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Electricity consumption and economic growth. Empirical evidence from 82 countries

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A thesis submitted for the degree of

Master of Science (MSc) in Energy Systems

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THESSALONIKI – GREECE

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Abstract

The extensively researched causal relationship between electricity consumption and economic growth is given in this dissertation a chance to be clarified with 61 countries and 21 region aggregates being examined on data spanning from 1971 up to 2011. The results verify the divergence in the outcomes of causality direction and existence even among different studies for a specified country and witness the sensitivity of the approaching methods to the associated variables. Moreover an attempt is made to correlate the outcomes of causality with each country’ s specificities like income level, region and potential of producing electricity by oil and natural gas reserves. Here the feedback hypothesis is found to be connected with countries that produce electricity through the aforementioned fossil fuels while the neutrality hypothesis seems to be possible for countries in Europe and central Asia.

Dimitrios Fardis

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1 Introduction

Energy as an essential part of life is indispensable to all lengths and widths of human activity in all of its forms. Securing energy resources and supply is a top priority for every nation in terms of independency and survival especially nowadays that on the one hand energy resources are becoming scarce whereas demand of energy rises and on the other hand environment calls for reducing energy demand and environment friendly management of energy in general.

Electricity is certainly the most debatable form of energy due to its particular characteristics but mainly because humans rely heavily on electricity in order to fulfill an enormous range of activities of everyday's life. As such, reducing demand of energy and especially electricity brings in changes in humans 'lifestyle and standards that should be taken into account seriously. Apart from that electricity is believed to be connected with economy as a big part of economic activity is based on electricity input, implying that every change in the availability on electricity could be linked with an equivalent change economic impact.

In this context approaching and if possible quantifying the relationship between energy/electricity and economic growth is highly important so as to take important decisions as far as energy conservation is concerned but also in accordance with economic efficiency. In fact if energy/electricity proves to be that ones that drives economical growth, in other words a country's gross domestic product, one could say that cutting down on electricity can take a toll on economic growth while in the opposite case reducing electricity could be implemented with no economic cost at all.

The numerous relative studies that have been carried out both in a county specific as well as in a multi country basis have shown contradicting results as far as existence and direction of causality are concerned. As such there has been no general conclusion but in contrast, what seems to be truth is that causality and causality direction between electricity consumption and economic growth depends on several parameters that characterize a country/region and nonetheless is quite sensitive to changes in these parameters.

Many different techniques have been used in order to draw a considerable conclusion as growth on econometric sciences has been climaxing through the years. Also the complexity of the studies has been varying from simple models that consider only two parameters to more complex approaches that incorporate additional parameters attempting thus to investigate the aforementioned causal relation in a more interactive frame. In this dissertation a lately developed technique by Toda and Yamamoto is being used as well as a binary dependent variable model, which model has never been used before in cases like causality studies, in order to categorize the final outcomes.

A total of 82 countries and regions is being studied regarding electricity consumption and economic growth for a time period of about 40 years aiming at an outcome for the existence and direction of causality in-between. Apart from that, each country's specific characteristics such as income level, region and fossil fuel potential and the causality outcomes are being studied together so as to investigate the existence of a possible connection between them.

After all what is obvious is that no consensus can be found in the direction of causality and the existence of causality as well. The biggest part of the countries, though with a quite small difference, show causality running from electricity consumption to economic growth while less countries witness the opposite effect. In even fewer countries there seems to be no causality at all or bidirectional causality between electricity consumption and economic growth.

What is more important though is that according to the final outcomes and categorization, the following trends are depicted: in countries that electricity is produced by means of oil or natural gas causality appears to run from electricity consumption to economic growth and vice versa (bidirectional causality) while in countries located in Europe and central Asia no causal relation is being traced at all.

Beginning with the literature review, the methodology framework used followed by the empirical results and the final implications that stem from these results, this dissertation aims at helping towards the investigation of the associations between electricity consumption and economic growth and approach as much as possible this relation in-between.

2 Literature Review

The causal relationship between energy/electricity consumption and growth has been thoroughly studied in the energy economics literature with different studies focusing on different countries, time periods, different variables and several econometric methodologies being. The empirical outcomes of these studies have been varying and sometimes have been found to be conflicting or different on the existence and the direction of causality. In general the up to date literature that focuses on the causal relationship between electricity consumption and economic growth is not yet persuasive enough in order to provide secure evidence for a policy scheme to be applied**.**

These conflicting results rise due to the different data set, variable selection, econometric methodologies and different characteristics among countries. The actual causality differs between countries and this might be due to different countries' characteristics, different political arrangements, different institutional arrangements, different cultures and different energy policies (Chen *et al*. 2007).

In general the causal relationship between electricity consumption and economic growth has been categorized into four hypothesizes within the literature as for example in Apergis and Payne, (2009a), Squalli (2007), Chen *et al*. (2007), Mozumder and Marathe (2007), Yoo (2005), Jumbe (2004), Shiu and Lam (2004). These are:

I. The growth hypothesis that suggests unidirectional causality from electricity consumption to economic growth implying that the reduction in electricity consumption due to electricity conservation policies may have a detrimental impact on economic growth.

II. The conservation hypothesis that introduces a unidirectional causality from economic growth to electricity consumption which means that electricity conservation policies designed to reduce electricity consumption and waste will have little or no effect on economic growth.

III. The neutrality hypothesis that suggests the absence of a causal relationship between electricity consumption and economic growth with the implication that electricity conservation policies will have no effect on economic growth.

IV. The feedback hypothesis which emphasizes on the interdependent relationship between electricity consumption and economic growth. In this case a causal relationship runs in both directions and as such, an energy policy towards electricity consumption improvements efficiency may not affect economic growth.

2.1 Studies on the casual relationship between energy/electricity consumption and economic growth

The outcomes of the most recent studies on the causal relationship between electricity consumption and economic growth on a country specific as well as on a multi-country basis are summarized in Table 2.2.1 (Payne 2004). In this table the econometric technique of every study as well as the variables associated are presented together with the final outcome. Most of them witness a positive causality running from electricity consumption to economic growth. However a general conclusion from these studies is that contradictory results are still being reported.

Additionally studies such as Ferguson *et al*. (2000), Narayan *et al*. (2007), Narayan and Smyth (2009) and Yoo and Lee (2009) which use different techniques and examine the different aspects of electricity–growth relationship, fail to provide a clear and unambiguous result. Ferguson *et al*. (2000) for instance study the relationship between electricity use and economic growth in over 100 countries and find a strong correlation between electricity usage and economic development. However, the presence of a strong correlation does not necessarily imply a causal relationship. In the same study correlation between electricity consumption per capita and GDP per capita is being analyzed and compared with the equivalent between total primary energy supply per capita and GDP per capita.

The majority of the studies use bi-variate models to examine the causality between economic growth and energy consumption while only in few studies multivariate models are employed. Rather than only energy and real GDP variables in the bi-variate models, real gross fixed capital formation, labor force and carbon dioxide emissions variables are being used in multivariate model studies like Ghali and El-Sakka (2007), Huang *et al*. (2008), and Apergis and Payne (2009a), among others, to investigate the causality between energy consumption and economic growth.

Also in the case of energy consumption and economic growth relationship, it is difficult to draw a conclusion about the causality direction/existence, since in most countries almost all types of causality results have been mentioned. Regarding multi-country studies, the results are also conflicting and there is no consensus neither on the existence nor on the direction of causality between energy consumption and economic growth.

The central idea of causal relationship between *energy* consumption and economic growth was first introduced with the seminal paper of Kraft and Kraft (1978), which examined the relationship between these variables for USA and found that causality runs from GNP to energy consumption. Studies conducted by Akarca and Long (1979, 1980) on the causal relationship between energy consumption and GNP for the USA, did not confirm Kraft and Kraft's (1978) outcomes.

In the following years numerous studies followed both country-specific as well as multi country oriented, both bi-variate as well as multivariate incorporating variables such as capital formation labor, temperature, and energy prices. Apart from that studies have been also carried out examining data on a bi-ivariate as well as on a panel basis.

With reference to the first hypothesis studies that confirm it are those of Yu and Choi (1985) for The Philippines, Cheng (1997) for Brazil, Chang et al. (2001) for Taiwan, Soytas and Sari (2003) for Turkey, France, Germany and Japan, Shiu and Lam (2004) for China, Wolde-Rufael (2004) for Shanghai, Lee (2005) for 18 developing countries, Altinay and Karagol (2005) for the case of Turkey, Wolde-Rufael (2006) for Benin, the Democratic Republic of Congo and Tunisia and Narayan and Singh (2007) for Fiji, Odhiambo (2009) for the case of Tanzania, and others.

Chang et al. (2001), who examine the temporal causality between energy consumption, employment and output, find a unidirectional causality running from energy consumption to economic growth in Taiwan and concluded that energy conservation will restrain the output growth in Taiwan. In the same sense, Lee (2005), while examining the relationship between energy consumption and GDP in developing countries, found that energy consumption causes economic growth in the study countries. Moreover, Narayan and Singh (2007) who investigated the nexus between electricity consumption and economic growth in Fiji in a multivariate framework found unidirectional causality running from electricity consumption to economic growth. They justified this outcome by saying that Fiji is an energy-dependent country, that’s why energy conservation policies are bound to have severe effects on economic growth.

Contrary to the above studies, there is a number of studies claiming that it is the economic growth that Granger-causes energy consumption like studies of Ghosh (2002) that found unidirectional causality running from economic growth to electricity consumption without any feedback effect in India, concluding that electricity restrictive policies can be initiated without any harmful economic effects. Wolde-Rufael (2006), while investigating the possible causal relationship between electricity consumption and economic growth in 17 African countries, witness unidirectional causality running from real GDP per capita to electricity consumption per capita in six countries; Cameroon, Ghana, Nigeria, Senegal, Zambia and Zimbabwe. Narayan and Smyth (2005),who test for ceausality a model incorporating electricity consumption, employment and real income in Australia find that real income causes electricity consumption. Likewise, studies of Fatai et al. (2004) for Australia, and Thoma (2004) for the USA, find among others unidirectional causality running from economic growth to electricity consumption.

Apart from the aforementioned studies, there is also a number of studies that confirm the bidirectional causality hypothesis between energy consumption and economic growth. Masih and Masih (1997) find bidirectional causality between energy consumption and real income in Korea and Taiwan. Accordingly, Morimoto and Hope (2004) show bidirectional causality between electricity consumption and economic growth in Sri Lanka for the period 1960–1998 while Yang (2000), verify bidirectional causality between total energy consumption and GDP for the period 1954–1997. Paul and Bhattachrya (2004) find a bidirectional causality between energy consumption and economic growth in India while Jumbe (2004), find two-way causal relationship between electricity consumption and economic growth in Malawi for the period 1970–1999. Other studies that witness bidirectional causality between energy and economic growth are those Soytas and Sari (2003) for Argentina, Wolde-Rufael (2006) for Egypt, Gabon and Morocco and Glosure and Lee (1997) for South Korea and Singapore.

Last but not least some previous studies have shown that no causality exists between energy and economic growth maintaining that energy and economic growth are neutral to each other. These studies are among others Yu and Hwang (1984) for the USA, Yu and Choi (1985) for the case of the USA, the United Kingdom and Poland, and Altinay and Karagol (2004) for Turkey.

2.2 Different econometric approaches on the causal relationship between energy/electricity consumption and economic growth.

Generally a time series X is said to cause, according to Granger, another time series Y if the prediction error of current Y decreases by using past values of X in addition to past values of Y . In the same sense, Y is said to Granger-cause X if the prediction error of current X decreases by using past values of Y in addition to past values of X (Granger 1969). With the advancement of time series econometric techniques, the econometric approaches undertaken to test for Granger-causality in terms of the electricity consumption-growth nexus have parallel evolved. According to Granger (Granger 1969) and Granger and Newbold (1996), Granger-causality tests should be applied on stationary time series. For this reason unit root tests are often conducted to discern whether the time series is stationary in level form, in other words integrated of order zero, or stationary after first-differencing (i.e. integrated of order one). However, after the seminal work of Perron (1989), the possibility of a structural break in the respective time series must be recognized. In fact, by not incorporating a structural break, one may fail to reject the null hypothesis of a unit root when in fact the time series is stationary taking into account a structural break in the unit root tests.

Failure to test for Granger-causality with stationary variables either in levels or first-differences can yield invalid inferences. Studies like Wolde-Rufael (2004), Altinay and Karagol (2005), Lee and Chang (2005), Narayan and Smyth (2005), (2009), and Yuan *et al*. (2008) investigate the possibility of structural breaks in the unit root process of the respective variables. As shown in Table 2.2.1 Wolde-Rufael (2004), Lee and Chang (2005), Narayan and Smyth (2005), (2009), and Yuan *et al*. (2007) use the Zivot and Andrews unit root test with endogenously determined structural breaks to find that the respective variables are integrated of order one with the inclusion of structural breaks. On the contrary, Altinay and Karagol (2005) find out that the variables are integrated of order zero with the inclusion of a structural break. Lee and Chang (2005), which use the Perron unit root test with endogenously determined structural breaks, also find that the variables are integrated of order one.

Regarding the electricity consumption-growth causal relationship, Murry and Nan (1996), Fatai *et al*. (2004), Abosedra *et al*. (2008), and Narayan and Prasad (2008) adopt standard Granger-causality tests without explicitly testing for cointegration.

Engle and Granger (1987) have extended the standard Granger-causality tests to include also the possibility that two time series may share a long-run common stochastic trend, namely to be cointegrated. The establishment of cointegration allows for testing of Granger-causality within the context of an error correction model where Granger-causality may originate from two sources:

i. shortrun causality tested by a partial F-test of the lagged coefficients associated with the first-differences of the respective variables in the model and
ii. long-run causality tested by a t-test of the error correction terms. If the respective variables are not cointegrated, but each variable is integrated of order one, standard Granger-causality tests of the variables in first-differences are implemented.

Yang (2000), Aqeel and Butt (2001), Morimoto and Hope (2004), Thoma (2004), and Yoo and Kim (2006) do not find cointegration using the Engle–Granger procedure and hence they induce Granger-causality tests within a vector autoregressive model. On the other hand, studies like Jumbe (2004) and Zamani (2007) realize cointegration and test for Granger-causality within a vector error correction model. Furthermore, Zamani incorporates dummy variables for structural breaks within the vector error correction model as well.

While the Engle–Granger procedure works efficiently within a bi-variate framework, the ordinary least estimation of the cointegrating parameters is sensitive to the choice of normalization variables in the model. The Johansen–Juselius multivariate cointegration procedure deals with the concerns raised by the Engle–Granger approach. Specifically, the Johansen–Juselius cointegration procedure allows: (Johansen and Juselius 1990, Johansen 1988)

i. all the variables to be viewed as endogenous circumventing the normalization issue
ii. the presence of more than one cointegrating vector
iii. the ability to test restrictions on the cointegrating vector(s), and
iv. Simultaneous estimation via maximum likelihood of the short-run dynamics which enhances estimation efficiency.

A restriction to the use of the Johansen–Juselius procedure is the appropriate specification of the intercept and trend terms within the cointegrating vector and error correction model (Kennedy 2003). The most common approach in the examination of the causality between electricity consumption and economic growth is the Johansen–Juselius cointegration approach.

Ghosh (2002) and Yoo (2006) use the Johansen–Juselius procedure, but do not find cointegration. However studies by Fatai *et al* (2004), Shiu and Lam (2004), Lee and Chang (2005), Yoo (2005), Chen *et al*. (2007), Ho and Siu (2005), Mozumber and Marathe (2007), Soytas and Sari (2007), Yuan *et al*. (2007), Yuan *et al*. (2008), Akinlo (2009), and Odhiambo (2009) find cointegration and proceed to test for Granger causality within a vector error correction model. In addition, Yuan *et al*. (2008) and Akinlo (2009) include co-feature analysis of the relationship between electricity consumption and economic growth.

Moreover, the co-feature analysis imposes the Hodrick–Prescott (Basdevant 2003) filter to decompose the trend and cyclical components of the variables under study before performing cointegration tests on these components. Lee and Chang (2005) employ the Hansen test (2002) for parameter stability and the Gregory and Hansen (1996) test of cointegration with endogenously determined structural breaks and they find parameter instability in the cointegration vector and the absence of cointegration once acceptance of structural breaks is made. On the contrary, Yoo (2005) and Soytas and Sari (2007) do not find any instability in the vector error correction model using Brown *et al*. (1975) cumulative sum and cumulative sum of squares tests for parameter stability while Ho and Siu (2007) rely on graphical analysis of the cointegration vector so as to infer the presence of instability.

