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Electricity consumption and economic growth: exploring panel-specific differences

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Abstract

In this paper, we examine the long- and short-run dynamics between electricity consumption and economic activities, using panel data of per capita electricity consumption and per capita GDP of 160 countries for the period of 1980—2010, accounting for the degree of electricity dependence and the level of urbanization. Furthermore, in order to capture the differences in this relationship, the full sample is divided into various subsamples based on countries' income levels, regional locations and OECD memberships. This framework is argued and found to be appropriate since the causal links and inferences arising therefrom differ considerably among the subsamples, which led us to conclude that the electricity-growth nexus is highly sensitive to regional differences, countries' income levels, urbanization rates and the supply risks.

Keywords: Electricity consumption; economic growth; electricity dependence; urbanization.

JEL codes: C23; O57; Q43

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1. Introduction

As one of the major components of energy consumption, the importance of electricity to economic growth has been recognized not only by economists, but also by prominent businessmen, various engineering, energy and government agencies. As stated by the U.S. Energy Information Administration (EIA): “a country's economy and its energy use, particularly electricity use, are linked. Short-term changes in electricity use are often positively correlated with changes in economic output" (EIA, 2013b).[1]

Generally speaking, the relationship between electricity consumption and economic growth can be categorized 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; (3) feedback hypothesis emphasizes the interdependence between electricity consumption and economic growth; (4) neutrality hypothesis assumes no causal link. In order 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, we add cross-sectional dimension 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. More specifically, using panel data of per capita electricity consumption and per capita real Gross Domestic Product (GDP) for 160

[1] EIA showed that the U.S. electricity use and economic growth are linked as suggested by data over the past 60 years. The projection through 2040 also shows that this relationship is about to change in the U.S.. See for more details EIA (2013b).

countries[2], the paper examines both the long- and short-run dynamics between electricity consumption and economic activities, taking into account both the degree of electricity dependence and the level of urbanization. Furthermore, in order to capture the differences in this relationship, the full sample is divided into: (1) four subsamples based on countries' income levels, (2) seven subsamples based on regional locations, and (3) two subsamples according to the identity of the OECD memberships.

The main contribution of this study is at least twofold. First, it attempts to determine the relationship between electricity consumption, economic growth, electricity dependence and urbanization in more detail and in a much broader geographic context compared to all previous studies. The 160 countries included in this paper represent 96.52% of global GDP[3] and 94.61% of global electricity consumption[4] in 2010. While the correlation between electricity consumption and economic growth has been confirmed by many scholars, it is not homogeneous for all countries. Through correlation analyses for more than 100 countries Ferguson et al. (2000) suggests that this relationship is stronger in wealthy countries and that the link with wealth creation would be more appropriately attributed to electricity consumption rather than energy use in general. Moreover, Yoo and Kwak (2010) show that electricity consumption-GDP nexus may have different forms depending on countries' income levels. Therefore, we choose to study electricity consumption-GDP nexus and conduct successively subsample studies

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[2] To be more specific, independent territories and special administrative regions are treated separately. For example, Hong Kong and Taiwan are separated from China mainland for estimation. Independent territories like Netherlands Antilles and French Polynesia are considered as different countries from Netherlands and France. A complete country list with the indications of their geographic locations, income levels and the status of the OECD membership can be found in Table A1 in Appendix A.

[3] Sourced from the United Nations' database *UNCTAD*, the total GDP in 2010 is 51,263,609 million US dollars at 2005 constant prices and 2005 constant exchange rates. We calculate the percentage of the total GDP of sample countries in global GDP in 2010.

[4] The total electricity consumption in 2010, namely 17,780 billion kilowatt hour, is given by website *indexmundi* (2013) sourced from *CIA World Factbook*. Other sources may provide information on total global electricity consumption with slight differences.

by using three different criterions, which account for income, organizational and geographic differences across panels.

We visualize all panels included in this study by mapping data into their geographic locations. Figs. (1)-(2) illustrate the distribution of electricity consumption per capita and GDP per capita by country.[5] It can be seen that high GDP per capita is generally associated with high electricity consumption per capita. Not surprisingly, OECD countries generally have higher levels of income and electricity use. Within the same geographic region, countries tend to have similar levels of electricity consumption and wealth. Therefore, we segment the full sample into two groups based on OECD membership, four groups based on income classification and seven groups based on geographic locations. In a nutshell, our categorization of subsamples is well justified.

[Figure 1 here]

[Figure 2 here]

Second, we use a multivariate framework, which allows us to go beyond a simple GDP-electricity nexus. In addition to electricity consumption and GDP, we incorporate net import of electricity and urbanization. The reason for including these two variables in the framework of this study is straightforward. First, net import of electricity captures to what extent a given country is dependent on imported electricity. As indicated by Gnansounou (2008) the net import of electricity is one of the three sub-dimensions of the electricity dependency or supply vulnerability (the non-diversification of electricity generation and the risk of non-acceptance by the public of a dominated technology of electricity generation are cited to be the other two dimensions). Being a negative

[5] As seen on the maps, the data of Russia and former member countries of the Soviet Union are excluded with caution due to the dissolution of the Soviet Union at the beginning of 90s. It is not appropriate to distribute these data before the 90s into 15 independent post-Soviet states. Accurate data do not exist even in the articles and reports written in Russian (Jobert et al., 2014).

externality, energy supply risks constitute the policy issue of security of supply. Therefore the supply risks are addressed by striving to "bring production home", which is an equal term as energy dependency (OECD, 2010). It is clear that high dependency may render the economy highly vulnerable to external shocks, and in this perspective, it may have an effect on the dynamic relationship between electricity consumption and income in the short run as well as the long run. Fig. (3) is a visualization of the data of electricity net import or export in 2010.[6] It shows that one electricity-export country is generally surrounded by electricity-import countries and vice versa. Electricity trade is generally localized within region. Due to high costs of storage and physical transmission constraints, electricity can be economically transported only over relatively short distances. Isolated island countries, such as Japan and Australia, must be able to cover national demand, therefore being electricity-independent. Hence the variable net import of electricity captures the flows of electricity exchange within one region. This gives further justification to our regional segmentation of the global data. Despite its potential role in the electricity usage and in turn in the level of economic activities, so far, electricity dependency or supply vulnerability has not been accounted for in the literature dealing with the GDP-energy causal links. The present paper fills this gap and yields some interesting insights and policy implications.

[Figure 3 here]

Unlike net import of electricity, the progress of urbanization has been studied in the environmental and regional economics literature, mostly for the purpose of analyzing greenhouse gas (GHG) emissions in relation to energy use (e.g., O'Neill et al., 2012; Parikh and Shukla, 1995). However, when focusing on panel cointegration and panel causality, only a few studies take urbanization progress into account. Especially, when it

[6] Negative values on net electricity import signify countries being net-exporters.

is not conclusive whether urbanization has a significant effect on electricity consumption per capita, it is worth more research attention to search for the impacts of urbanization on electricity consumption. On one hand, electricity is more accessible in urban areas and urban inhabitants plausibly possess more electronic belongings and lead a more “electricity-consuming" lifestyle compared to inhabitants in rural areas (Holtedahl and Joutz, 2004). This fact tends to increase electricity consumption per capita. On the other hand, a counter hypothesis can be put forward: an urbanization progress creates higher density of population and shorter travel distances in urban areas, which may decrease electricity consumption per capita (Poumanyvong and Kaneko, 2010; Chen et al., 2008). In addition, the impacts of urbanization on electricity use may not be homogeneous across countries or regions and they may differ on countries' characteristics and development levels. According to a recent survey of the United Nations (2013), while urbanization is growing, for the first time in history, the world’s absolute number of rural inhabitants is declining. All in all, the provision of energy and more particularly electricity is the dominant element of economic sustainability. Detailed and extended analyses of the dynamic relationships between urbanization, electricity consumption and economic activities in different regions and with respect to different development levels remain an important research agenda.

The paper is organized as follows. Section 2 summarizes very briefly the empirical literature on electricity-growth or energy-growth nexus by exploring panel data. Section 3 introduces and describes the dataset used and the models employed in this study. Section 4 provides empirical results and finally Section 5 concludes.

2. Literature review

For the purpose of this paper, we focus on studies that explore panel data properties. Table 1 summarizes the main findings of previous panel studies on the causal relationships between electricity consumption and economic growth. The first set of studies performs a bivariate analysis, using cointegration and Granger (1969) causality techniques and reports mixed findings. One can reasonably conclude that region or country specific characteristics may have an impact on the electricity-income nexus and that the results may vary depending on whether the variables are at aggregate or disaggregate levels. To address this issue, at least partially, the second set of panel studies focus on countries having common characteristics, mostly members of the same international organizations such as G7, BRICS or OECD. In the third set of studies, the databases generally contain heterogeneous countries across different continents. Finally, to avoid a possible omitted variable bias, some recent studies have employed multivariate frameworks.

