affected by the presence of similar electrical values, economic characteristics and environmental factors but there is no geographical aggregation. In Table 3, spatial proximity is positive but insignificant in all possible models, in contrast with economic proximity in Table 4 which is not only positive but also significant in all models. Electric and environmental proximities are significant and positive in both tables highlighting their contribution to growth. Tables 5 and 6, shed more light on the existing literature by introducing alternative definitions of neighbouring criteria. Their results do consist key contribution of the current research area.

Table 5. Economic, electric and environmental neighbouring spillovers underestimated weights

	Types of weights		
	Economic, No Electric and No Emissions	**No economic, Electric and No Emissions**	**No economic, No Electric and Emissions**
Model	**(1)**	**(2)**	**(3)**
λ lngdp	0,167* (0,065)		
μ lnelectric		0,905* (0,464)	
v lnemissions			0,238* (0,119)
GDP(pc)_2011 (economic)	0,014 (0,772)		
GDP(pc)_2011 (energy)		0,211 (0,907)	
GDP(pc)_2011 (emissions)			0,841 (0,683)
Electric_consumption(pc)	0,124* (0,061)	0,288* (1,610)	0,331* (0,154)
Energy_use	-0,039* (0.021)	-0,099* (0,045)	-0,075* (0,033)
FDI_out	0,018 (1,309)	0,027 (0,945)	0,438 (0,762)
Energy_inv(pp)	1,129 (1,441)	-0,065* (0,031)	-0,052* (0,031)
CO_2 emissions	-0,088 (0,921)	-0,751 (0,552)	-0,943 (1,332)
Urban_population	0,301* (0,161)	0,154* (0,071)	0,066* (0,032)
constant	1,632 (1,552)	1,889 (1,339)	1,512 (1,294)
N	354	354	306
F-test	781,02	702,41	994,52

*Notes: Standard errors are given in parentheses; p-values for the tests. Standard errors are robust to heteroscedasticity and are clustered by year to allow for spatial-serial correlation in the errors [35]. Also, *, **, and ***, respectively, indicate statistical significance at the 0.10, 0.05, and 0.01 levels.*

Table 6. Robustness under estimated weights

	Types of weights		
	Economic, electric and no emissions	**Economic, no electric and emissions**	**No economic, electric and emissions**
Model	**(1)**	**(2)**	**(3)**
λ lngdp	0,121*	0,241*	
	(0,058)	(0,119)	
μ lnelectric	0,621*		0,893*
	(0,295)		(0,502)
v lnemissions		0,174*	0,089*
		(0,089)	(0,048)
GDP(pc)_2011 (economic)	0,014	0,019	0,026
	(0,772)	(0,821)	(0,642)
Electric_consumption(pc)	0,745	0,953	0,548
	(0,912)	(0,759)	(0,686)
Energy_use	-0,035*	-0,163*	-0,187*
	(0.022)	(0,084)	(0,095)
FDI_out	0,023	0,049	1,004
	(0,921)	(0,623)	(0,828)
Energy_inv(pp)	1,189	-0,045*	-0,076*
	(1,773)	(0,024)	(0,041)
CO_2 emissions	-0,318	-0,209	-0,592
	(0,828)	(0,954)	(1,001)
Urban_population	0,215*	0,178*	0,122*
	(0,108)	(0,079)	(0,061)
constant	1,907	1,383	1,952
	(1,721)	(0,995)	(1,047)
N	354	354	306
F-test	682,53	787,38	862,11

*Notes: Standard errors are given in parentheses; p-values for the tests. Standard errors are robust to heteroscedasticity and are clustered by year to allow for spatial-serial correlation in the errors [35]. Also, *, **, and ***, respectively, indicate statistical significance at the 0.10, 0.05, and 0.01 levels.*

5. CONCLUDING REMARKS

Energy consumption is a key challenge for building sustainable societies. Due to growing populations, increasing incomes and the industrialisation of developing countries, the world primary energy consumption is expected to increase annually every year This scenario raises issues related to the increasing scarcity of natural resources, the accelerating pollution of the environment, and the looming threat of global climate change.

The efficiency of the supply systems and thus the amount of energy consumption is a critical topic to understand energy needs at relatively high spatial and economic resolution. An accurate prediction of energy demands could provide useful information to make decisions on energy generation and purchase. Furthermore, an accurate prediction would have a significant impact on preventing overloading and allowing an efficient energy storage. Many EU citizens may have a poor or incomplete understanding of the linkage between electricity infrastructure and the risk of power failures in their region. Creating an awareness of the broader economic and environmental benefits associated with a tighter transmission grid also matters, as indicated by the strong and significant treatment effects for the sample at large [40]. Hence, several computational works have started developing machine-learning models to predict the energy consumption of residential and commercial buildings using features such as weather and energy bills.

In the current paper, we explicitly address the effect of regional externalities of energy consumption pattern on the GDP growth. The reasoning behind such externalities is basically the consumption or production patterns between countries caused by energy consumption as well as emissions. Specifically, we target two different tasks of paramount importance: (i) estimating the *average energy consumption* using both spatial and economic neighbouring relations, and (ii) examining the *energy consumption related to growth and patterns of emissions*.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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