Due to the relatively short data span in many of the studies on the causal relationship between electricity consumption and economic growth, the power and size properties of conventional unit root and cointegration tests are undermined. The panel cointegration tests advanced by Pedroni (1999, 2004) and Westerlund (2006) attempts to confront these concerns by providing additional power in combining cross-section and time series data while allowing for heterogeneity across countries. Chen *et al*. (2007) find cointegration using the Pedroni (1999, 2004) panel cointegration procedure, like Narayan and Smyth (2009) who also find cointegration with endogenously determined structural breaks using the Westerlund (2006) panel cointegration test.

The estimation of a non-linear equilibrium relationship between electricity consumption and economic growth rather than a linear equilibrium is another possibility in the cointegration error correction modeling approaches. Hu and Lin (2008) implement the threshold cointegration framework of Hansen and Seo (2002) to capture the possibility of asymmetric adjustment within a vector error correction model. This research is particularly worthwhile given that the emphasis on the linear relationship between electricity consumption and economic growth may not adequately capture the influence of electricity consumption on economic growth beyond a specific threshold.

Taking into consideration the econometric methodologies, the validity of causality testing under these approaches depends a great deal on the pre-testing for unit roots and cointegration. According to Clark and Mizra (2006), the pre-tests for unit roots and cointegration may suffer from size distortions and yield variables with different orders of integration. These issues raise questions to the appropriateness of the model when undertaking causality tests. However, several econometric procedures have claimed to avoid the potential biases of pre-testing when conducting causality tests. Furthermore, these procedures are valid irrespective of whether the times series are integrated of different orders, non-cointegrated, or cointegrated. These procedures include the autoregressive distributed lag (ARDL) model and bounds testing approach set forth by Pesaran and Shin (1999) and Pesaran *et al*. (2001) as well as the Toda–Yamamoto (1995) and Dolado–Luetkepohl (1996) tests of long-run causality.

The ARDL approach to cointegration and error correction modeling performs well in small samples, which is often in the electricity consumption-growth literature, and allows the simultaneous estimation of short-run and long-run components within a vector error correction model. Apart from Tang (2008), studies by Fatai *et al*. (2004), Narayan and Smyth (2009), Narayan and Singh (2007), Squalli (2007), Ghosh (2009), and Odhiambo (2009) find cointegration using the ARDL bounds testing approach. Additionally, Narayan and Smyth (2005) find no parameter instability in the cointegration vector after using Brown's (1975) cumulative sum and cumulative sum of squares tests and the Hansen (1992) procedure.

In the same sense, Ghosh (2009) implements Brown *et al*. (1975) cumulative sum and cumulative sum of squares tests in order to find stability in the cointegration vector. The Toda–Yamamoto (1995) and Dolado–Luetkepohl (1996) approaches enable the inference of causality by using a vector autoregressive model on the levels of the variables which provides long-run information. The caveat to the estimation of a vector autoregressive model in levels as the case of the Toda–Yamamoto and Dolado–Lótkepohl approaches is the loss in efficiency and power provided that these approaches by definition over-fit the vector autoregressive model. These kind of approaches for the testing of causality between electricity consumption and economic growth can be found in the studies by Fatai *et al*. (2004), Wolde-Rufael (2004, 2006), Altinay and Karagol (2005), Squalli (2007), and Tang (2008).

Table 2.2.1 shows that results may vary from country to country, as well as among a country's different studies. The majority of studies have investigated the electricity consumption-growth relationship for industrialized, emerging market, and developing countries. As for transition economies of Eastern Europe and the Commonwealth of Independent States studies are limited due to the non-availability of time series data. Apart from that most of the studies surveyed incorporate bi-variate causality tests of electricity consumption going along with the common problem associated with bi-variate analysis which is the possibility of variable bias, undermining the validity of the inferences for a causal relationship. Additionally, except studies by Wolde-Rufael (2004, 2006), Squalli (2007), and Tang (2008), the majority of the studies do not take under consideration the positive or negative sign of coefficients bundled with the magnitude of the relationship between electricity consumption and economic growth.

Regarding growth, conservation, neutrality, and feedback hypotheses the up to now results are indeed mixed across the countries reported shown favoring, even though by little, the neutrality hypothesis with the conservation hypothesis right after it. Third comes the growth hypothesis and fourth the feedback hypothesis. Taking for granted that nearly 60% of the countries surveyed support either the neutrality or conservation hypotheses, one can infer that electricity conservation policies can be implemented leading consequently to greater reliability of the electrical system, a reduction in electricity prices, and greenhouse gas emissions. These conservation measures will have little or no effect at all on economic growth for more than half the counties.

Table 2.2.1: Summary of studies on electricity consumption-economic growth nexus

Author(s)	Countrie(s)	Period	Methodology	Main variables	Other variables	Conclusion
Abosedra, Dah and Ghosh	Lebanon	1995:1-2005:12M	Granger-causality, VAR	Electricity consumption, real import growth, growth,	Temperature, relative humidity	ELC→IMP
Akinlo	Nigeria	1980–2006A	Johansen–Juselius, cointegration, VEC, co-feature analysis	Electricity consumption, real GDP		ELC→GDP
Altinay and Karagol	Turkey	1950–2000A	Dolado–Lutkepohl causality Zivot–Andrews structural break test	Electricity consumption, real GDP		ELC→GDP
Aqeel and Butt	Pakistan	1955–1996A	Engle–Granger ,no cointegration, VAR	Electricity consumption per capita, real GDP per capita		ELC→GDP
Chen, Kuo, and Chen	China Hong Kong Indonesia India Korea Malaysia Philippines Singapore Taiwan Thailand	1971–2001A 1971–2001A 1971–2001A 1971–2001A 1971–2001A 1971–2001A 1971–2001A 1971–2001A 1971–2001A 1971–2001A	Johansen–Juselius, Pedroni panel cointegration, cointegration, VEC.	Electricity consumption, real GDP		ELC ≠ GDP ELC↔GDP ELC→GDP GDP→ELC GDP→ELC GDP→ELC GDP→ELC GDP→ELC ELC≠GDP ELC≠GDP Ten country panel ELC↔GDP
Fatai, Oxley, and Scrimgeour	Australia	1960–1999A	Granger-causality, Toda–Yamamoto causality, ARDL bounds test, Johansen–Juselius VEC cointegration	Electricity consumption, real GDP	Consumer prices	JJ GDP→ELC TY GDP→ELC ARDL GDP→ELC
Ghosh	India	1950–1997A	Johansen–Juselius, no cointegration, VAR	Electricity consumption per capita, real GDP per capita		GDP≠ELC
Ghosh	India	1970–2006A	ARDL bounds test, cointegration, VEC, Brown parameter stability test	Electricity supply, real GDP	Employment	GDP →ELS
Hu and Lin	Taiwan	1982:1 2006:4Q	Hansen–Seo threshold cointegration, VEC	Electricity consumption, real GDP		GDP→ELC
Jumbe	Malawi	1970–1999A	Engle–Granger, cointegration, VEC	Electricity consumption, GDP	agricultural GDP	ELC↔GDP
Lee and Chang	Taiwan	1954–2003A	Johansen–Juselius, cointegration, VEC Zivot–Andrews and Perron structural break tests, Hansen parameter stability test, Gregory and Hansen structural break test	Electricity consumption, real GDP per capita		ELC→GDP
Morimoto and Hope	Sri Lanka	1960–1998A	Engle–Granger, no cointegration, VAR	Electricity production, real GDP		ELP→GDP

Murry and Nan	Canada	1970–1990A	Granger-causality, VAR	Electricity consumption, real GDP		ELC→GDP
	Colombia	1970–1990A				GDP→ELC
	El Salvador	1970–1990A				GDP→ELC
	France	1970–1990 A				ELC ≠ GDP
	Germany	1970–1990A				ELC ≠ GDP
	Hong Kong	1970–1990A				ELC→GDP
	India	1970–1990A				ELC ≠ GDP
	Indonesia	1970–1990A				GDP→ELC
	Israel	1970–1990A				ELC ≠ GDP
	Kenya	1970–1990A				GDP→ELC
	Luxembourg	1970–1990A				ELC ≠ GDP
	Malaysia	1970–1990A				ELC↔GDP
	Mexico	1970–1990A				GDP→ELC
	Norway	1970–1990A				ELC ≠ GDP
	Pakistan	1970–1990A				ELC→GDP
	Philippines	1970–1990A				ELC→GDP
	Portugal	1970–1990A				ELC ≠ GDP
	Singapore	1970–1990A				ELC→GDP
	South Korea	1970–1990A				ELC↔GDP
	Turkey	1970–1990A				ELC→GDP
	UK	1970–1990A				ELC ≠ GDP
	US	1970–1990A				ELC ≠ GDP
	Zambia	1970–1990A				ELC ≠ GDP
Narayan and Prasad	Australia	1960–2002A	Bootstrapped Granger-causality	Electricity consumption real GDP		ELC→GDP
	Austria	1960–2002A				ELC ≠ GDP
	Belgium	1960–2002A				ELC ≠ GDP
	Canada	1960–2002A				ELC ≠ GDP
	Czech Republic	1960–2002A				ELC→GDP
	Denmark	1960–2002A				ELC ≠ GDP
	Finland	1960–2002A				GDP→ELC
	France	1960–2002A				ELC ≠ GDP
	Germany	1960–2002A				ELC ≠ GDP
	Greece	1960–2002A				ELC ≠ GDP
	Hungary	1965–2002A				GDP→ELC
	Iceland	1960–2002A				ELC↔GDP
	Ireland	1960–2002A				ELC ≠ GDP
	Italy	1960–2002A				ELC→GDP
	Japan	1960–2002A				ELC ≠ GDP
	Korea	1971–2002A				ELC↔GDP
	Luxembourg	1960–2002A				ELC ≠ GDP
	Mexico	1971–2002A				ELC ≠ GDP
	Netherlands	1960–2002A				GDP→ELC
	New Zealand	1960–2002A				ELC ≠ GDP
	Norway	1960–2002A				ELC ≠ GDP
	Poland	1960–2002A				ELC ≠ GDP
	Portugal	1960–2002A				ELC→GDP
	Slovak Republic	1971–2002A				ELC→GDP
	Spain	1960–2002A				ELC ≠ GDP
	Sweden	1960–2002A				ELC ≠ GDP
	Switzerland	1960–2002A				ELC ≠ GDP
	Turkey	1960–2002A				ELC ≠ GDP
	UK	1960–2002A				ELC↔GDP
	US	1970–2002A				ELC ≠ GDP
Narayan and Singh	Fiji Islands	1971–2002A)	ARDL bounds test cointegration VEC	Electricity consumption, real GDP	Labor force	ELC→GDP and ELC→L

Narayan and Smyth	Australia	1966–1999A	ARDL bounds test, VEC, Zivot–Andrews structural break test, Hansen and Brown parameter stability tests, cointegration	Electricity consumption per capita, real GDP per capita	Manufacturing employment index	GDP→ELC, MEMP→ELC
Narayan and Smyth	Iran Israel Kuwait Oman Saudi Arabia Syria	1974–2002A 1974–2002A 1974–2002A 1974–2002A 1974–2002A 1974–2002A	Westerlund panel cointegration, cointegration, VEC	Electricity consumption per capita, real GDP per capita	Real exports per capita	panel, ELC↔GDP
Odhiambo	Tanzania	1971–2006A	ARDL bounds test VEC cointegration, VEC	Electricity consumption per capita, real GDP per capita		ELC→GDP
Odhiambo	South Africa	1971–2006A	Johansen–Juselius VEC cointegration, VEC	Electricity consumption per capita real GDP per capita	Employment	ELC↔GDP
Shiu and Lam	China	1971–2000A	Johansen–Juselius, cointegration, VEC	Electricity consumption, real GDP		ELC→GDP
Soytas and Sari	Turkey	1968–2002A)	Johansen–Juselius, cointegration, VEC Brown parameter stability test	Industry electricity consumption, value added-manufacturing	Manufacturing employment, manufacturing, real fixed investment	IELC→VA
Squalli	Algeria Indonesia Iran Iraq Kuwait Libya Nigeria Qatar Saudi Arabia UAE Venezuela	1980–2003A 1980–2003A 1980–2003A 1980–2003A 1980–2003A 1980–2003A 1980–2003A 1980–2003A 1980–2003A 1980–2003A 1980–2003A	ARDL bounds test, cointegration, Toda–Yamamoto causality	Electricity consumption per capita Capita, real GDP per		ARDL GDP→ELC, TY GDP→ELC ARDL GDP→ELC, TY ELC→GDP ARDL ELC↔GDP, TY ELC↔GDP ARDL GDP→ELC, TY GDP→ELC ARDL ELC→GDP, TY GDP→ELC ARDL GDP→ELC, TY GDP→ELC ARDL ELC↔GDP, TY ELC→GDP ARDL ELC↔GDP, TY ELC↔GDP ARDL ELC↔GDP, TY ELC→GDP and GDP→ELC(+) ARDL ELC↔GDP, TY ELC→GDP ARDL ELC→GDP, TY ELC→GDP
Tang	Malaysia	1972:1–2003:4Q	ARDL bounds test, no cointegration, Toda–Yamamoto causality, Brown parameter stability test	Electricity consumption per capita, real GNP per capita		ELC→GDP
Thoma	US	1973:1–2000:1 M	Engle–Granger, no cointegration VAR	Total, commercial, industrial, other, residential electricity usage, industrial production		IP→ELC, IP→CELC, IP→IELC, OELC ≠ IP, RELC ≠ IP
Wolde-Rufael	Shanghai	1952–1999A	Toda–Yamamoto causality Zivot–Andrews structural break test	Electricity consumption, real GDP		ELC→GDP
Wolde-Rufael	Algeria Benin Cameroon Congo, DR Congo, Rep Egypt Gabon Ghana	1971–2001A 1971–2001A 1971–2001A 1971–2001A 1971–2001A 1971–2001A 1971–2001A 1971–2001A	Toda–Yamamoto causality	Electricity consumption, per capita, real GDP per capita		ELC ≠ GDP ELC→GDP GDP→ELC ELC→GDP ELC ≠ GDP ELC↔GDP GDP→ELC ELC→GDP GDP→ELC

	Kenya Morocco Nigeria Senegal South Africa Sudan Tunisia Zambia Zimbabwe	1971–2001A 1971–2001A 1971–2001A 1971–2001A 1971–2001A 1971–2001A 1971–2001A 1971–2001A 1971–2001A				ELC ≠ GDP ELC↔GDP GDP→ELC GDP→ELC ELC ≠ GDP ELC ≠ GDP ELC→GDP GDP→ELC GDP→ELC
Yang	Taiwan	1954–1997A	Engle–Granger, no cointegration, VAR	Electricity consumption, real GDP		ELC↔GDP
Yoo	Korea	1970–2002A	Johansen–Juselius cointegration, VEC, Brown parameter stability test	Electricity consumption, real GDP		ELC↔GDP
Yoo	Indonesia Malaysia Singapore Thailand	1971–2002A 1971–2002A 1971–2002A 1971–2002A	Johansen–Juselius, no cointegration, VAR	Electricity consumption per capita, real GDP per capita		GDP→ELC ELC↔GDP ELC↔GDP GDP→ELC
Yoo and Kim	Indonesia	1971–2002A	Engle–Granger, no cointegration, VAR	Electricity production, Electricity consumption, real GDP		GDP→ELP, GDP→ELC
Yuan, Kang, Zhao, and Hu	China	1963–2005A	Johansen–Juselius, cointegration, VEC, Zivot–Andrews structural break test	Electricity consumption, real GDP	Capital, employment	ELC↔GDP
Yuan, Zhao, Yu, and Hu	China	1978–2004A	Johansen–Juselius cointegration co-feature analysis, VEC	Electricity consumption, real GDP		ELC→GDP
Zamani	Iran	1967–2003A	Engle–Granger VEC cointegration, dummy variables	Industrial electricity and agricultural electricity consumption	Industrial valued added, agricultural value added	IVA→IELC, AVA↔AELC

Abbreviations

- →, ↔, and ≠ stand for unidirectional causality, bidirectional causality, and no causality, respectively.
- ELC = electricity consumption
- ELP = electricity production
- ELS = electricity supply
- AELC = agricultural electricity consumption
- IELC = industrial electricity consumption
- CELC = commercial electricity consumption
- IELC = industrial electricity consumption
- OELC = other sector electricity consumption
- RELC = residential electricity consumption
- AVA = agricultural value added
- IVA = industrial value added
- MVA = manufacturing value added
- IMP = imports
- GDP = gross domestic product (real/nominal)
- IP = industrial production;
- EMP = employment
- NEMP = non-farm employment
- MEMP = manufacturing employment
- VAR = vector autoregressive model and
- VEC = vector error correction mode
- JJ: Johansen–Juselius
- TY: Toda–Yamamoto

2.3 Literature review summary

Realizing the causal relationship between electricity consumption and economic growth helps on the appropriate design and implementation of environmental and energy policies. The fact that the empirical results have yielded mixed results in terms of the four hypotheses related to the causal relationship between electricity consumption and economic growth is not unexpected. On the other hand, it is clear that there is plenty of room for future research on the electricity consumption-growth causal relationship. Examining the relationship between electricity consumption and economic growth nexus within a model including other variables, such as real income per capita, employing panel error correction modeling may prove beneficial estimating the impact of electricity consumption within the stages of economic development. Apart from that the examination of the electricity consumption-growth nexus in the transition economies of Eastern Europe and the Commonwealth of Independent States should be a challenge for the researchers. Finally in addition to identifying the causal relationship, future studies should examine both the sign effect rather than only magnitude of the coefficients associated with the causality tests by testing whether the sum of the lagged coefficients of the variables are equal to zero.