[Table 1 here]

Besides the above three sets of studies, it is worth taking a glance of literature on urbanization in connection with energy use. Although some studies on the determinants of energy demand and environmental impacts have used urbanization as an explanatory variable, it has been used very few times in the energy-GDP Granger causality studies. One of the examples, which is also somewhat close to our own, is the quite recent paper by Niu et al. (2013) who showed that a feedback relation exists between electricity consumption and urbanization and that this relationship varies weakly while income increases. The paper by Mishra et al. (2009) represents another example for the same scheme. In fact, the impacts of urbanization on energy use are still under debate. Some scholars study the effect of urbanization on energy use in developing countries and while doing so they consider both the threat of GHG emissions and the expanding fossil fuel use brought by rapid urbanization process. For example, Liu (2009) shows that there exists only a unidirectional Granger causality running from urbanization to total energy consumption in China in both the short and long runs. In a larger model, Hossain et al. (2011) empirically examine the dynamics among carbon dioxide (CO_2) emissions, energy consumption, GDP growth, trade openness and urbanization level for nine newly industrialized economies. The results reveal a causality running from urbanization to economic growth but no causality between urbanization and energy use.

The present paper differs from all previous work in several aspects. It aims at making a further breakthrough on the dynamic links between electricity consumption and economic growth. The world is facing the challenge of surge in electricity demand that is driven by population growth, progressive urbanization and globalization trend. In order to put the analysis into a global perspective, our study takes part in the third set of studies by including the largest number of countries and constructing 13 subsets according to regional, income and organizational differences. In addition to that, our paper highlights the influences on electricity system vulnerability and globalization by means of electricity dependency, apparently for the first time in the literature. Note finally that while the above-argued reasoning that urbanization affects electricity consumption seems quite evident, only Niu et al. (2013) has incorporated urbanization level to study the dynamic causal relationship between GDP and electricity use.

3. Data description and methodology

3.1 Data description

The dataset used for estimation is constructed from different sources according to availability. The annual data for electricity consumption and net import are obtained for 160 countries from the U.S. EIA for the period of 1980—2010. Electricity consumption per capita and electricity net import per capita are measured in million watt-hour (MWh) per thousand people. The data on each country's economic level, population and percentage of urban population are sourced from the United Nation's database

(UNCTAD). GDP per capita is measured in US Dollars at 2005 constant prices and exchange rates. We further construct subsets of the data based on income levels and geographic regions according to the classification of the World Bank (2013). Finally, a complete list of OECD countries can be found on the official OECD website, according to which OECD countries are separated from the rest. A number of countries have become the member countries of the Organization during the study period (e.g., Czech Republic, Hungary, Mexico), thus a country is categorized as OECD member as long as it has joint the Organization by the end of 2010.

Since we include as many as 160 countries, before entering in rigorous and panel econometric analyses, it is useful to inspect the evolution of electricity consumption and GDP in the full sample and subsamples. Fig. (4) shows the average trend of the series of electricity consumption and GDP in the global sample, with the values in 1980 normalized to 100 for comparisons.[7] Analogously, the figures of the same series for all subsamples can be found in Appendix B.

[Figure 4 here]

Based on Fig. (4) the global average of electricity consumption grows faster than the average GDP and these two series grow steadily with slight stagnation at the beginning of 80s. We consider that the world's economy started to recover from the 1970s' energy crisis since the beginning of 1980. During the energy crisis period, the major industrial economies of the world faced substantial real and perceived oil shortages, as well as elevated prices, but after 1980, oil prices began to decline as production started to recover (for more details, see Barsky and Kilian (2004)). A more recent setback hits electricity use and output growth in 2008 due to global financial crisis.[8] While at the

[7] All average values are weighted by national population.
[8] For robustness check, the results are invariant to the exclusion of data after 2008.

segmented level the co-movement of GDP and electricity consumption has similarities compared to the global panel, divergent temporal trends can be observed from subsamples. The evolutions of the same series in Appendix B demonstrate heterogeneous trends depending on countries' OECD memberships, income levels and regional locations. Middle-income countries have been consuming electricity and creating income with increasing rates in the recent 30 years, whereas the growth rates of electricity use and GDP have been slowing down in high-income countries. For low-income countries and Sub-Saharan Africa region, economic growth and electricity use are disturbed during the 1980s. The economic activities and electricity consumption in these countries surge together since the early 1990s. Because of these, it is thus reasonable to expect the relationships between GDP and electricity consumption to be different among subsamples.

3.2 Methodology

To analyze the relationship between the aforementioned variables in a more analytical manner, the econometric framework employed in this paper consists of panel unit root, cointegration and causality tests. In the first place, panel unit root tests are used to check the stationarity properties of each of the variables separately. The conventional augmented Dickey-Fuller (ADF) (Dickey and Fuller, 1979) tests may be weak in testing stationarity for panel data since they contain both time and cross-section dimensions. To address this issue, the recent literature proposes a number of panel unit root tests from which we chose to use LLC (Levin et al., 2002) and IPS (Im et al., 2003) panel unit root tests. While the former assumes common unit root for all panels in the sample, the later relaxes this assumption and allows individual unit roots to be tested for each panel member separately.

The results of the panel unit root tests will determine the estimation strategy to be followed. If the variables are found to have unit root in their levels, but are stationary in their first differences, this indicates that the series are integrated of order one (i.e. I(1)) and thus a long-run equilibrium relationship can be investigated employing cointegration techniques.

To test the cointegration relationship we follow the methodology proposed by Pedroni (1999) who extends the Engle and Granger (1987) two-step procedure to the heterogeneous panel data framework. The equation to be estimated proposed by Pedroni (1999) can be written in our case in the following manner:

$$EC_{jt} = \mu_j + \gamma_1 GDP_{jt} + \gamma_2 M_{jt} + \gamma_3 U_{jt} + \varepsilon_{jt} \quad (1)$$

where EC, GDP, M and U represent the variables for, respectively, electricity consumption, real GDP, electricity net imports (all in per capita terms), and urbanization ratio of country j in year t. On the other hand, μ_j is the country-specific intercept, ε_{jt} is an i.i.d. error term and the parameters γ_i with i=1, 2, 3, are the slope coefficients that may be different for each country j. In this way the test accounts for a possible heterogeneity across countries. Just as in the standard Engle-Granger two-step approach, after predicting the residuals of Eq. (1), the second step of Pedroni's panel cointegration test consists of testing for unit root in ε_{jt}, that is:

$$\varepsilon_{jt} = \rho_j \varepsilon_{jt-1} + u_{jt} \quad (2)$$

The null hypothesis of no cointegration becomes simply $\rho_j = 1$. Furthermore, based on the properties of the coefficient ρ_j, Pedroni (1999, 2004) proposes seven different tests for cointegration.[9]

[9] A detailed discussion of these panel cointegration tests can be found in Pedroni (1999, 2004) along with their critical values.

The cointegration test results will have implications for the model specifications that will be estimated in order to examine causal links among the variables. For any given panel, if the cointegration tests indicate that the variables are cointegrated, then there exist a long-run relationship between them and the direction of causality should be estimated using a vector error correction (VEC) model. Conversely, if no cointegrating vector is found, then a vector autoregression (VAR) model should be estimated.

In the framework of our analysis, a VAR model including four non-stationary and non-cointegrated variables in first differences can be represented in the following system of equations:

$$\Delta EC_{jt} = \psi_{1j} + \sum_{k=1}^{n} \gamma_{11jk} \Delta EC_{jt-k} + \sum_{k=1}^{n} \gamma_{12jk} \Delta GDP_{jt-k} + \sum_{k=1}^{n} \gamma_{13jk} \Delta M_{jt-k} + \sum_{k=1}^{n} \gamma_{14jk} \Delta U_{jt-k} + v_{1jt} \quad (3)$$

$$\Delta GDP_{jt} = \psi_{2j} + \sum_{k=1}^{n} \gamma_{21jk} \Delta EC_{jt-k} + \sum_{k=1}^{n} \gamma_{22jk} \Delta GDP_{jt-k} + \sum_{k=1}^{n} \gamma_{23jk} \Delta M_{jt-k} + \sum_{k=1}^{n} \gamma_{24jk} \Delta U_{jt-k} + v_{2jt} \quad (4)$$

$$\Delta M_{jt} = \psi_{3j} + \sum_{k=1}^{n} \gamma_{31jk} \Delta EC_{jt-k} + \sum_{k=1}^{n} \gamma_{32jk} \Delta GDP_{jt-k} + \sum_{k=1}^{n} \gamma_{33jk} \Delta M_{jt-k} + \sum_{k=1}^{n} \gamma_{34jk} \Delta U_{jt-k} + v_{3jt} \quad (5)$$

$$\Delta U_{jt} = \psi_{4j} + \sum_{k=1}^{n} \gamma_{41jk} \Delta EC_{jt-k} + \sum_{k=1}^{n} \gamma_{42jk} \Delta GDP_{jt-k} + \sum_{k=1}^{n} \gamma_{43jk} \Delta M_{jt-k} + \sum_{k=1}^{n} \gamma_{44jk} \Delta U_{jt-k} + \upsilon_{4jt} \tag{6}$$

where ψ_{ij} with $i = 1,2,3,4$, are constant terms and n is the optimal lag length based on Akaike's Information Criterion (AIC). For each of the equations involved in the VAR system, the short-run causal inferences can be tested using a Wald test. More formally, in order to test the existence of causality, for example, from *GDP* to *EC*, the following hypothesis testing should be considered in Eq. (3):

$$H_0: \gamma_{12jk} = 0 \ \ \forall k = 1, \dots, n$$

$$H_0: \exists \gamma_{12jk} \neq 0 \ \ \forall k = 1, \dots, n$$

If the null hypothesis of no causality can be rejected, then it can be concluded that in the short run, real GDP per capita causes electricity consumption per capita in the sense of Granger.