3 Data and Methodology

The scope of this task is the investigation of the existence of a causal relationship on the one hand and the direction of it on the other, between Electricity Consumption on aggregate levels and the Gross Domestic Product of 82 countries through a technique proposed by Toda and Yamamoto (1995) and Dolado–Lutkepohl (1996).

Annual data for 61 countries as well as for 21 specific area aggregates including real GDP and Electricity consumption for the period 1971–2011 have been acquired from the World Bank and are measured in current US$ and kWh respectively. Equivalent graphs can be seen in the rest of this section.

Toda and Yamamoto and Dolado and Lutkepohl suggest a procedure for testing the Granger causality in both integrated and cointegrated systems of any integration order through the use of an augmented level Vector Autoregression (VAR) model. By this procedure Granger causality tests can be performed, as said earlier, providing the user with the long-run information often being ignored in such models. Apart from that, Toda Yamamoto methodology does not consider as necessary the testing for unit root and cointegration, which is very often in models like the vector error correction. However the integration level of both series is investigated.

Many studies on this field take for granted the assumption that the time series data are stationary bringing in bias to their final results. The fact that for an investigation of a cointegration relationship an integration order of one, i.e variable I(1), is required brings additional limitations to the estimation technique. In case that a series is not integrated of order I(1) or is integrated in different orders, no test for long-run relationship can be performed. On the other hand unit root and cointegration tests have been criticized by bibliography as possibly suffering from low power and pre-testing bias (Toda and Yamamoto, 1995).

The technique developed by Toda and Yamamoto (1995) uses a modified Wald test for restriction on the parameters of the VAR (k) model with k being the optimal lag length of the VAR system. In this approach the optimal order of the system (k) is augmented by the maximal order of integration (d max) and then the VAR (k + d max) is being estimated with the coefficients of the last lagged d max vector being ignored.

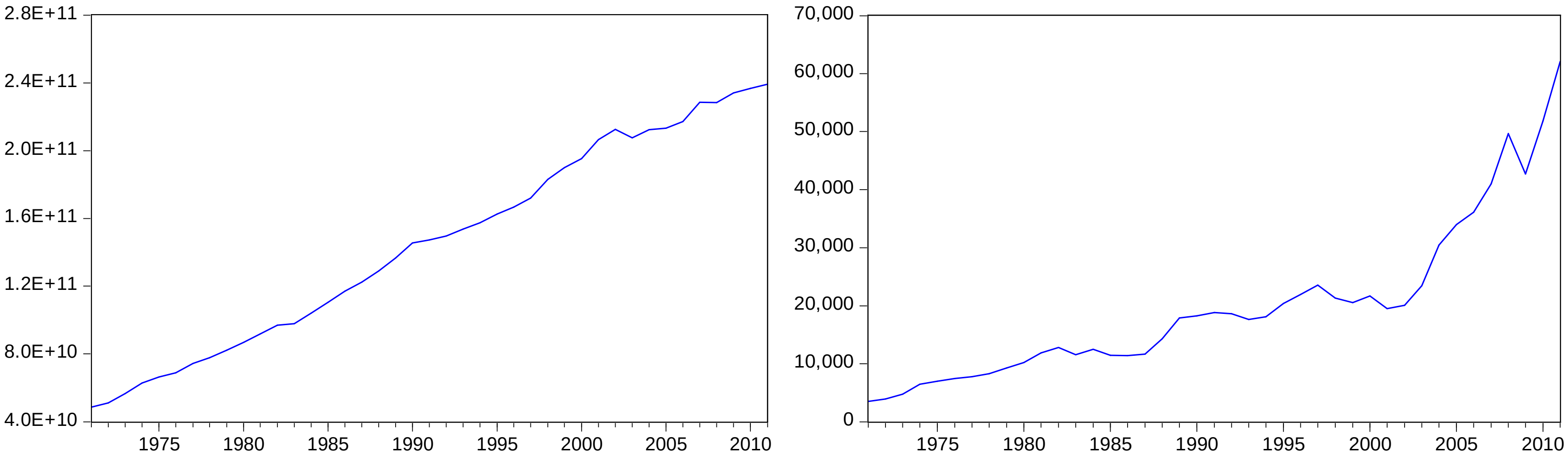


Figure 3-1: Electricity consumption and gross domestic product of Australia

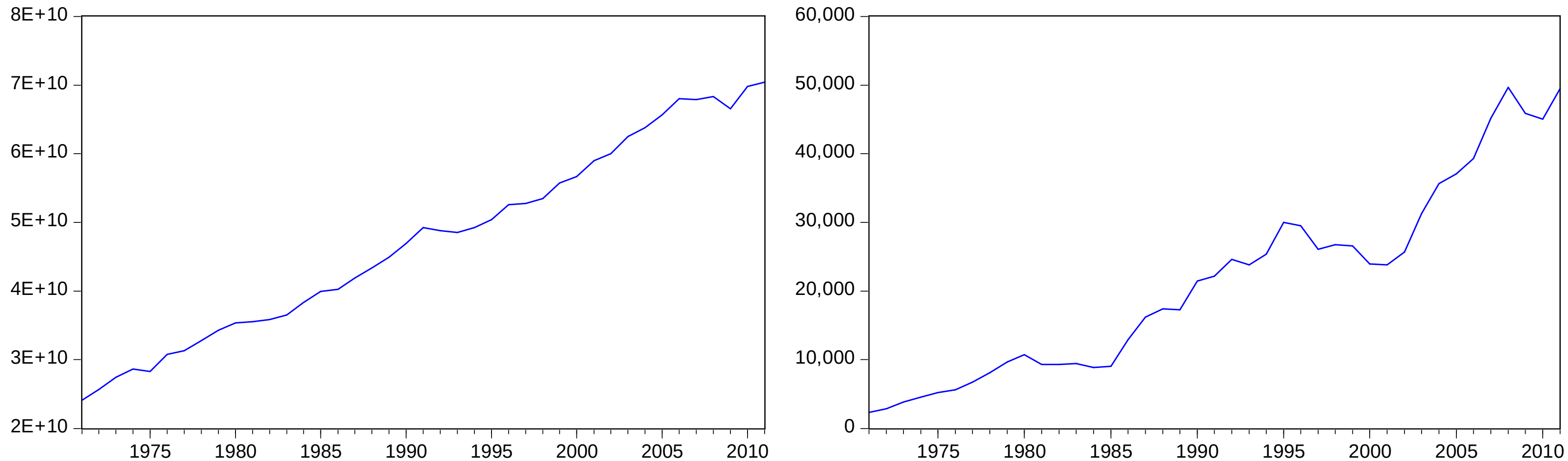


Figure 3-2: Electricity consumption and gross domestic product of Austria

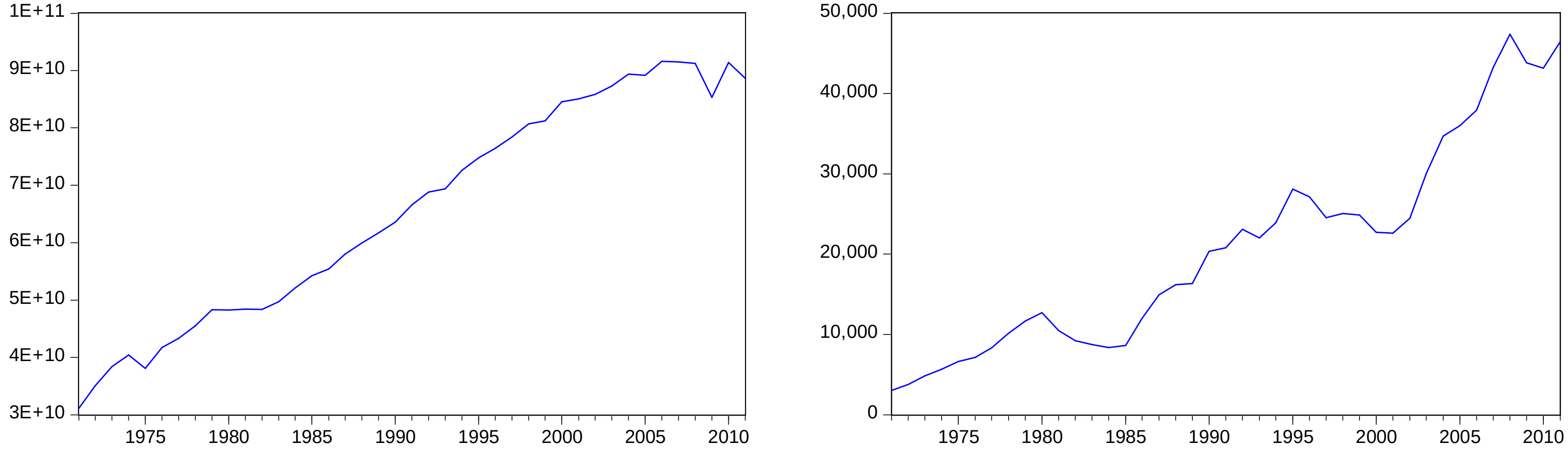


Figure 3-3: Electricity consumption and gross domestic product of Belgium

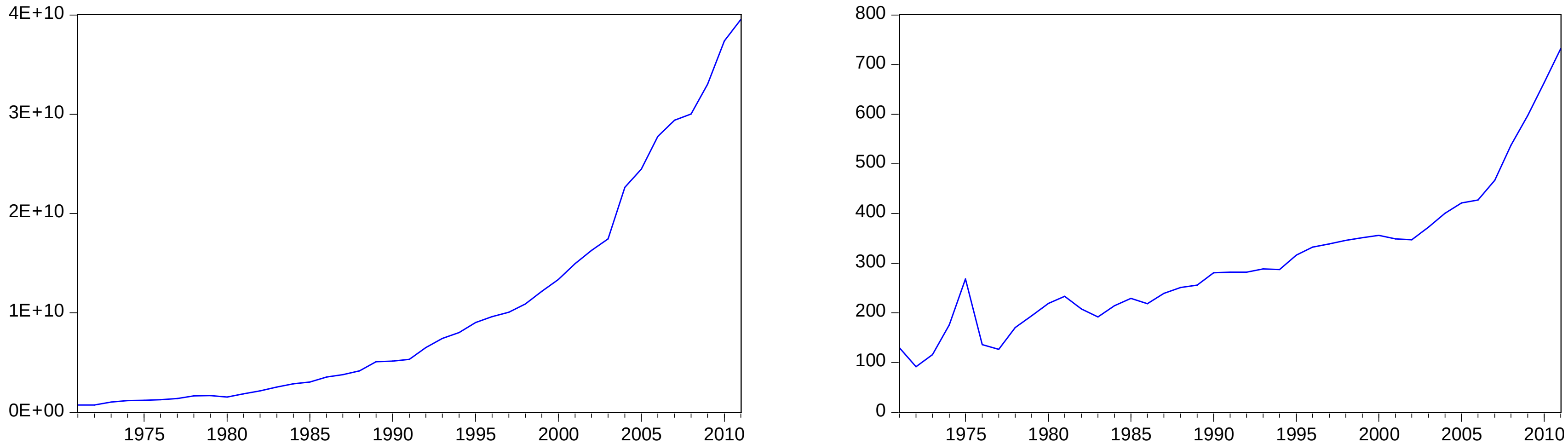


Figure 3-4: Electricity consumption and gross domestic product of Bangladesh

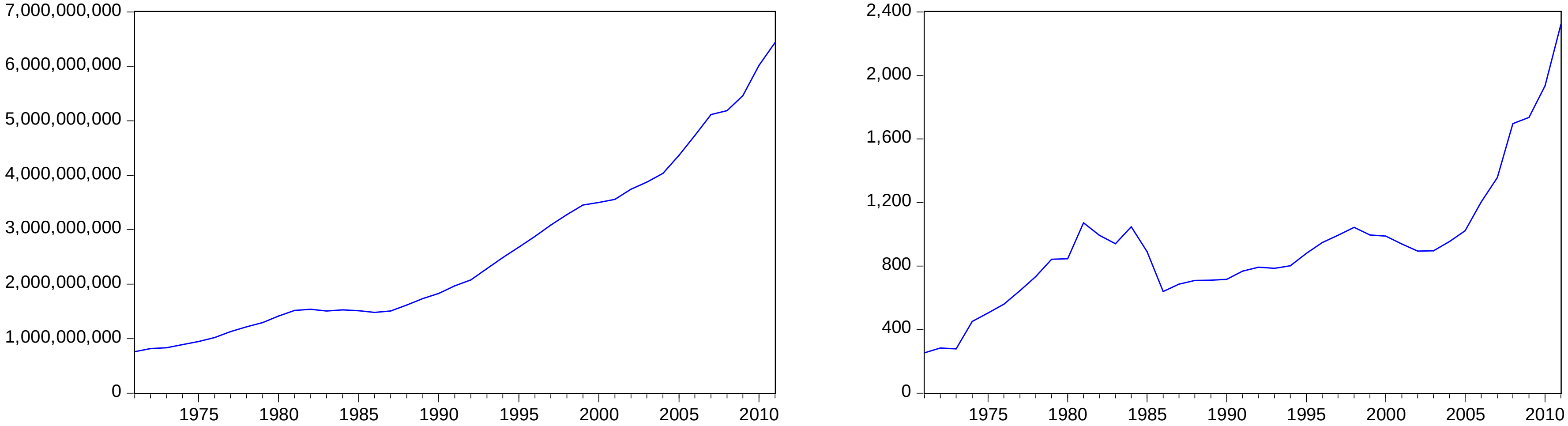


Figure 3-5: Electricity consumption and gross domestic product of Belgium

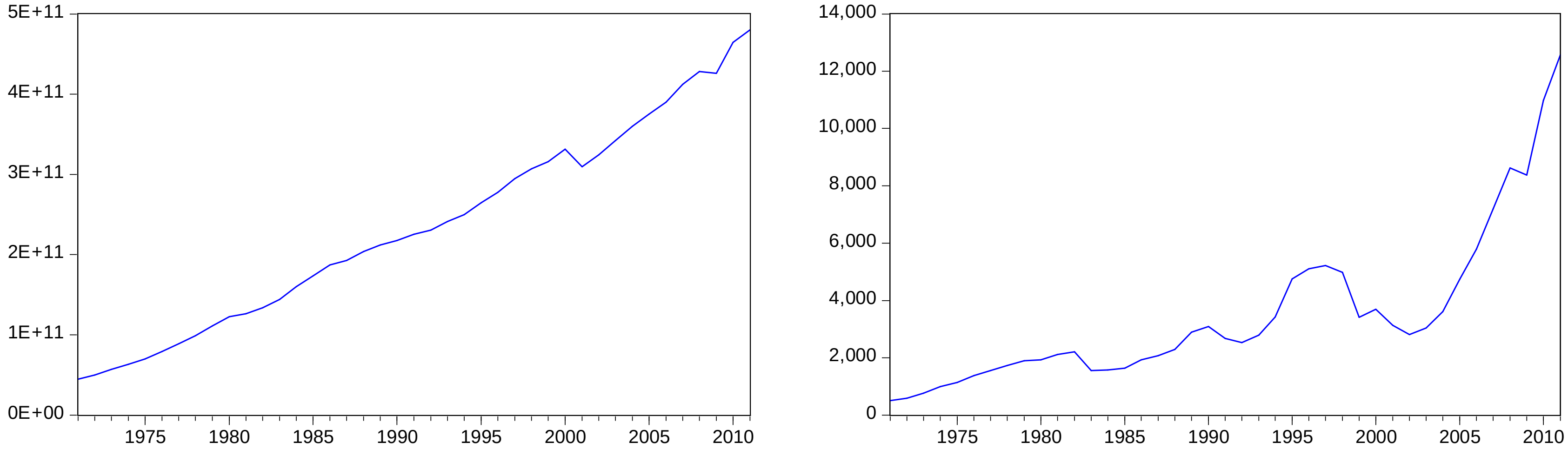


Figure 3-6: Electricity consumption and gross domestic product of Brazil

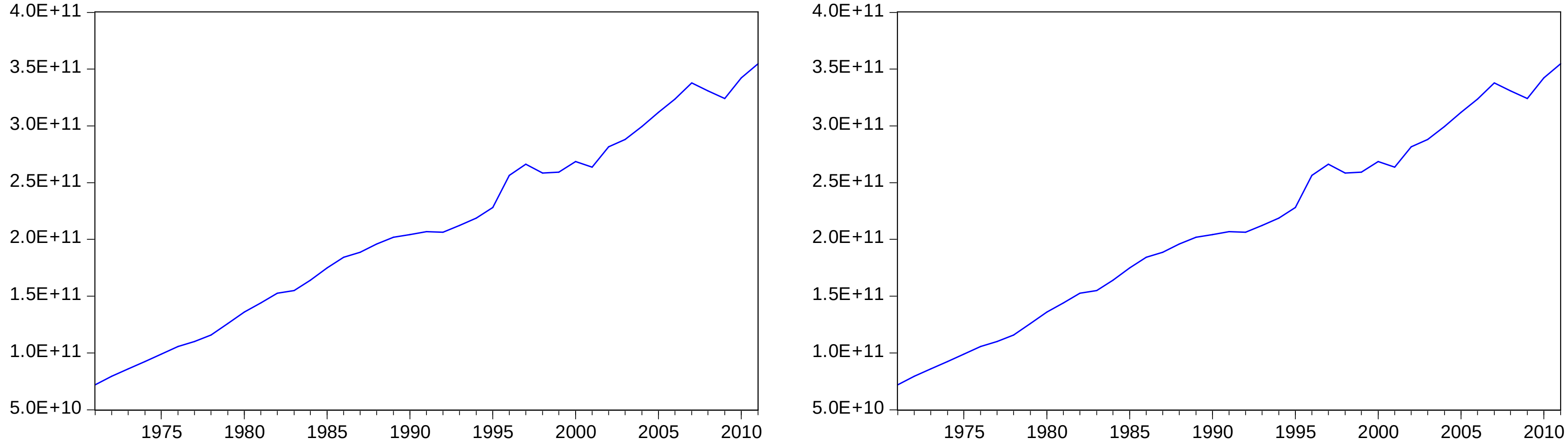


Figure 3-7: Electricity consumption and gross domestic product of Sub-Saharan Africa (developing only)