In the case of non-stationary and cointegrated variables, a VEC model involves one-lagged error correction term in a VAR model, which takes then the following form:

$$\Delta EC_{jt} = \psi_{1j} + \sum_{k=1}^{n} \gamma_{11jk} \Delta EC_{jt-k} + \sum_{k=1}^{n} \gamma_{12jk} \Delta GDP_{jt-k} + \sum_{k=1}^{n} \gamma_{13jk} \Delta M_{jt-k} + \sum_{k=1}^{n} \gamma_{14jk} \Delta U_{jt-k} + \omega_{1j} \varepsilon_{jt-1} + \upsilon_{1jt} \tag{7}$$

$$\Delta GDP_{jt} = \psi_{2j} + \sum_{k=1}^{n} \gamma_{21jk} \Delta EC_{jt-k} + \sum_{k=1}^{n} \gamma_{22jk} \Delta GDP_{jt-k} + \sum_{k=1}^{n} \gamma_{23jk} \Delta M_{jt-k} + \sum_{k=1}^{n} \gamma_{24jk} \Delta U_{jt-k} + \omega_{2j} \varepsilon_{jt-1} + \upsilon_{2jt} \quad (8)$$

$$\Delta M_{jt} = \psi_{3j} + \sum_{k=1}^{n} \gamma_{31jk} \Delta EC_{jt-k} + \sum_{k=1}^{n} \gamma_{32jk} \Delta GDP_{jt-k} + \sum_{k=1}^{n} \gamma_{33jk} \Delta M_{jt-k} + \sum_{k=1}^{n} \gamma_{34jk} \Delta U_{jt-k} + \omega_{3j} \varepsilon_{jt-1} + \upsilon_{3jt} \quad (9)$$

$$\Delta U_{jt} = \psi_{4j} + \sum_{k=1}^{n} \gamma_{41jk} \Delta EC_{jt-k} + \sum_{k=1}^{n} \gamma_{42jk} \Delta GDP_{jt-k} + \sum_{k=1}^{n} \gamma_{43jk} \Delta M_{jt-k} + \sum_{k=1}^{n} \gamma_{44jk} \Delta U_{jt-k} + \omega_{4j} \varepsilon_{jt-1} + \upsilon_{4jt} \quad (10)$$

where, ε_{jt-1}, the error correction term, is the lagged estimated residual from Eq. (1). It measures the deviations of the variables *EC*, *GDP*, *M* and *U* from their long-run equilibrium relationship. While the short-run causalities can still be tested following the same hypothesis testing procedure indicated in the VAR framework, the long-run causalities can now be examined by the significance of the error correction parameters ω_j. For example in Eq. (7) based on the t-statistics, the significance of ω_{1j} reveals that the variables *GDP*, *M* and *U* Granger cause *EC* in the long run. To assess the individual long-run causalities, the joint significance of the parameters γ_j and ω_j should be tested. For instance still in Eq. (7), based on Wald statistics, finding the parameters γ_{12jk} and ω_{1j} jointly significant implies that *GDP* causes *EC* in both the short and long runs.

4. Empirical results and discussion

We follow the estimation procedure described in the previous section. We begin with running LLC and IPS panel unit root tests. From these tests, it can be concluded that for all panels the variables are non-stationary in levels but stationary in first differences.[10] We then proceed to test for cointegration employing Pedroni's (1999) panel cointegration tests based on Eq. (1). The results are provided in Table 2. In some panels, all tests fail to reject the null of no cointegration while in some others mixed results are reported. In this situation, we follow Pedroni (2004), who, after having examined the small sample size properties of these tests, indicated that when the time dimension is small, the group-ADF statistic usually performs best, that panel-ADF statistic is the second best, and that panel variance and the group-ρ statistics do poorly. We can therefore reasonably conclude that for 9 out of the 14 panels the variables are cointegrated.[11] For the remaining 5 panels the variables are found not to have a long-run relationship. These panels include, with one exception, either high-income OECD countries or major oil exporting Middle Eastern countries. The exception is the East Asia & Pacific panel, which includes the biggest growing economy China, being also the most heterogeneous regional panel with respect to development levels of the countries in the panel.

[Table 2 here]

Based on the above-discussion, for the 9 cointegrated panels we estimated VEC model, while for the remaining 5 panels a VAR model is estimated. The results are presented in

[10] For most of the cases, a model with an intercept is estimated and the variable is found to be I(1). However, in some cases, other specifications such as including a trend or a constant are needed to conclude that the series are I(1). We do not report the results obtained from the LLC and IPS panel unit root tests to conserve space. These and all other unreported results are available from the authors upon request.

[11] After conducting a comprehensive survey on the econometrics of nonstationary panels, Baltagi and Kao (2000) indicate that developments in the econometric theory fall short of the demand for empirical studies and in consequence, they acknowledge that "several issues have been resolved but a lot remains to be done" (Baltagi and Kao, 2000, p.35).

Tables 3 and 4. Furthermore, to make the results easier to interpret, we also presented them in a graphical form in Figs. (5) and (6), in which directions of causality are indicated by arrows.[12] More specifically for the panels listed next to one of the direction lines, one causality is found; for the panels listed between two direction lines, two causalities are confirmed according to our estimation results.

[Table 3 here]

First, consider Fig. (5) that depicts short-run causal links based on both VAR and VEC specifications. In most of the panels, bi-directional causality is found between electricity consumption and GDP. This means that electricity consumption and GDP globally stimulate each other in these panels. More interestingly, while we found the same results for the full panel, OECD and non-OECD panels, the results differ with respect to income levels and regions. This confirms our initial suggestion that taking into account regional segmentations and differences in development levels may reveal different causal inferences. For instance, urbanization or electricity net imports are found to be an important factor of electricity consumption in all income levels other than high-income countries, in which urbanization has been stabilized and energy security issues have been addressed in a more rigorous way than other developing countries. For low and lower-middle income countries, electricity net imports along with GDP cause electricity consumption in a catch-up process, while for the upper-middle income countries the factor that causes electricity is found to be urbanization. Especially for the case of low-income countries, on the one hand the security of supply is dependent on electricity import and on the other hand, the variations in electricity consumption have an impact

[12] Since the main objective of this paper is to examine the causal links between electricity consumption and three other variables, we do not discuss the results obtained for the interrelationships between these three variables, although they may reveal some interesting insights.

on both GDP and urbanization levels. This indicates that electricity shortages (or short-term import volatilities) can be one of the vulnerabilities of low-income economies.

[Figure 5 here]

At regional level, in the Sub-Saharan African countries electricity net imports are also of a major concern for the short-run variations in electricity consumption. A further important inference based on this result is that, in this region, electricity consumption causes both urbanization and electricity net imports. As mentioned in Wolde-Rufael (2006), a large number of Africans still does not have access to electricity. According to data provided by International Energy Agency (IEA), in 2009 the average electrification rate in Sub-Saharan Africa is only 30.5% and it drops to 14.2% in rural areas (IEA, 2011). In such a region, electricity represents therefore the prerequisite of urban agglomeration. In other words, urbanization rates are influenced by electricity access, which is indispensable for urban activities. Another finding for this panel is that while electricity has a causal influence on urbanization and electricity net imports, it does not have a causal effect on GDP in the short run. In this regard, Sub-Saharan Africa is an atypical panel. Note finally that this result validates the neutrality hypothesis between electricity consumption and GDP, which is also the case for upper-middle and North American panels.

For the case of South Asia where over one-fifth of the population lacks access to electricity (IEA, 2011), expanding electricity access causes both economic growth and electricity net import. As we will see below, the same causal links exist in the long run too. This result not only confirms the growth hypothesis for the South Asian countries, but also suggests that the cost of satisfying additional electricity consumption can be found, *ceteris paribus*, in the level of net electricity imports. In line with these arguments, after analyzing the factors affecting the progress of power sector reforms in South Asia, Bhattacharyya (2007) indicated that the future increases in electricity demand of the region will raise the demand for investment in electricity system expansion and concluded that "the uncertainty of reform at the level of institutional environment and institutional arrangements introduces additional risk in conducting business'' (Bhattacharyya, 2007, p. 331).