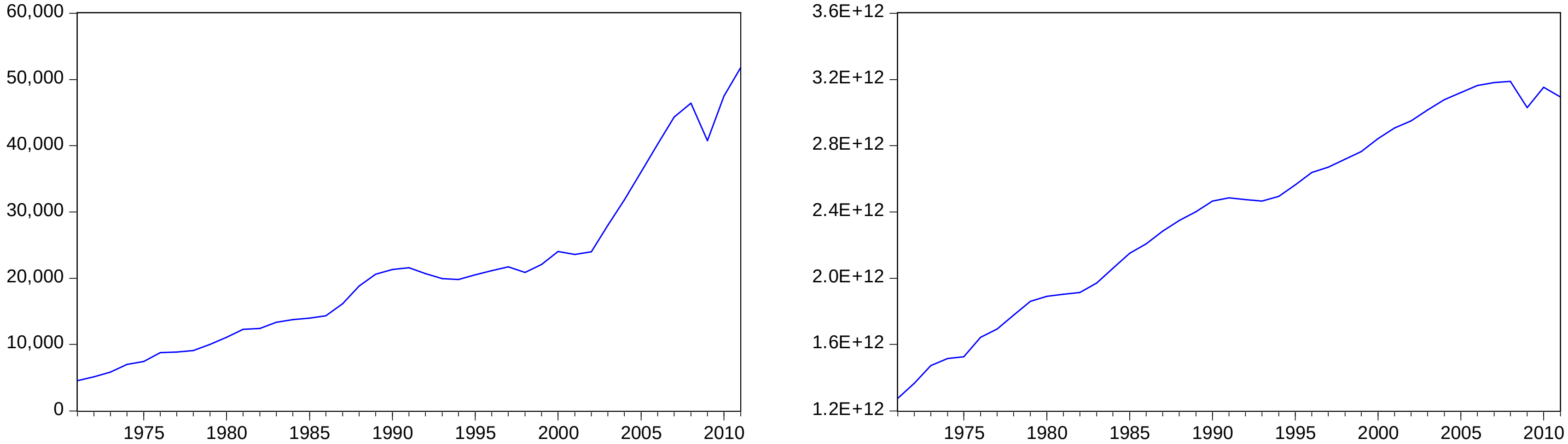


Figure 3-8: Electricity consumption and gross domestic product of Canada

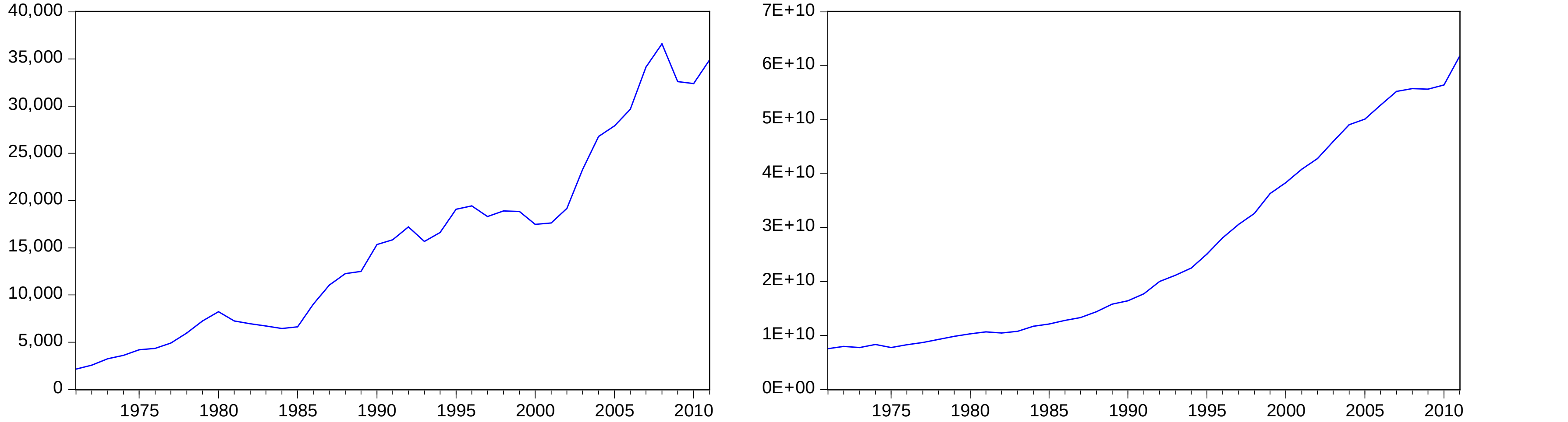


Figure 3-9: Electricity consumption and gross domestic product of European Union

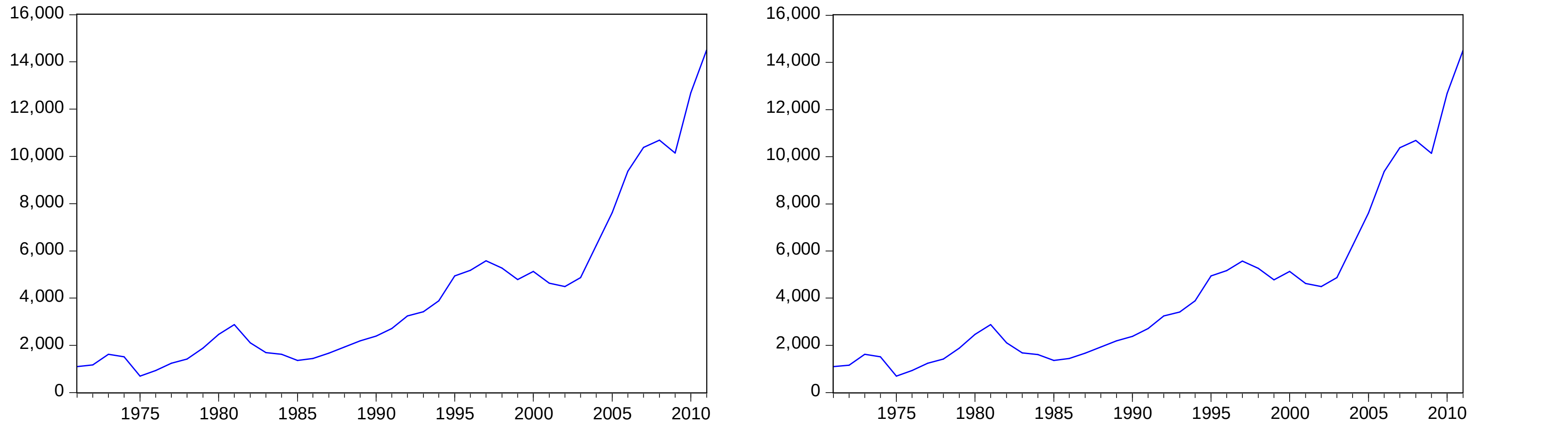


Figure 3-20: Electricity consumption and gross domestic product of Chile

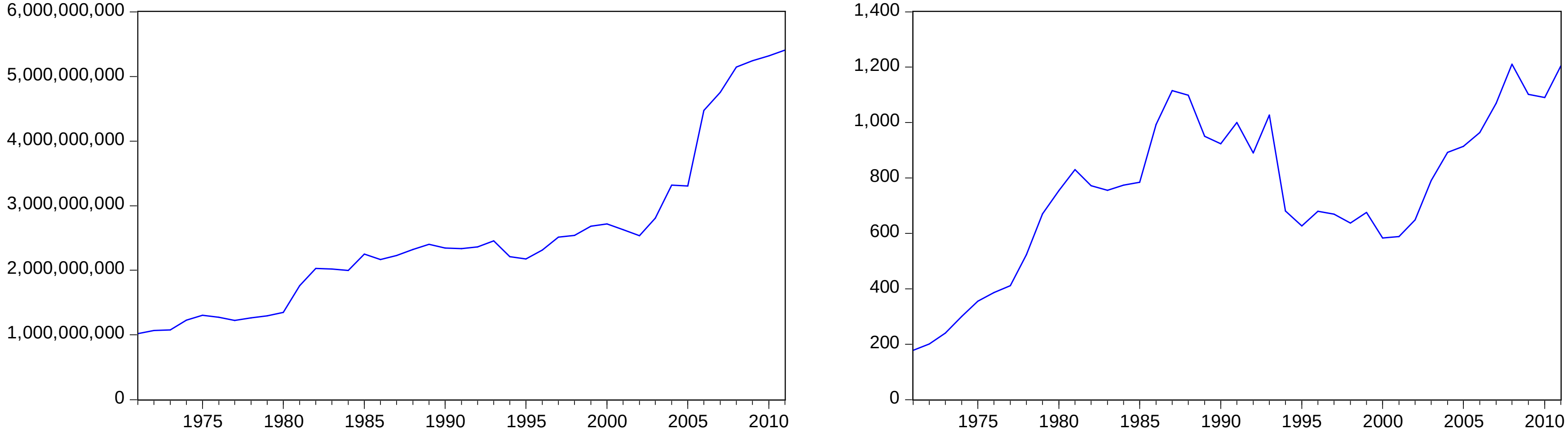


Figure 3-11: Electricity consumption and gross domestic product of China

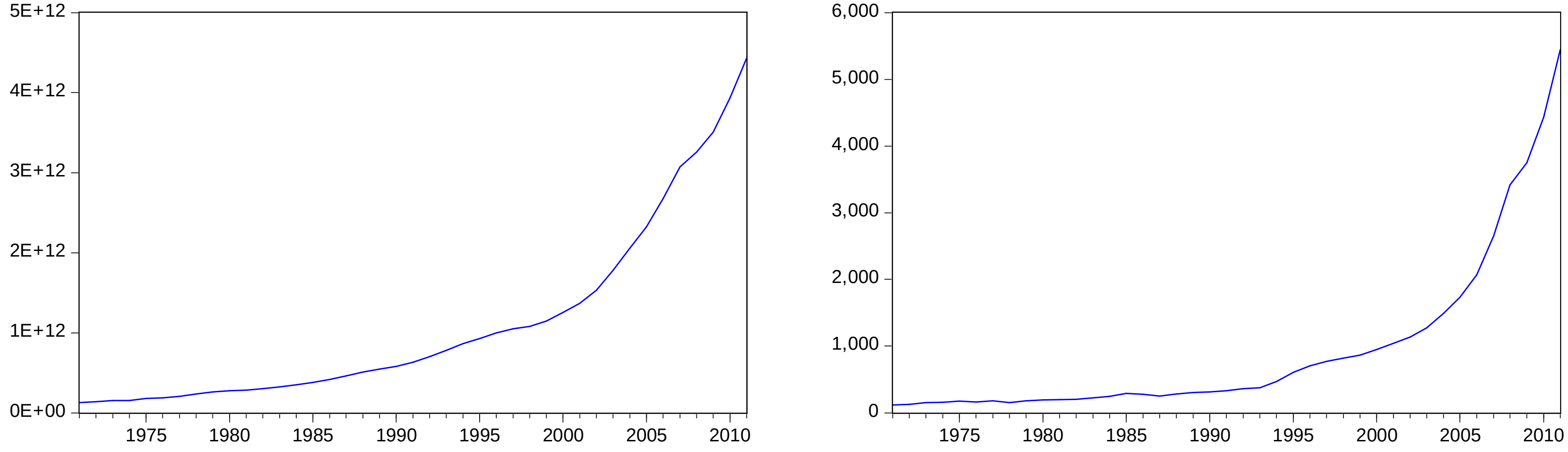


Figure 3-12: Electricity consumption and gross domestic product of Cameroon

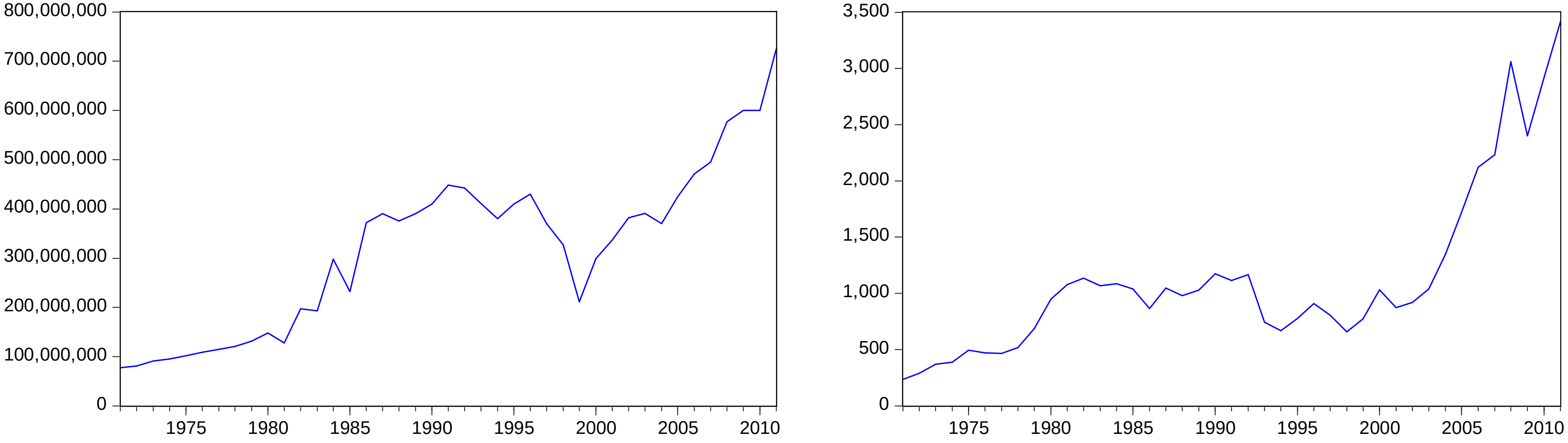


Figure 3-13: Electricity consumption and gross domestic product of Congo, Rep.