[Table 4 here]

Having discussed the short-run causalities, let us now turn our attention to Fig. (6), which displays strong causalities obtained by the joint significance of the error correction terms (the significance of which indicates a long-run causality) and short-run parameters γ_{jk} in Eqs. (7-10). The first remark that should be made is that none of the 9 cointegrated panels supports the neutrality hypothesis between electricity consumption and GDP in the long run. In all panels except for two (low and lower-middle incomes), all variables cause electricity consumption. Compared to the short-run results depicted in Fig. (5), it is clear that in the long run urbanization plays a more significant role in electricity consumption. Indeed, rural-to-urban migration process combined with income increases accelerates electricity access among the population of a given country and hence raises the energy consumption. This holds also for Sub-Saharan panel for which no causal link is identified in the short run. In fact, in a similar perspective, Onyeji et al. (2012) studied the determinants of electrification in a cross-sectional framework in order to compare the factors affecting the level of electricity access particular to Sub-Saharan countries and other emerging regions, and they found that poverty, corruption and the share of the population living in rural areas are highly correlated with the access to electricity services. However, the same reasoning does not seem to hold for the two lowest income panels studied in this paper, i.e. low income and lower-middle income. For these countries in addition to what we mentioned previously for the short-run causalities, it should be further noted that the urbanization process does not follow the same patterns as in other income groups. This point has been discussed by, among others, Popkin (2002) who indicated that "unlike urbanization in the world's higher-income countries, which is associated with major advances in science, technology, and social organization as well as absorption of large populations, urbanization in low-income countries has not been accompanied by the same level of economic and cultural progress" (Popkin, 2002, p. 124). Our results suggest that this statement applies also for the electricity consumption trends in the lowest income panels.

[Figure 6 here]

When we analyze the long-run causalities running from electricity consumption to other variables, we have seen that the results do not vary much with respect to the short-run causalities. Table C.1 in Appendix C, by presenting the major differences among regions, allows us to further explore our results. Correspondingly to the two least urbanized regions in Table C.1, in Fig. (6) we have once again Sub-Saharan Africa in the north-west quadrant (in addition to the North-east) and South Asia in the south-east quadrant, that is, the aforementioned arguments hold true also in the long run for these panels. Furthermore, along with the revealed significant impact of urbanization in the short run in East Asia, the development of population composition displays predominantly in Africa and Asia. The two continents, as the most important urbanization forces, are predicted to account for 86% of all growth in the world's urban population over the next four decades (UN, 2012). However, per capita electricity consumption growth is considerably different in these two regions, e.g. 72% in China as compared to only 3% in Sub-Saharan Africa (UN, 2011). Our results shed light on one of the underlying reasons that this may be explained by the different causal chains involved between electricity consumption and other variables implicated herein. Being the three least market-integrated regions, Sub-Saharan Africa, East Asia & Pacific and South Asia's electricity-GDP nexus presents a significant reliance on electricity net imports. The problem of low electrification rates is mentioned in previous discussions. On top of that, in East Asia, "electricity market integration lags behind other continents where physical electricity cross-border exchanges have increased considerably. In terms of market development, most East Asian countries are yet to develop a national electricity market, let alone the pursuit of regional integration" (Wu et al., 2012, p.2). On the other hand, in both Latin America and Europe electricity consumption causes solely GDP without an effect on urbanization and electricity net imports. It is evident that for the case of Latin American countries this can be partially explained by the electricity sector reforms started in the 1990s (Ruiz-Mendoza and Sheinbaum-Pardo, 2010). Seeking to increase competition and efficiency as well as to improve security of supply, Latin America has been heading in the direction of electricity market integration by creating three major blocs: the Southern Cone, the Andean Community and Central America, eventually creating an integrated Latin American electricity exchange, spanning from Mexico to Chile (Ochoa et al., 2013). For the case of European countries, while cross-border transmission system has been put into place gradually, the Green Paper published by European Commission (European Commission, 2006) on 8 March 2006 called for a ''common, coherent European Energy Policy'' towards the creation of a single electricity market. Moreover, urbanization process in Europe has started much earlier than other countries and it has already reached a high level of urban development, limiting thus its effect on the variations in electricity consumption over the sample period. Following the same rationale, it is quite logical that North American electricity system does not appear to be constrained by either urbanization or electricity net import, as it is a region with the highest GDP per capita and urban population rates, and "the North American electricity system, which interconnects Canadian and U.S. electricity markets, is among the most integrated and reliable in the world" (Canadian Electricity Association, 2006). These factors allow North America a relatively stable and secured electricity sector. Finally according to Table C.1, with moderate urbanization and market integration levels, the average growth of electricity consumption in Middle East & North Africa reaches as high as 4.40% per year. As discussed in Narayan and Smyth (2009), the Middle East as a whole, is highly dependent on revenues from oil exports that are also the main driver to the growth of electricity consumption. Consistent with Squalli (2007), our results indicate that policies for energy conservation can have little or no impact on economic growth in Middle Eastern countries.

Last but not least it should be pointed out that from the aggregated panels (i.e. full panel and non-OECD panels) we obtained the same results, which cannot be found once regional, and income differences are accounted for. This finding, along with the other findings of the present study, has significant and particular policy implications, which will be discussed in the last section.

5. Conclusion

In this paper, we investigated the short- and long-run dynamics between electricity consumption and economic activities, using panel data of per capita electricity consumption and per capita GDP for 160 countries for the period of 1980—2010, accounting for the degree of electricity dependency and the level of urbanization. We found long-run cointegration relationship between electricity consumption and economic growth, implying feedback hypothesis, in the full sample and the majority of the subsamples. In the short run, unidirectional causality running from economic growth to electricity consumption supports conservation hypothesis in East Asia & Pacific, Middle East & North Africa, and lower-middle panels, and the evidence of neutrality is provided in North America, Sub-Saharan Africa and upper-middle income countries. In all panels, our results do not provide support for growth hypothesis. Additionally, the causal relationships among other variables, including urbanization and electricity net import, differ among subsample estimates, depending on panels' institutional, income and regional differences. That is to say, electricity-growth nexus is highly sensitive to regional differences, countries' income levels, urbanization rates and electricity dependency.

We conclude that GDP and electricity consumption present only short-run or little causality for wealthy economies whereas their relationship tends to be stronger in the long run for low-income economies. Moreover, we found urbanization or electricity net imports to be an important factor of electricity consumption in all income levels except for high-income economies. In other words, electricity dependency appears to be crucial for low and lower-middle income countries, whereas the main driver to electricity consumption is urbanization in upper-middle income countries. Moreover, higher electricity consumption per capita induces urbanization in regions such as Sub-Saharan Africa due to the accessibility to electricity being the rudiment of urban activities. In other emerging economies as East Asia and South Asia, the causality runs in the opposite direction. Furthermore, numerous panel results present significant long-run impacts of electricity dependency on electricity consumption and GDP.

Finally, the paper gives policy implications as follows: (1) electricity conservation policies have to be implemented with great caution as bidirectional causality between electricity consumption and economic growth is found in a number of income groups and geographic regions; (2) successful implementation of a certain reform requires the understanding of the long- or short-run effects on electricity consumption as well as the awareness of the status of urbanization and market integration process; (3) for regions as Sub-Saharan Africa and South Asia, to make electricity accessible to overall economic sectors can improve living standard, accelerate urbanization process and stimulate economic development (World Bank, 2008); (4) regarding the security of supply, the geographical diversification of energy imports from different countries and diversification of energy sources in the energy mix could reduce a given country's energy vulnerability and supply risks (European Commission, 2013), and this is especially important for Africa and Asia; (5) expansion in transmission systems and increase in regional interconnection of electricity, especially in low and lower-middle income countries, call for investments and international cooperation.

Eventually, there is no universal electricity conservation policy that can adapt to every single country, since the global context is rather complex and differs in many aspects. Therefore policymakers should take into account various economic conditions while formulating electricity consumption and conservation policies.

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Appendix A. Country list

[Table A.1 here]

Appendix B. Evolution of the series for all subsamples

[Figure B.1 here]

Appendix C. Summary of statistics of regional subsets

[Table C.1 here]

Table 1: Summary of findings in panel causality studies

Author	Period	Sample	Result
Yoo, Kwak (2010)	1975-2006	Latin America	EC -> GDP: Argentina, Brazil, Chile, Columbia, Ecuador EC <-> GDP Venezuela No causality: Peru
Chen, Kuo, Chen (2007)	1971-2001	Asia	EC -> GDP: Hong Kong GDP -> EC: India, Singapore, Malaysia, the Philippines No causality: Indonesia, Korea, Taiwan, Thailand Unidentified: China
Yoo (2006)	1971-2002	Asia	EC <-> GDP Malaysia, Singapore GDP -> EC: Indonesia, Thailand
Abbas, Chouhurry (2012)	1972-2008	India, Pakistan	GDP -> EC: India EC <-> GDP: Pakistan
Saunoris, Sheridan (2013)	1970-2009	48 states, US	EC -> GDP: aggregate sample and industrial sector GDP -> EC: Residential and commercial sectors
Wolde-Rufael (2006)	1971-2001	Africa	EC -> GDP: Benin, Congo, DR., Egypt, Gabon, Morocco, Tunisia GDP -> EC: Cameroon, Ghana, Nigeria, Senegal, Zambia, Zimbabwe No causality: Algeria, Congo, Rep., Kenya, South Africa, Sudan
Ciarreta, Zarraga (2010)	1970-2007	Europe	EC -> GDP
Narayan, Smyth (2009)	1974-2002	Middle East	EC <-> GDP
Narayan, Narayan, Prasad (2008)	1970-2002	G7	EC -> GDP: Canada, Italy, France, Japan, Germany, UK GDP -> EC: USA
Narayan, Prasad (2008)	1965-2002	OECD	EC -> GDP: Australia, Iceland, Italy, Slovak, Czech, Korea, Portugal, the UK No causality: Belgium, Canada, Denmark, France, Germany, Greece, Ireland, Japan, Luxembourg, New Zealand, Norway, Poland, Spain, Sweden, Switzerland, Turkey, Mexico, USA
Cowan, Chang, Inglesi-Lotz, Gupta (2014)	1990-2010	BRICS	EC <-> GDP: Russia GDP -> EC: South Africa No causality: China, Brazil, India
Acaravci, Ozturk (2010)	1990-2006	EU transition	No causality
Squalli (2007)	1980-2003	OPEC	EC -> GDP: Algeria, Iraq, Libya GDP -> EC: Kuwait, Saudi Arabia, United Arab Emirates EC <-> GDP: Iran, Qatar
Niu, Jia, Wang, He, Liu (2013)	1990-2009	50 countries	EC <-> GDP
Apergis, Payne (2011b)	1990-2006	88 countries	EC <-> GDP: high, upper middle income panels, lower middle income (Long run) EC -> GDP: lower middle income panels, low income panels
Narayan, Narayan, Popp (2010)	1980-2006	93 countries	EC <-> GDP GDP -> EC: Middle East
Mishra, Smyth, Sharma (2009)	1980-2005	PIC	E <-> GDP
Liu (2009)	1978-2008	China	Urbanization -> E
Hossain (2011)	1971-2007	NIC	GDP-> E: Brazil, China, India, Malaysia, Mexico, Philippines, South Africa, Thailand, Turkey
Apergis, Payne (2011a)	1990-2007	Emerging countries	GDP -> renewable EC GDP <-> non-renewable EC
Al-Mulali, Fereidouni, Lee (2013)	1980-2010	Latin America	EC -> GDP (with stronger effect of renewables)

Note: E stands for energy consumption; EC stands for electricity consumption.

Table 2: Panel cointegration tests

Test	Full Panel	OECD membership: OECD	Non-OECD	Income Level: High	Upper-Middle	Lower-Middle	Low
Panel ν − statistic	-2.077	-0.772	-2.501	-1.477	0.565	1.094	5.588**
Panel ρ − statistic	4.993	2.424	4.733	3.095	1.135	0.709	-8.730**
Panel PP-statistic	1.886	0.535	2.667	1.456	-0.484	-0.208	-14.11**
Panel ADF-statistic	1.487	0.321	2.332	1.363	-1.529	-2.370**	-16.39**
Groupρ − statistic	3.294	3.642	1.609	3.926	1.269	1.310	-0.458
Group PP-statistic	-3.061**	1.457	-4.521**	2.097	-3.258**	-1.587	-4.065**
Group ADF-statistic	-4.928**	0.143	-5.901**	0.893	-4.943**	-2.029**	-4.226**
Region							
	East Asia & Pacific	**Europe & Central Asia**	**Latin America & Caribbean**	**Middle East & North Africa**	**North America**	**South Asia**	**Sub-Saharan Africa**
Panel ν − statistic	1.282	-0.356	0.789	-1.887	-0.514	1.349	4.350**
Panel ρ − statistic	1.592	1.638	0.724	2.463	1.255	-0.607	-4.078**
Panel PP−statistic	2.107	-0.824	-0.435	1.574	1.430	-1.533	-9.213**
Panel ADF−statistic	2.432	-1.223	-2.316*	1.313	1.678	-1.668*	-9.946**
Group ρ − statistic	2.43	2.46	1.483	0.722	1.913	0.698	-0.305
Group PP−statistic	1.151	-0.31	-1.543	-1.387	2.092	-0.434	-4.873**
Group ADF−statistic	-0.729	-1.791*	-2.865**	-1.133	1.413	-0.420	-4.584**

**, * indicate statistical significance at 1 and 5 percent level of significance, respectively.

Table 3: Causality test results based on the VAR specification

	Dependent variable	Sources of causation (independent variables)			
		ΔE	ΔGDP	ΔM	ΔU
OECD	ΔE		11.590**	0.639	0.697
	ΔGDP	32.185**		0.552	1.568
	ΔM	0.403	0.518		2.303
	ΔU	1.106	1.085	0.446	
High	ΔE		20.413**	0.649	0.250
	ΔGDP	25.094**		0.154	5.353
	ΔM	0.280	0.186		0.797
	ΔU	0.321	0.277	0.106	
East Asia & Pacific	ΔE		15.622**	2.308	18.641**
	ΔGDP	3.636		2.281	13.549**
	ΔM	2.834	4.383		8.182*
	ΔU	1.168	7.527*	3.604	
Middle East & North Africa	ΔE		28.661**	0.097	0.098
	ΔGDP	3.339		0.003	0.048
	ΔM	1.057	0.030		0.020
	ΔU	0.050	0.160	0.144	
North America	ΔE		1.227	0.932	0.013
	ΔGDP	1.535		0.058	0.356
	ΔM	0.897	0.066		1.816
	ΔU	0.711	0.646	12.896**	

**, * indicate statistical significance at 1 and 5 percent level of significance, respectively.

Table 4: Causality test results based on the VEC specification

	Dependent variables	Sources of causation (independent variables)								
		Short-run causality				Long-run causality	Strong (Joint) causality			
		ΔE	ΔGDP	ΔM	ΔU	ε_(t-1)	ΔE	ΔGDP	ΔM	ΔU
Full Panel	ΔE		61.297**	1.246	0.608	112.92**		191.89**	114.60**	113.12**
	ΔGDP	112.55**		0.365	0.631	139.39**	184.02**		139.88**	140.87**
	ΔM	0.569	0.613		0.263	0.132	0.777	0.856		0.363
	ΔU	3.399	0.530	0.024		17.714**	17.859**	20.057**	17.723**	
Non-OECD	ΔE		101.73**	0.031	0.641	95.422**		203.25**	95.482**	95.766**
	ΔGDP	28.524**		0.296	0.859	27.405**	43.965**		27.579**	28.300**
	ΔM	0.639	0.148		0.453	0.922	1.375	1.104		1.452
	ΔU	2.867	0.938	0.002		13.678**	14.126**	14.957**	13.695**	
Upper-Middle	ΔE		4.885	0.516	6.173*	9.273**		14.597**	9.779*	17.400**
	ΔGDP	0.515		0.162	4.417	0.096	0.610		0.269	4.754
	ΔM	1.744	1.100		1.915	5.186*	6.923	6.442		6.444
	ΔU	3.316	4.045	0.818		5.651*	8.957*	9.471**	6.092	
Lower-Middle	ΔE		17.063**	7.670*	0.028	1.364		22.178**	8.486*	1.381
	ΔGDP	4.936		0.128	2.099	9.158**	17.067**		9.514*	14.017**
	ΔM	2.675	0.919		0.341	0.489	2.781	1.656		1.037
	ΔU	2.581	0.986	0.141		2.728	4.429	4.412	3.036	
Low income	ΔE		18.545**	42.493**	3.232	0.204		18.655**	42.732**	3.676
	ΔGDP	6.350*		0.650	11.055**	18.190**	23.939**		18.881**	32.483**
	ΔM	1.947	0.560		0.541	1.202	3.095	1.825		1.644
	ΔU	10.642**	115.97**	0.094		5.908*	16.976**	123.93**	5.992	
Europe & Central Asia	ΔE		8.628*	0.833	1.125	21.828**		31.736**	22.856**	22.407**
	ΔGDP	43.998**		0.885	0.521	19.900**	46.923**		20.990**	22.525**
	ΔM	0.219	0.349		3.692	0.321	0.533	0.723		3.719
	ΔU	1.572	0.070	2.326		2.977	3.776	3.297	5.189	
Latin America & Caribbean	ΔE		92.877**	0.138	3.398	21.167**		153.96**	21.303**	23.796**
	ΔGDP	15.559**		0.034	22.926**	3.071	16.792**	3.168	3.168	25.511**
	ΔM	0.444	0.102		0.016	0.274	0.673	0.373		0.289
	ΔU	2.407	30.531**	0.108		1.406	3.487	30.774**	1.569	
South Asia	ΔE		19.261**	1.064	0.771	33.260**		38.092**	44.797**	39.062**
	ΔGDP	10.312**		2.699	7.375*	6.838**	18.901*		8.008*	11.637**
	ΔM	12.440**	3.504		2.268	32.432**	33.029**	33.306**		41.796**
	ΔU	5.965	1.272	1.296		3.021	6.058	3.187	3.024	
Sub-Saharan Africa	ΔE		2.691	11.133**	2.238	90.973**		107.30**	96.753**	91.768**
	ΔGDP	3.358		0.160	1.676	30.738**	30.789**		31.061**	31.604**
	ΔM	13.298**	0.602		0.214	0.303	14.206**	0.665		0.531
	ΔU	8.919*	1.112	0.114		0.022	9.201*	1.120	0.141	