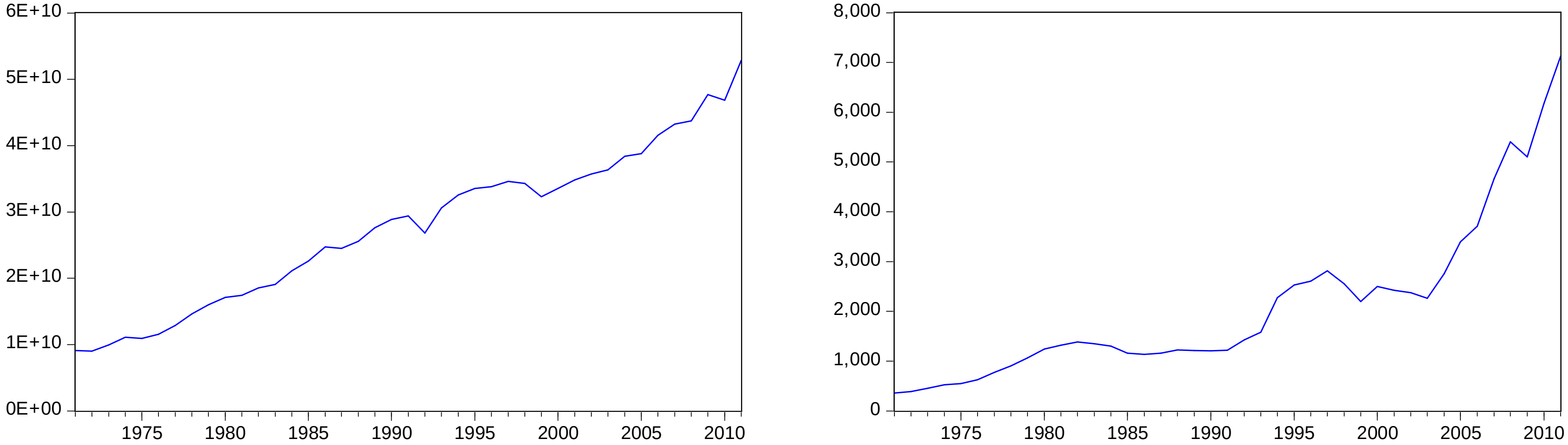


Figure 3-14: Electricity consumption and gross domestic product of Colombia

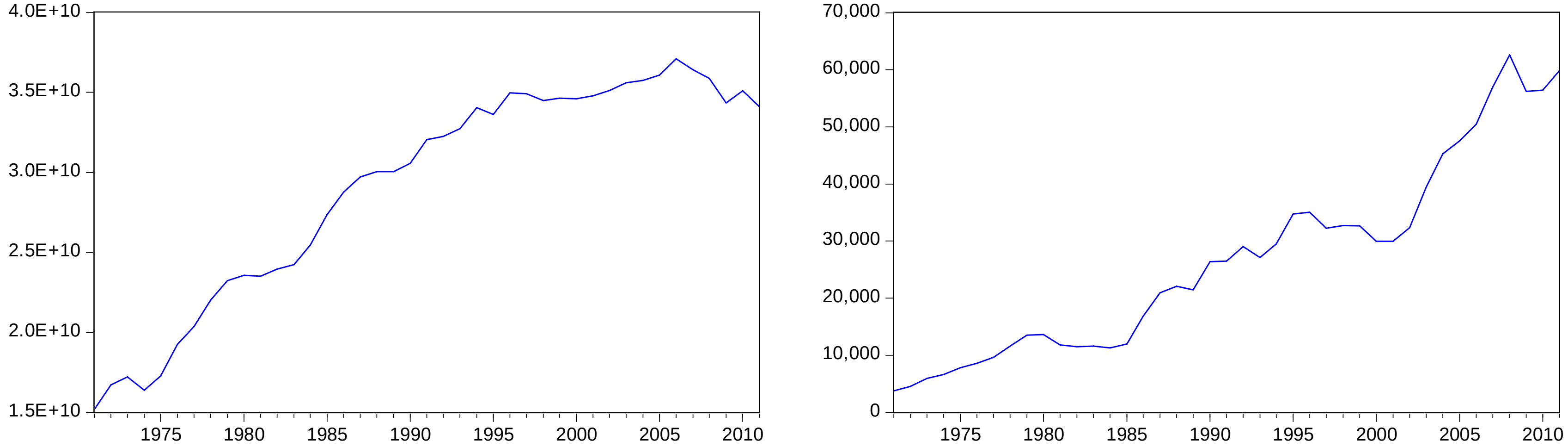


Figure 3-15: Electricity consumption and gross domestic product of Costa Rica

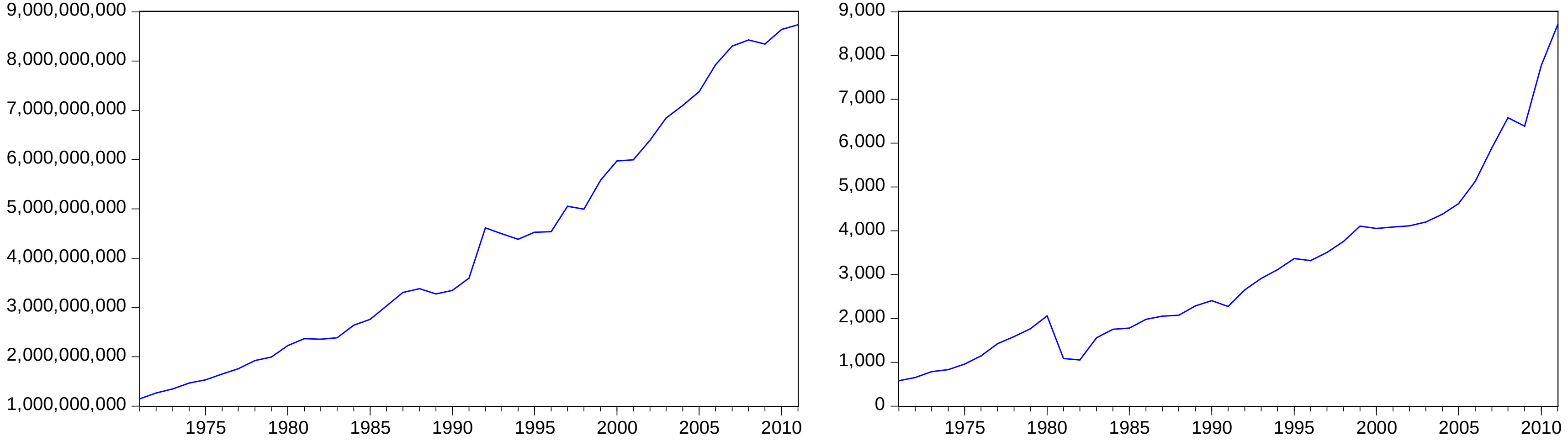


Figure 3-16: Electricity consumption and gross domestic product of Denmark

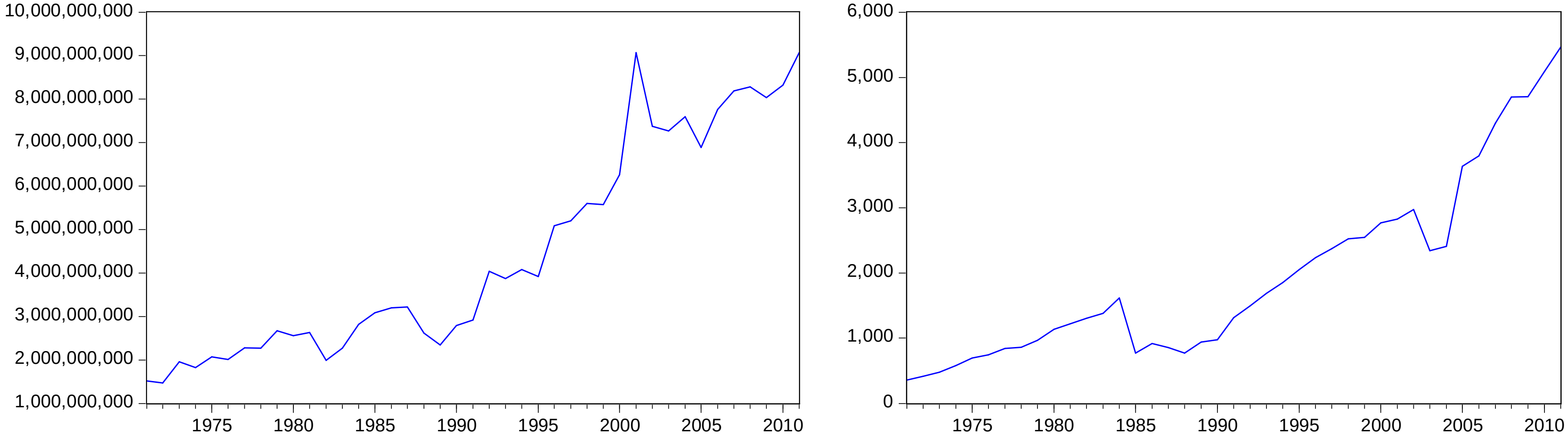


Figure 3-17: Electricity consumption and gross domestic product of Dominican Republic

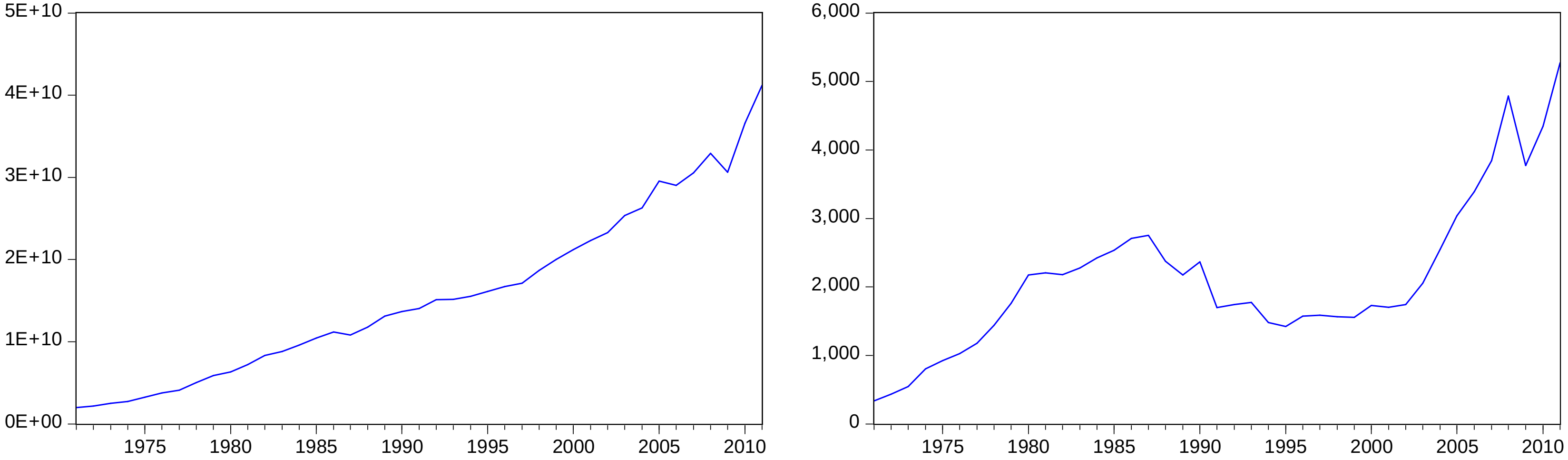


Figure 3-18: Electricity consumption and gross domestic product of Algeria

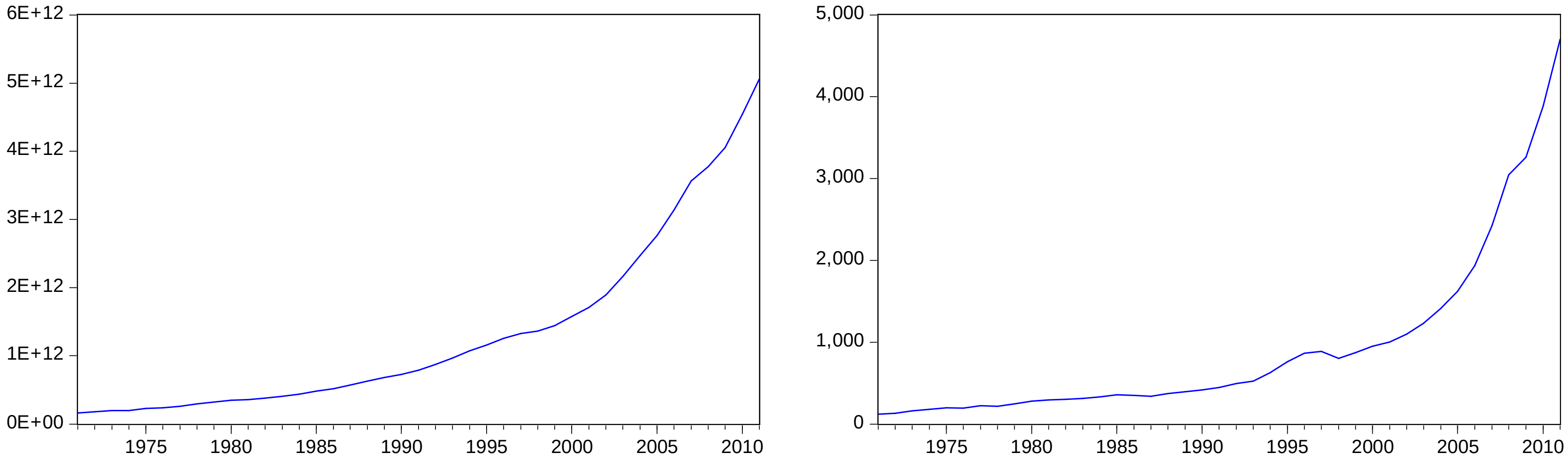


Figure 3-19: Electricity consumption and gross domestic product of East Asia & Pacific (developing only)

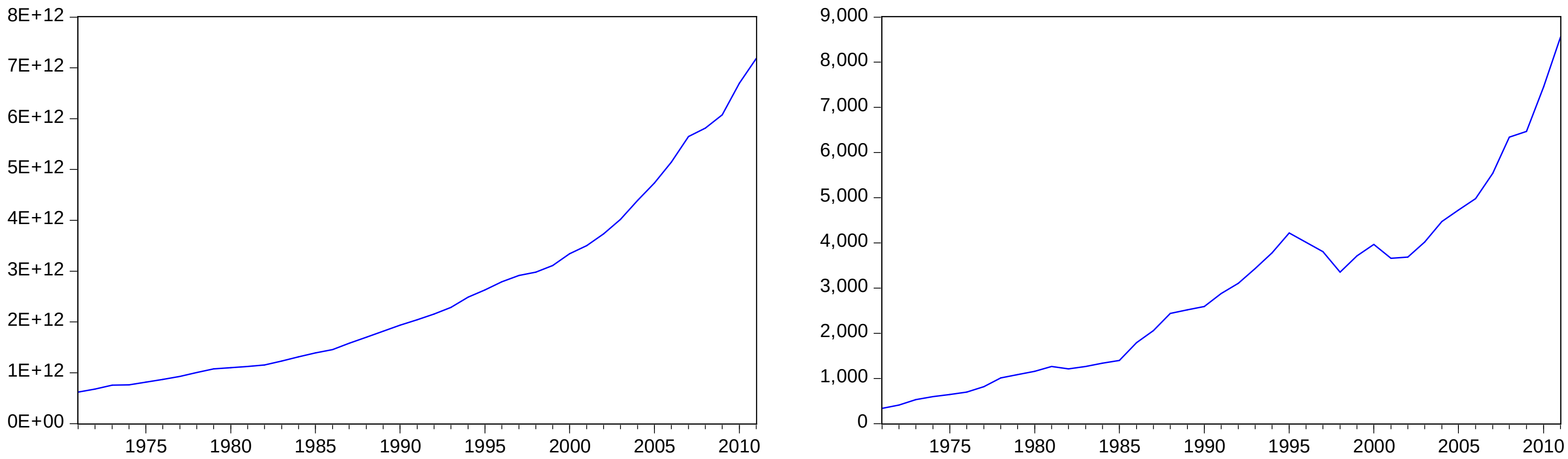
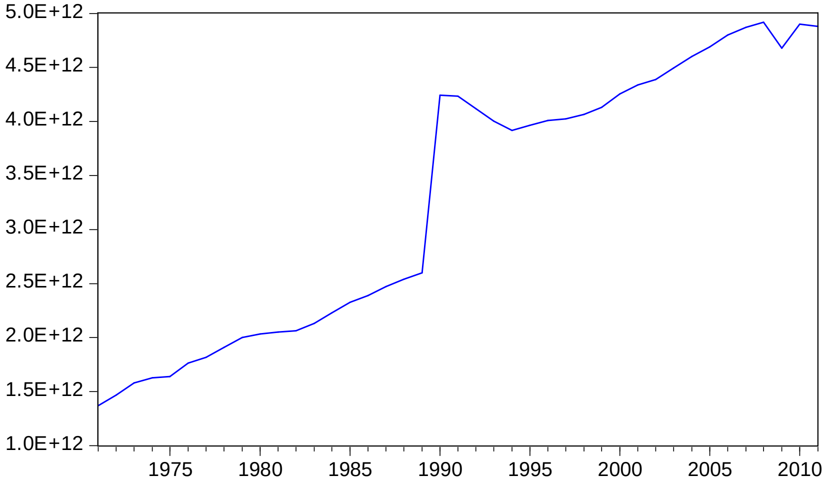


Figure 3-20: Electricity consumption and gross domestic product of East Asia & Pacific (all income levels)



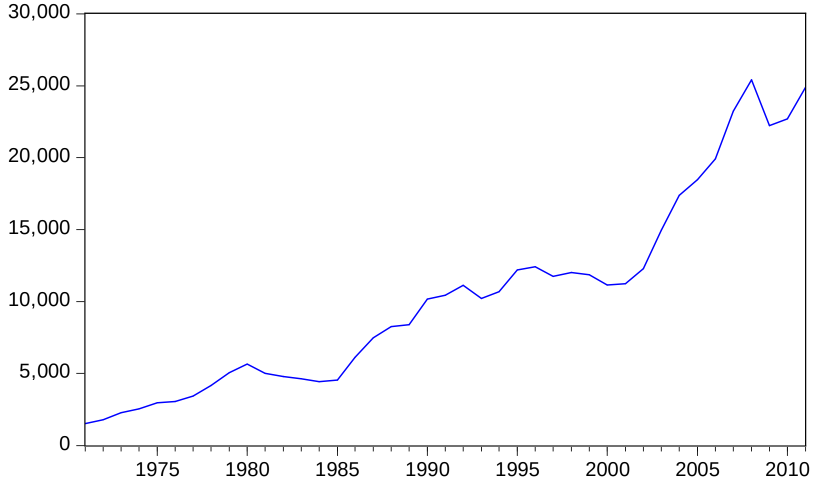
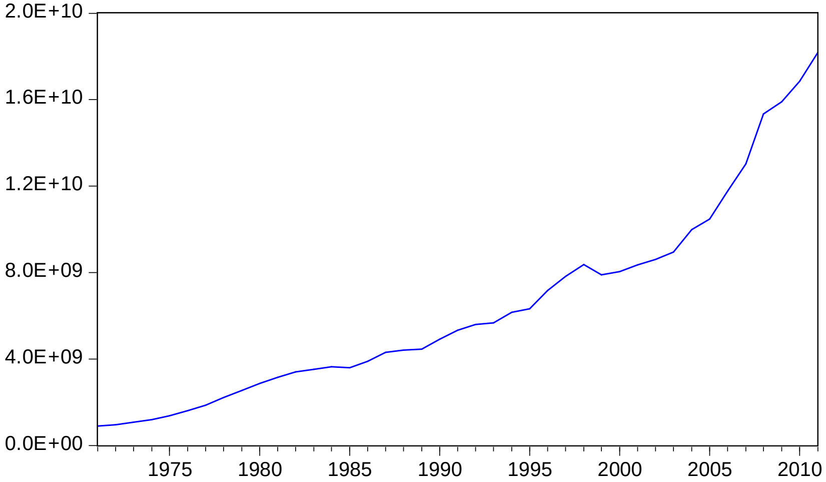


Figure 3-21: Electricity consumption and gross domestic product of Europe & Central Asia (all income levels)



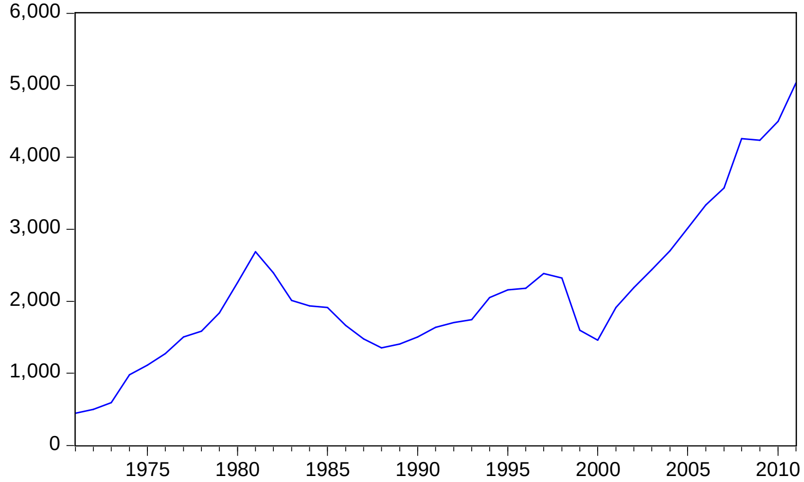


Figure 3-22: Electricity consumption and gross domestic product of Ecuador

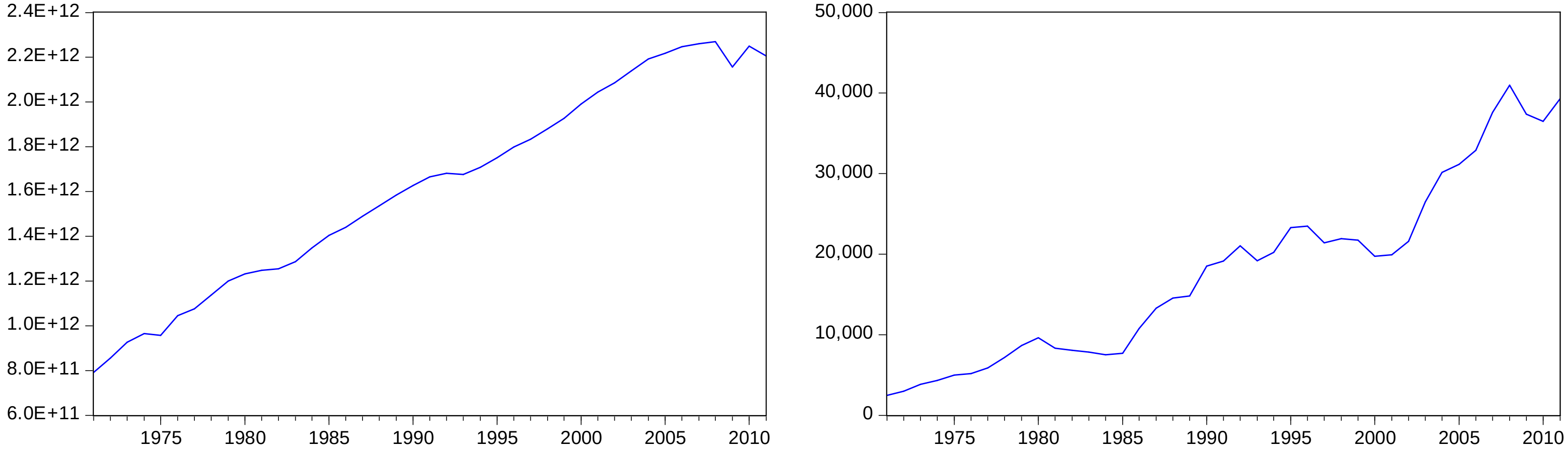


Figure 3-23: Electricity consumption and gross domestic product of Euro area

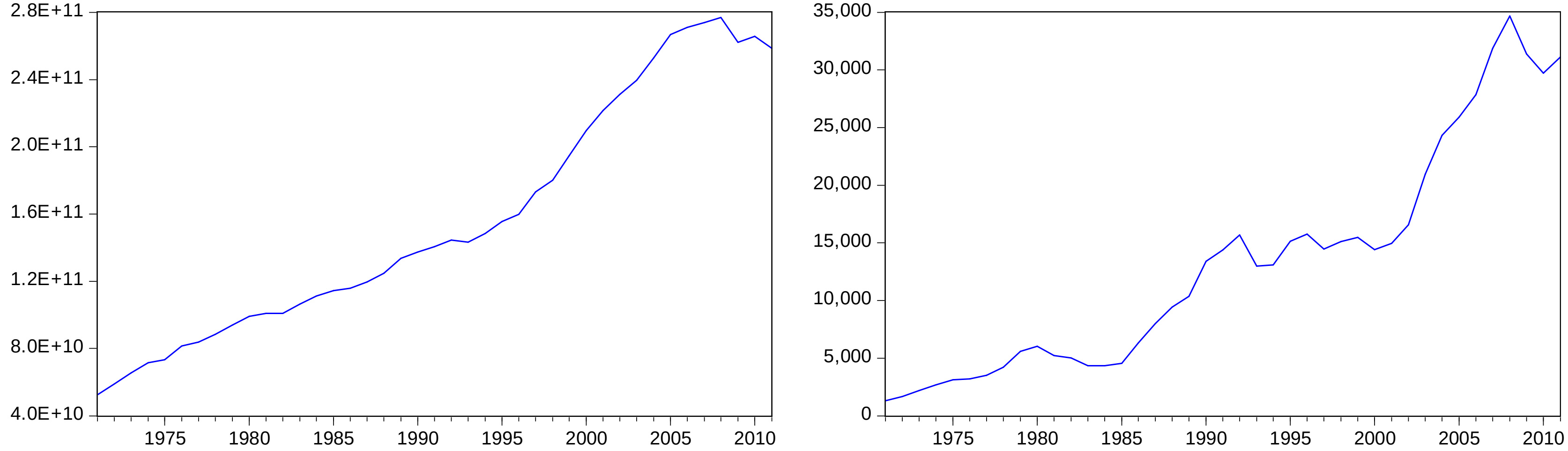


Figure 3-24: Electricity consumption and gross domestic product of Spain

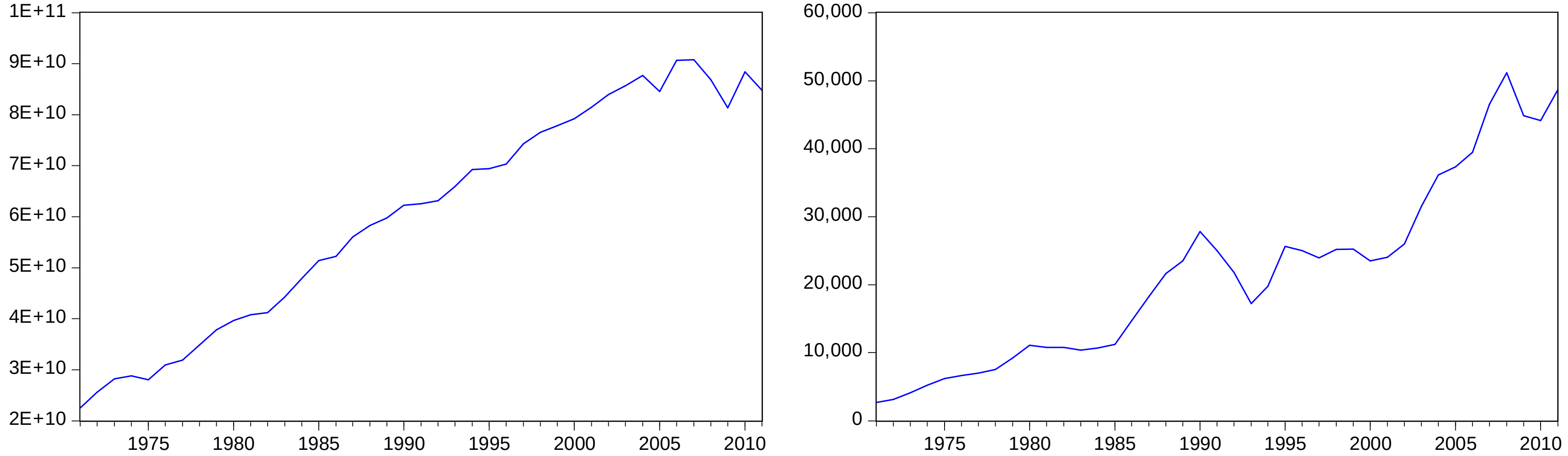


Figure 3-25: Electricity consumption and gross domestic product of Finland

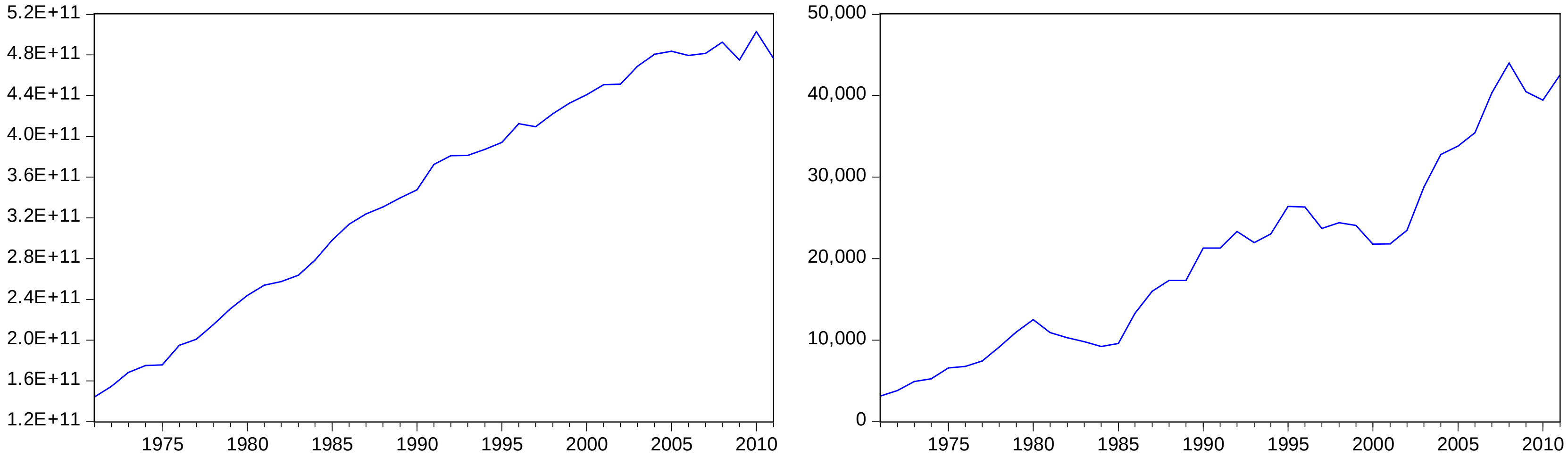


Figure 3-26: Electricity consumption and gross domestic product of France

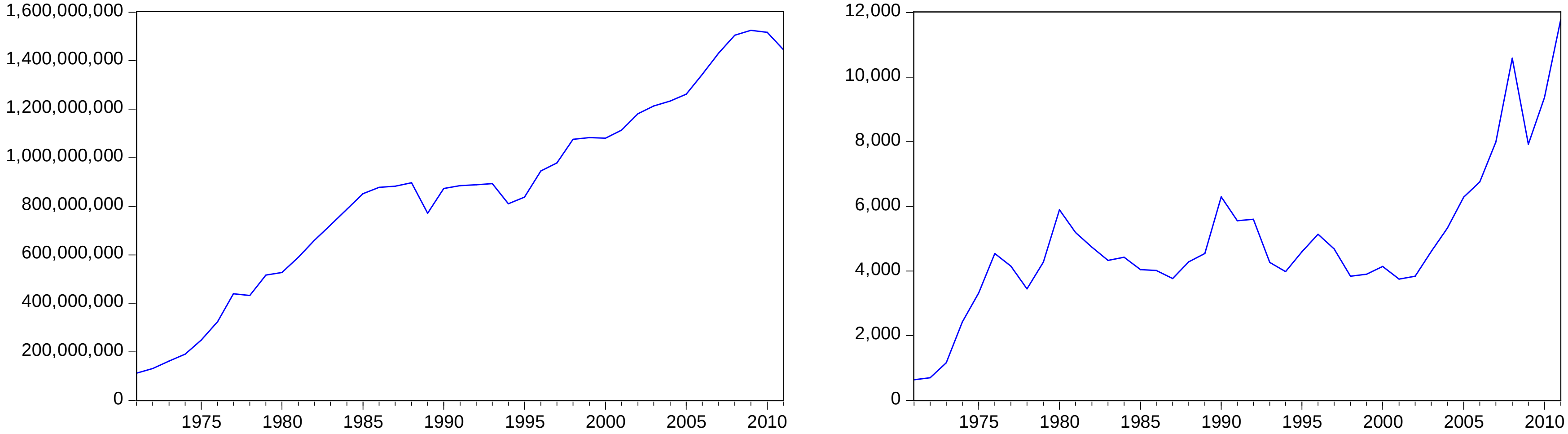


Figure 3-27: Electricity consumption and gross domestic product of Gabon

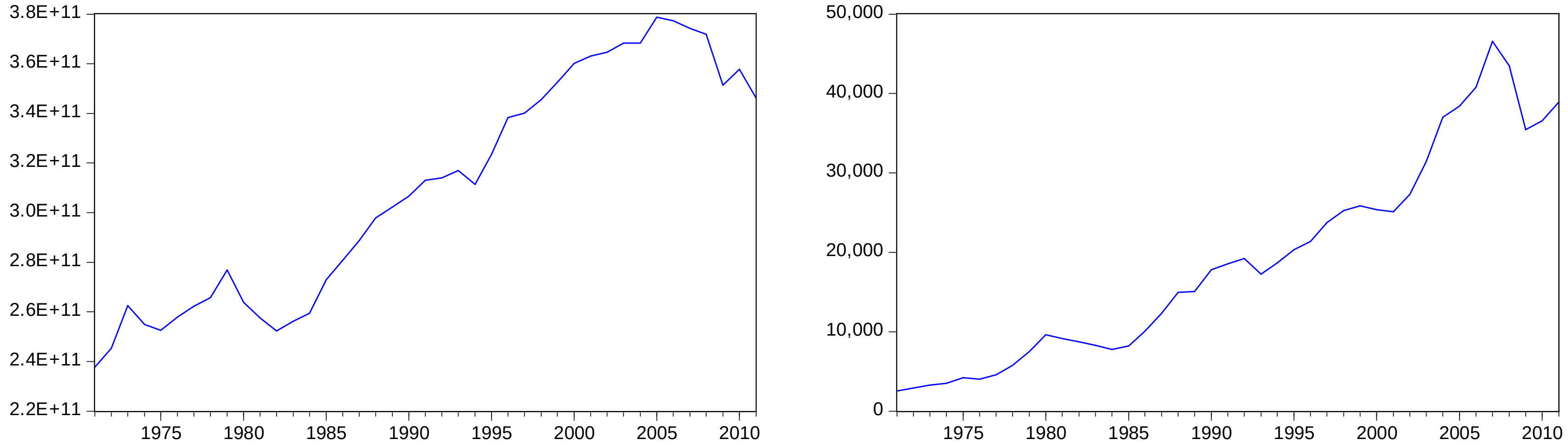


Figure 3-28: Electricity consumption and gross domestic product of United Kingdom