**, * indicate statistical significance at 1 and 5 percent level of significance, respectively.

Table A.1: List of countries included in the paper

Geographic Region	Country	Abbreviation	Income Classification	OECD membership
East Asia & Pacific	Australia	AUS	High	OECD member
	Japan	JPN	High	OECD member
	Korea	KOR	High	OECD member
	New Zealand	NZL	High	OECD member
	French Polynesia	PYF	High	
	Hong Kong, China	HKG	High	
	New Caledonia	NCL	High	
	Singapore	SGP	High	
	Taiwan, China	TWN	High	
	China	CHN	Upper middle	
	Fiji	FJI	Upper middle	
	Malaysia	MYS	Upper middle	
	Thailand	THA	Upper middle	
	Tonga	TON	Upper middle	
	Indonesia	IDN	Lower middle	
	Kiribati	KIR	Lower middle	
	Laos	LAO	Lower middle	
	Mongolia	MNG	Lower middle	
	Papua New Guinea	PNG	Lower middle	
	Philippines	PHL	Lower middle	
	Samoa	WSM	Lower middle	
	Vanuatu	VUT	Lower middle	
	Vietnam	VNM	Lower middle	
	Cambodia	KHM	Low	
	Dem. People's Rep. Korea	PRK	Low	
	Myanmar	MMR	Low	
Europe & Central Asia	Austria	AUT	High	OECD member
	Belgium	BEL	High	OECD member
	Denmark	DNK	High	OECD member
	Finland	FIN	High	OECD member
	France	FRA	High	OECD member
	Germany	DEU	High	OECD member
	Greece	GRC	High	OECD member
	Iceland	ISL	High	OECD member
	Ireland	IRL	High	OECD member
	Italy	ITA	High	OECD member
	Luxembourg	LUX	High	OECD member
	Netherlands	NLD	High	OECD member
	Norway	NOR	High	OECD member
	Poland	POL	High	OECD member
	Portugal	PRT	High	OECD member
	Spain	ESP	High	OECD member
	Sweden	SWE	High	OECD member
	Switzerland	CHE	High	OECD member
	United Kingdom	GBR	High	OECD member
	Cyprus	CYP	High	
	Greenland	GRL	High	
	Hungary	HUN	Upper middle	OECD member
	Turkey	TUR	Upper middle	OECD member
	Albania	ALB	Upper middle	
	Bulgaria	BGR	Upper middle	
	Romania	ROM	Upper middle	

Table A.1 (continued)

Geographic Region	Country	Abbreviation	Income Classification	OECD membership
Latin America & Caribbean	Chile	CHL	High	OECD member
	Antigua and Barbuda	ATG	High	
	Bahamas	BHS	High	
	Barbados	BRB	High	
	Cayman Islands	CYM	High	
	Netherlands Antilles	ANT	High	
	Saint Kitts and Nevis	KNA	High	
	Trinidad and Tobago	TTO	High	
	Turks and Caicos Islands	TCA	High	
	Uruguay	URY	High	
	Mexico	MEX	Upper middle	OECD member
	Argentina	ARG	Upper middle	
	Belize	BLZ	Upper middle	
	Brazil	BRA	Upper middle	
	Colombia	COL	Upper middle	
	Costa Rica	CRI	Upper middle	
	Cuba	CUB	Upper middle	
	Dominica	DMA	Upper middle	
	Dominican Republic	DOM	Upper middle	
	Ecuador	ECU	Upper middle	
	Grenada	GRD	Upper middle	
	Jamaica	JAM	Upper middle	
	Panama	PAN	Upper middle	
	Peru	PER	Upper middle	
	Saint Lucia	LCA	Upper middle	
	Saint Vincent and the Grenadines	VCT	Upper middle	
	Suriname	SUR	Upper middle	
	Venezuela	VEN	Upper middle	
	Bolivia	BOL	Lower middle	
	El Salvador	SLV	Lower middle	
	Guatemala	GTM	Lower middle	
	Guyana	GUY	Lower middle	
	Honduras	HND	Lower middle	
	Nicaragua	NIC	Lower middle	
	Paraguay	PRY	Lower middle	
	Haiti	HTI	Low	
Middle East & North Africa	Israel	ISR	High	OECD member
	Bahrain	BHR	High	
	Kuwait	KWT	High	
	Malta	MLT	High	
	Oman	OMN	High	
	Qatar	QAT	High	
	Saudi Arabia	SAU	High	
	United Arab Emirates	ARE	High	
	Algeria	DZA	Upper middle	
	Iran	IRN	Upper middle	
	Iraq	IRQ	Upper middle	
	Jordan	JOR	Upper middle	
	Lebanon	LBN	Upper middle	
	Libya	LBY	Upper middle	
	Tunisia	TUN	Upper middle	
	Djibouti	DJI	Lower middle	
	Egypt	EGY	Lower middle	
	Morocco	MAR	Lower middle	
	Yemen	YEM	Lower middle	

Table A.1 (continued)

Geographic Region	Country	Abbreviation	Income Classification	OECD membership
South Asia	Maldives	MDV	Upper middle	
	Bhutan	BTN	Lower middle	
	India	IND	Lower middle	
	Pakistan	PAK	Lower middle	
	Sri Lanka	LKA	Lower middle	
	Afghanistan	AFG	Low	
	Bangladesh	BGD	Low	
	Nepal	NPL	Low	
Sub-Saharan Africa	Equatorial Guinea	GNQ	High	
	Angola	AGO	Upper middle	
	Botswana	BWA	Upper middle	
	Gabon	GAB	Upper middle	
	Mauritius	MUS	Upper middle	
	Seychelles	SYC	Upper middle	
	South Africa	ZAF	Upper middle	
	Cameroon	CMR	Lower middle	
	Cape Verde	CPV	Lower middle	
	Congo	COG	Lower middle	
	Cote d'Ivoire	CIV	Lower middle	
	Ghana	GHA	Lower middle	
	Mauritania	MRT	Lower middle	
	Nigeria	NGA	Lower middle	
	Sao Tome and Principe	STP	Lower middle	
	Senegal	SEN	Lower middle	
	Swaziland	SWZ	Lower middle	
	Zambia	ZMB	Lower middle	
	Benin	BEN	Low	
	Burkina Faso	BFA	Low	
	Burundi	BDI	Low	
	Central African Republic	CAF	Low	
	Chad	TCD	Low	
	Comoros	COM	Low	
	DR Congo	ZAR	Low	
	Ethiopia	ETH	Low	
	Gambia	GMB	Low	
	Guinea	GIN	Low	
	Guinea-Bissau	GNB	Low	
	Kenya	KEN	Low	
	Liberia	LBR	Low	
	Madagascar	MDG	Low	
	Malawi	MWI	Low	
	Mali	MLI	Low	
	Mozambique	MOZ	Low	
	Niger	NER	Low	
	Rwanda	RWA	Low	
	Sierra Leone	SLE	Low	
	Somalia	SOM	Low	
	Togo	TGO	Low	
	Uganda	UGA	Low	
	Zimbabwe	ZWE	Low	
North America	Canada	CAN	High	OECD member
	United States	USA	High	OECD member
	Bermuda	BMU	High	

Table C.1: Descriptive statistics of regional subsets

Region	Electricity consumption per capita[2]		GDP per capita[3]		Share of urban population		Electricity trading per capita[4]	Income distribution	
	2010	Average[1] annual growth rate	2010	Average annual growth rate	2010	Average Annual Growth rate	2010	% high income countries	% low income countries
North America	12525.07	0.96%	41000.75	1.64%	81.72	0.34%	73.17	100.00%	0.00%
Europe & Central Asia	5643.56	1.27%	27318.81	1.54%	73.47	0.34%	141.10	80.77%	0.00%
East Asia & Pacific	2823.43	4.61%	5681.73	2.91%	51.86	2.03%	8.08	34.62%	11.54%
Latin America & Caribbean	1889.57	2.54%	5586.74	0.91%	77.88	0.66%	77.44	27.78%	2.78%
Middle East & North Africa	2500.28	4.40%	5131.85	0.78%	62.85	0.68%	31.70	42.11%	0.00%
Sub-Saharan Africa	425.61	0.21%	1045.29	0.23%	36.71	1.28%	14.32	2.38%	57.14%
South Asia	515.42	4.60%	924.43	3.72%	31.01	1.08%	4.10	0.00%	37.50%

Data sources: Authors' calculations based on

UNCTAD (2013), EIA (2013a) and World Bank (2013).