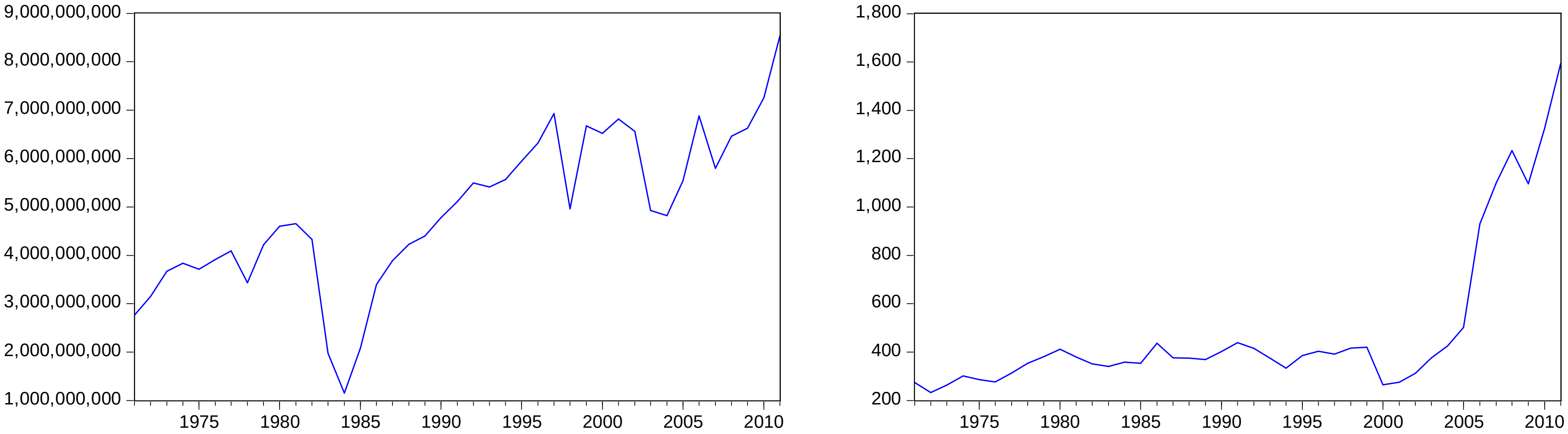


Figure 3‐29: Electricity consumption and gross domestic product of Ghana

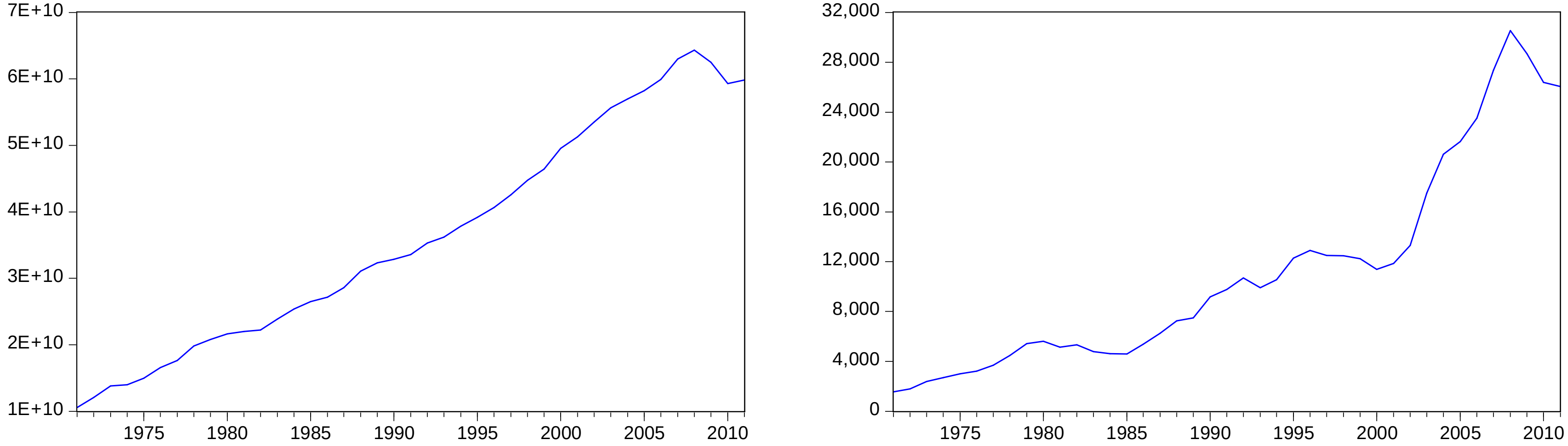


Figure 3‐30: Electricity consumption and gross domestic product of Greece

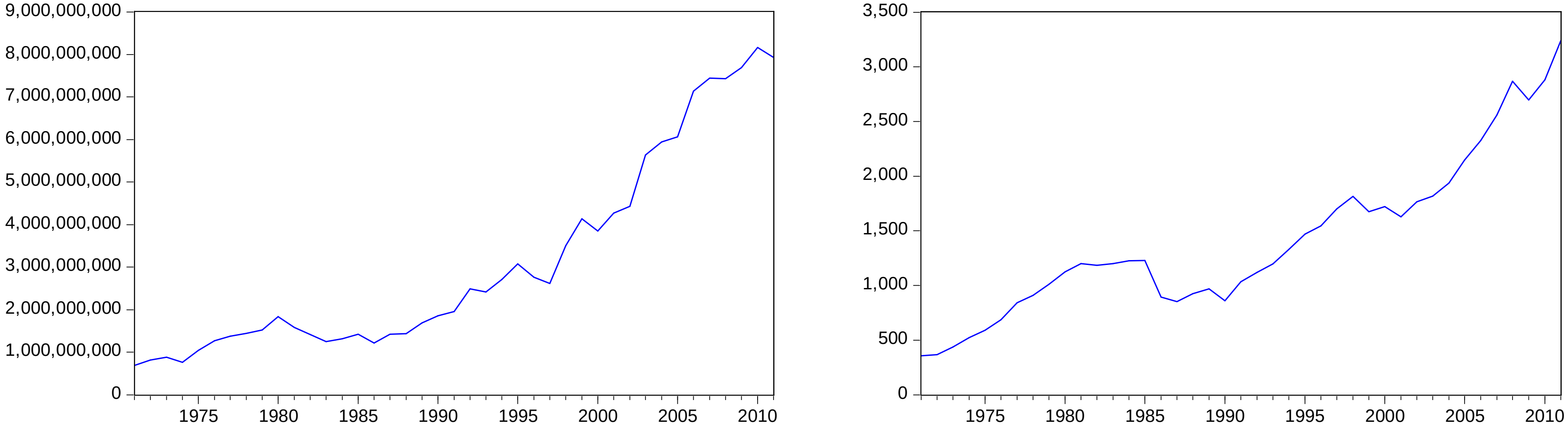


Figure 3-31: Electricity consumption and gross domestic product of Guatemala

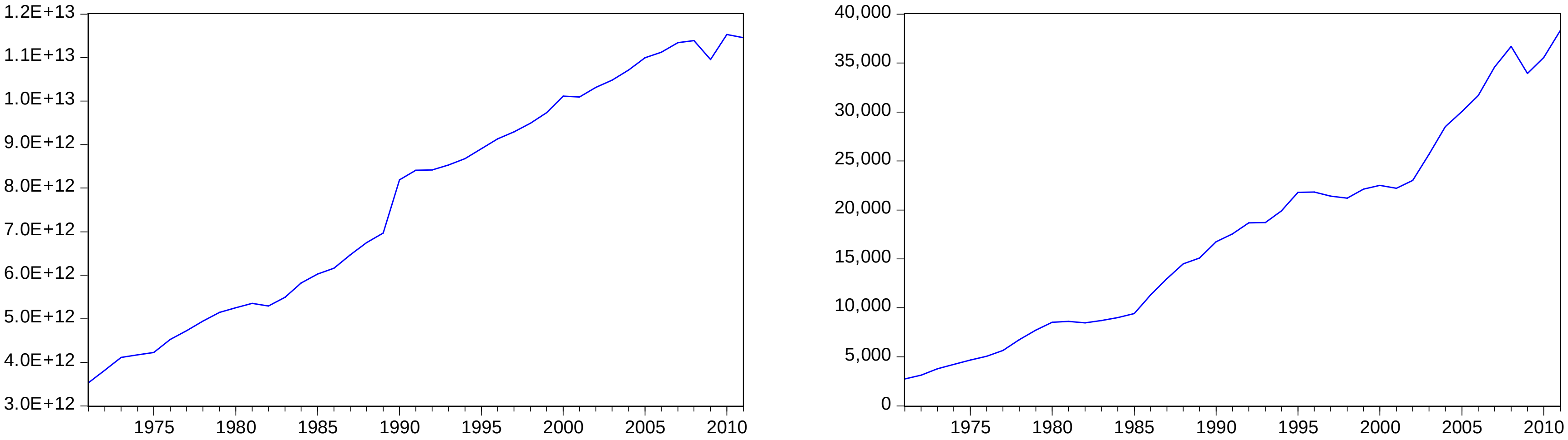


Figure 3-32: Electricity consumption and gross domestic product of High income

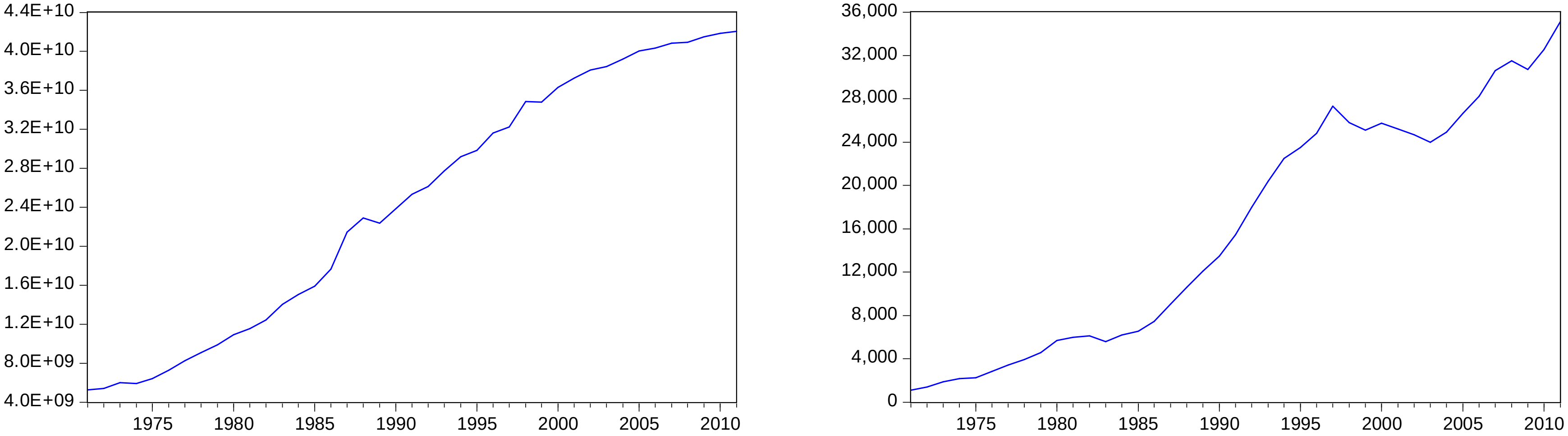


Figure 3-33: Electricity consumption and gross domestic product of Hong Kong SAR, China

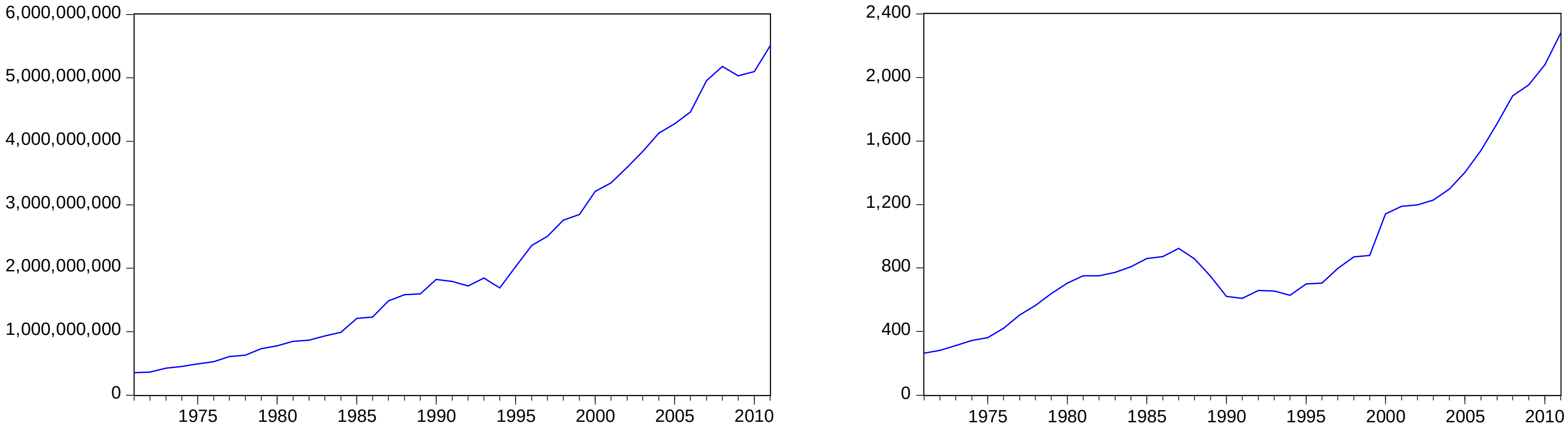


Figure 3-34: Electricity consumption and gross domestic product of Honduras

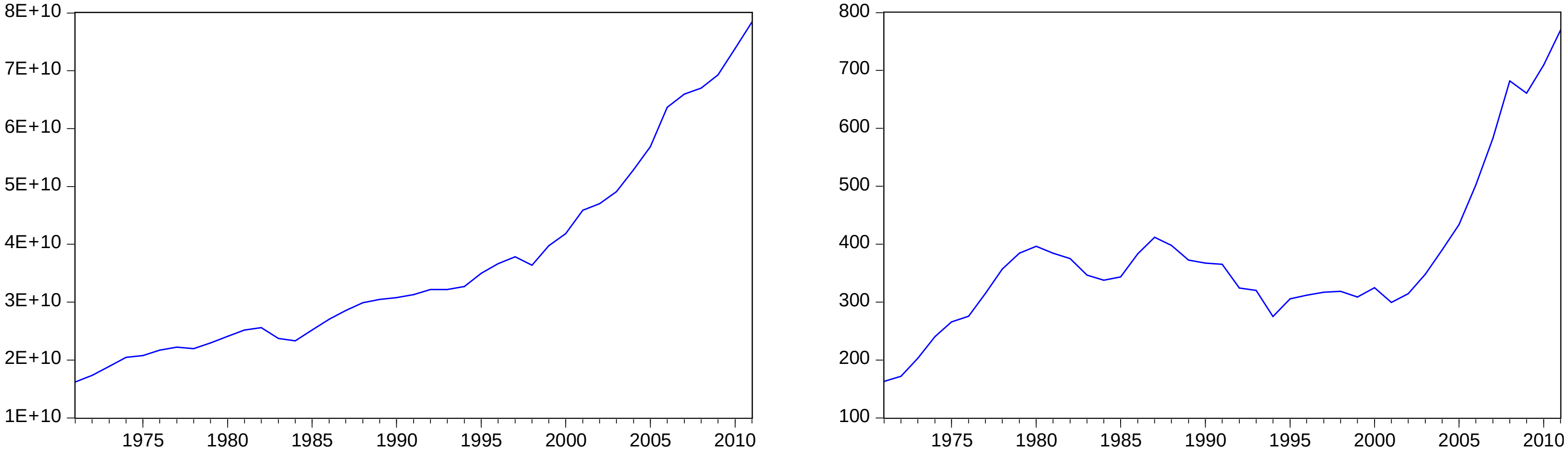


Figure 3‐35: Electricity consumption and gross domestic product of Heavily indebted poor countries (HIPC)