Notes: [1] The regional means in 2010 of electricity consumption per capita, GDP per capita, share of urban population and electricity trading per capita are weighted by national populations.

[2] Electricity consumption per capita and electricity trading per capita are measured in million watt-hour (MWh) per thousand people.

[3] GDP per capita is measured in US Dollars at 2005 constant prices and exchange rates.

[4] Electricity trading per capita is an approximated value for the quantity of electricity of cross-border exchanges. It is calculated by dividing the sum of the absolute values of electricity net imports by two. The calculation is no more than a proxy for within-region electricity trading, replying on the hypothesis that all electricity exchanges take place inside regions. Therefore it does not take into account for cross-regional imports or exports. Hence, these values may be either underestimated or overestimated depending on the net flows of electricity exchanges across regional borders. For this reason, we tend to not to calculate the annual growth rates of electricity trading based on these values.

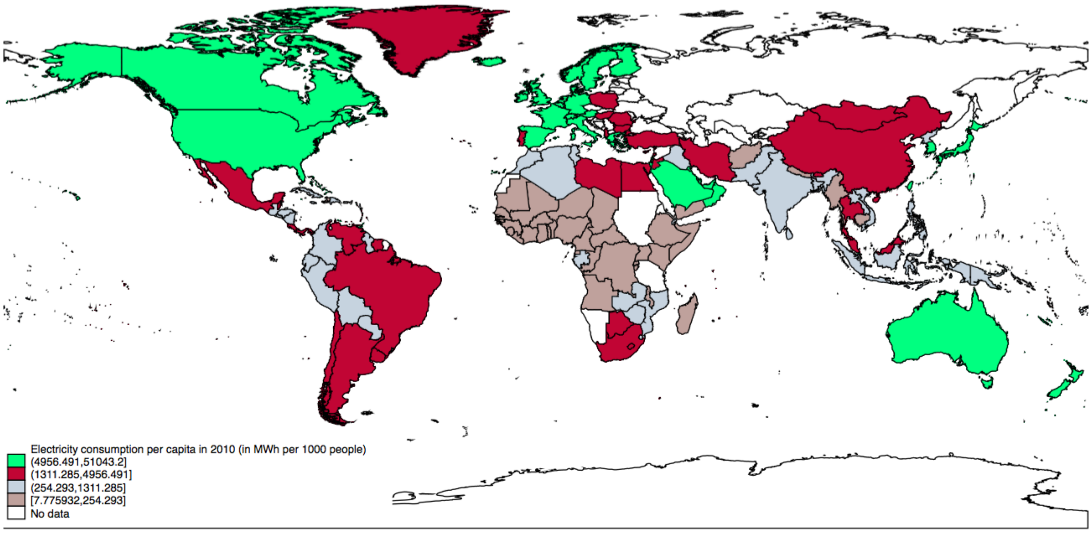

Figure 1: Electricity consumption per capita across countries
Data sources: Authors' calculations based on UNCTAD (2013) and EIA (2013a).

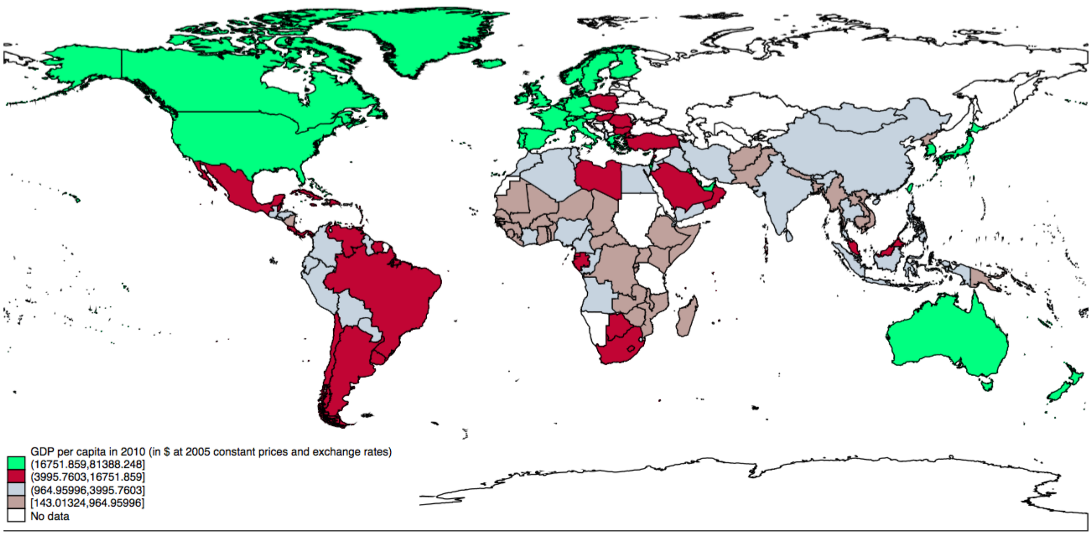

Figure 2: Gross domestic product (GDP) per capita across countries.
Data sources: Authors' calculations based on UNCTAD (2013).

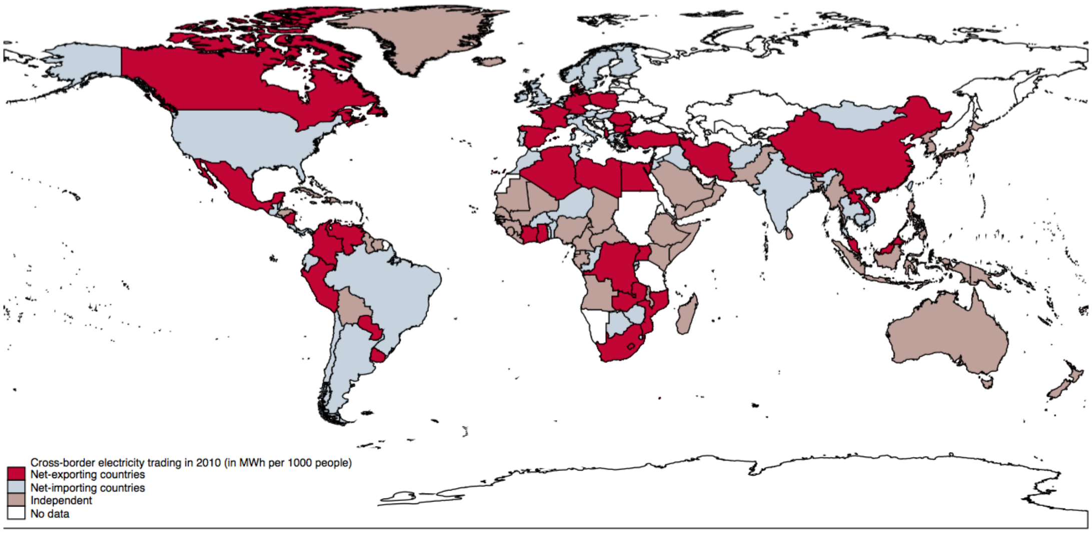

Figure 3: Net electricity import across countries.
Data sources: Authors' calculations based on UNCTAD (2013) and EIA (2013a).

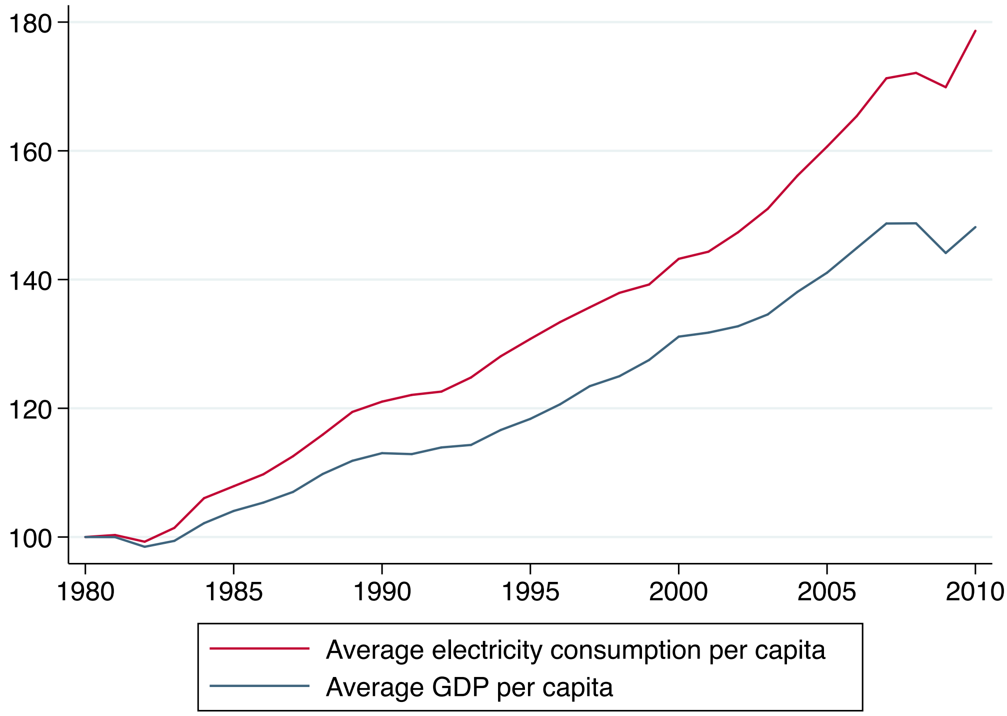

Figure 4: Evolutions of electricity consumption and GDP for 160 countries.
Data sources: Authors' calculations based on UNCTAD (2013) and EIA (2013a).

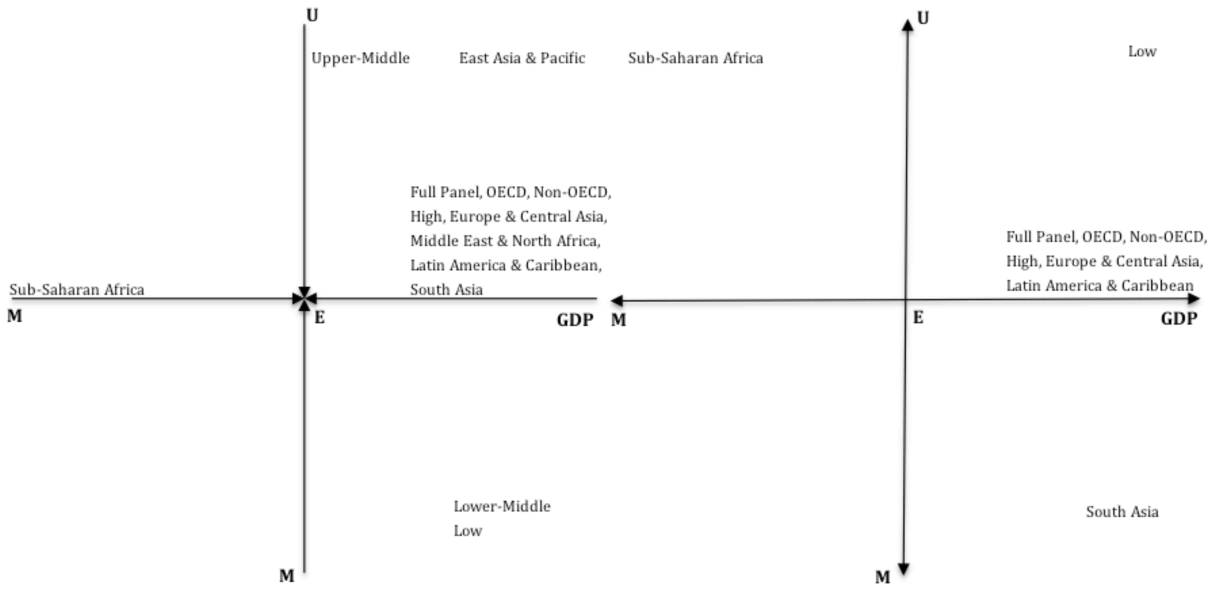

Figure 5: Short-run causal links

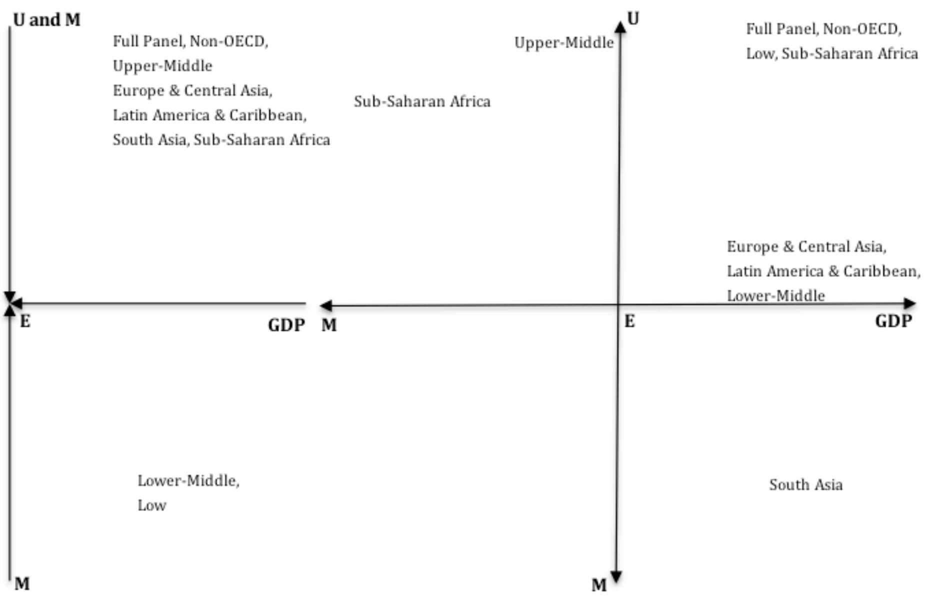

Figure 6: Strong (Joint) causal links

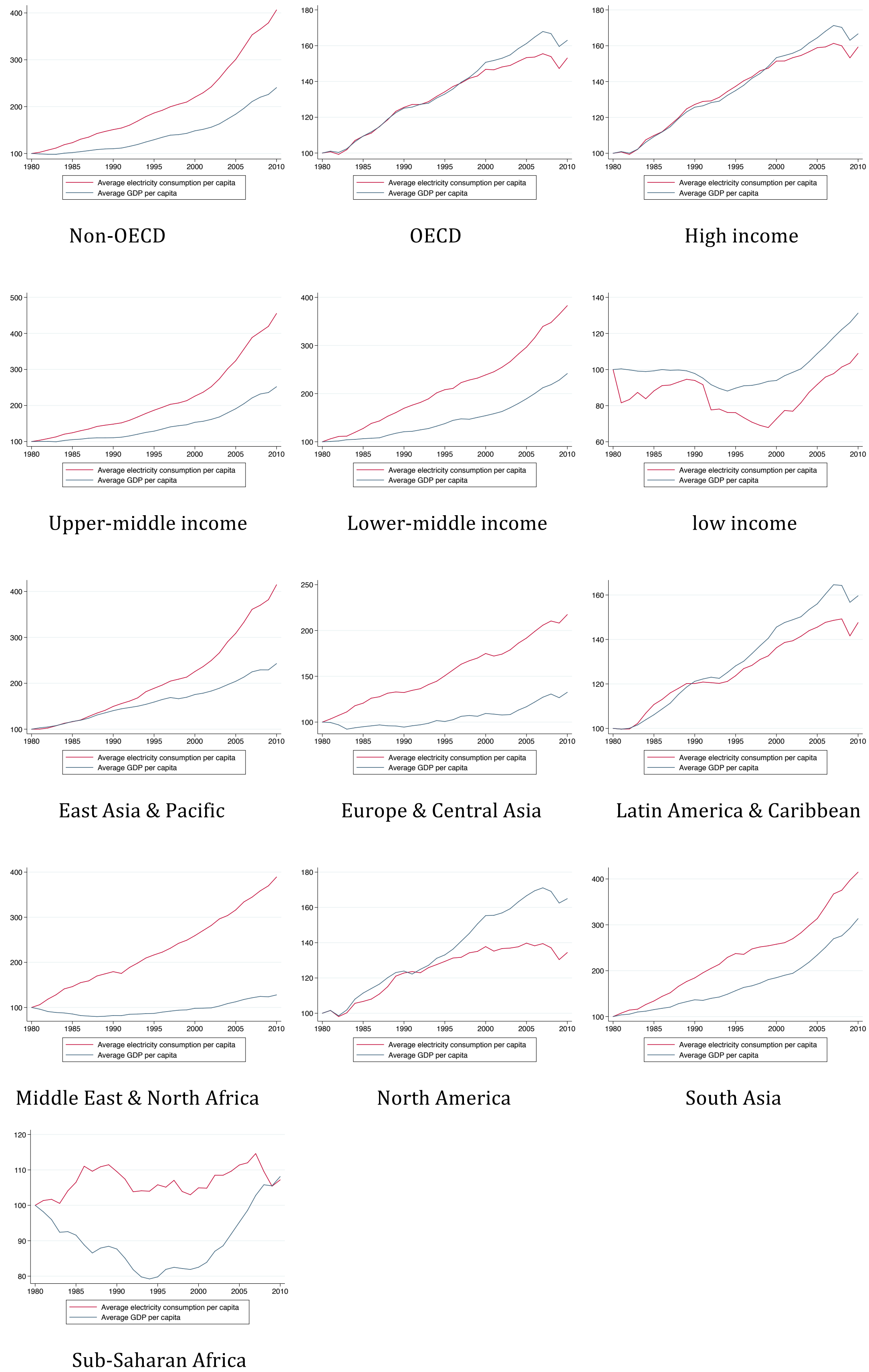

Figure B.1: Evolutions of electricity consumption and GDP for subsamples.

Data sources: Authors' calculations based on UNCTAD (2013) and EIA (2013a).