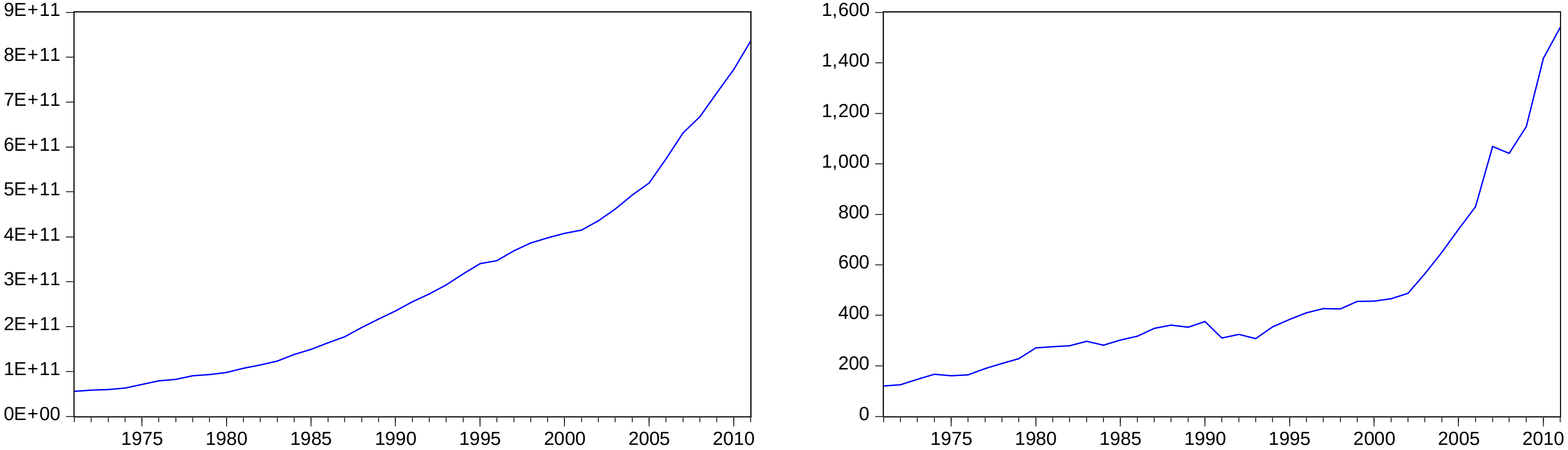


Figure 3‐36: Electricity consumption and gross domestic product of India

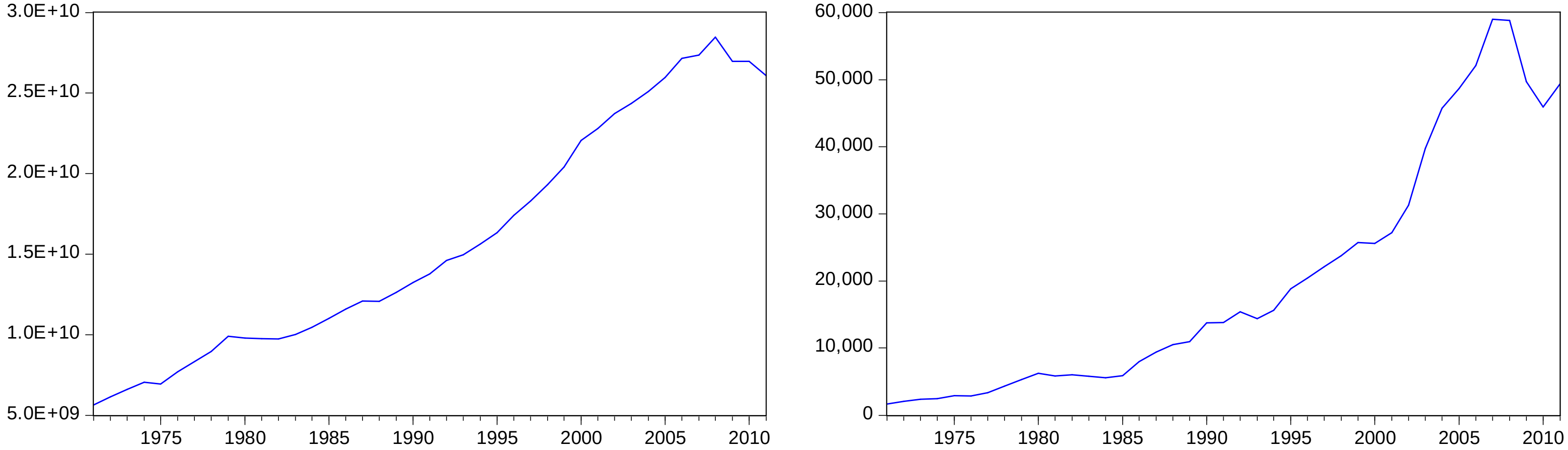


Figure 3-37: Electricity consumption and gross domestic product of Ireland

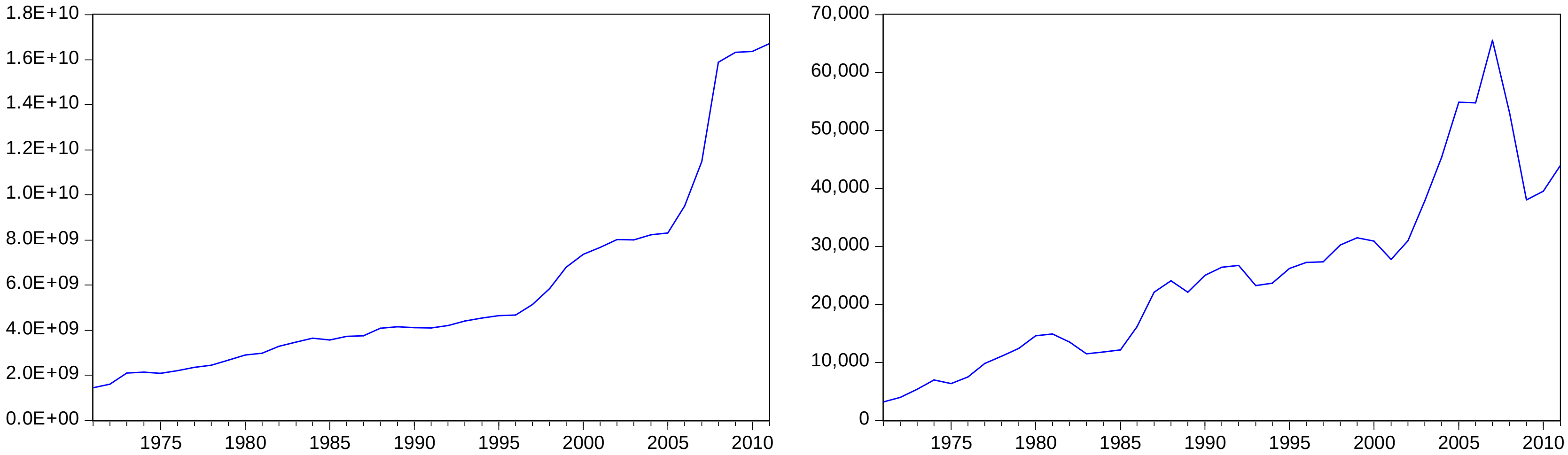


Figure 3-38: Electricity consumption and gross domestic product of Iceland

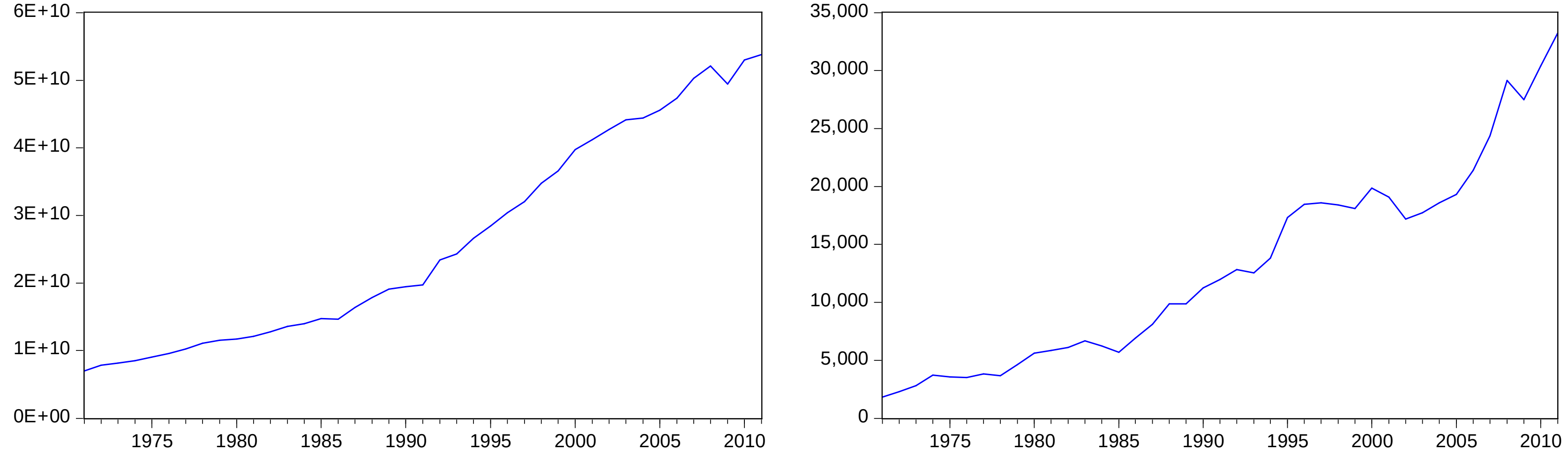


Figure 3-39: Electricity consumption and gross domestic product of Israel

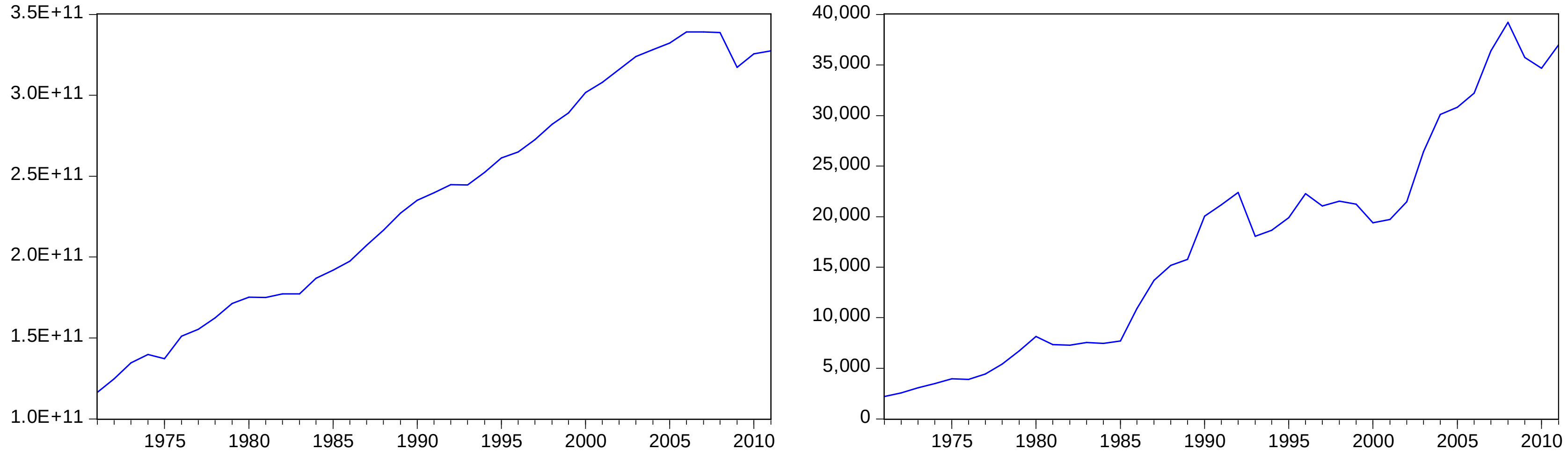


Figure 3-40: Electricity consumption and gross domestic product of Italy

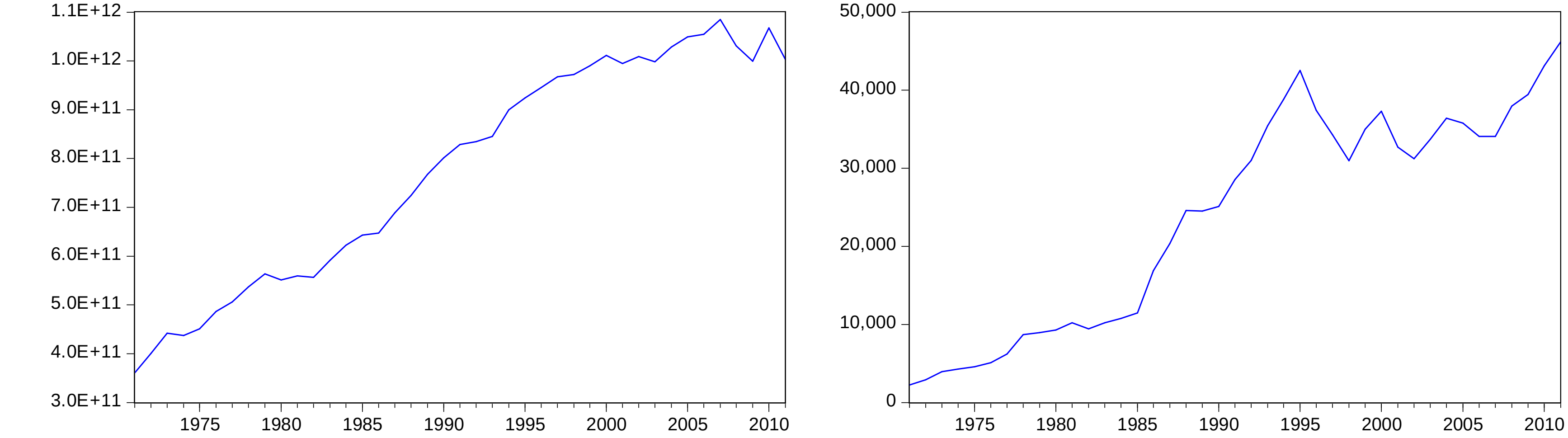


Figure 3-41: Electricity consumption and gross domestic product of Japan

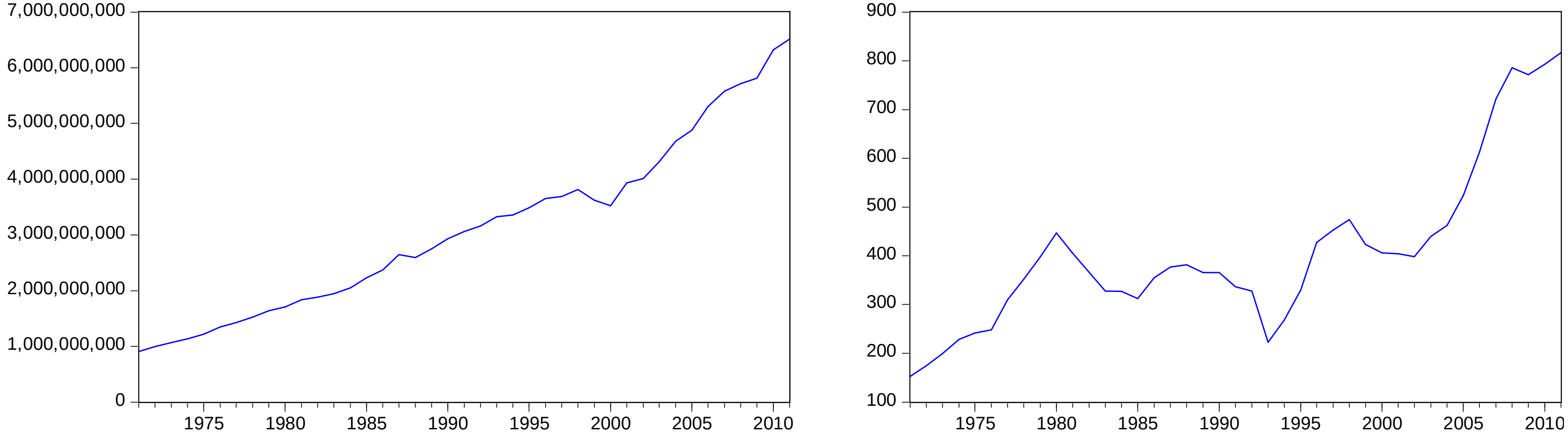


Figure 3-42: Electricity consumption and gross domestic product of Kenya

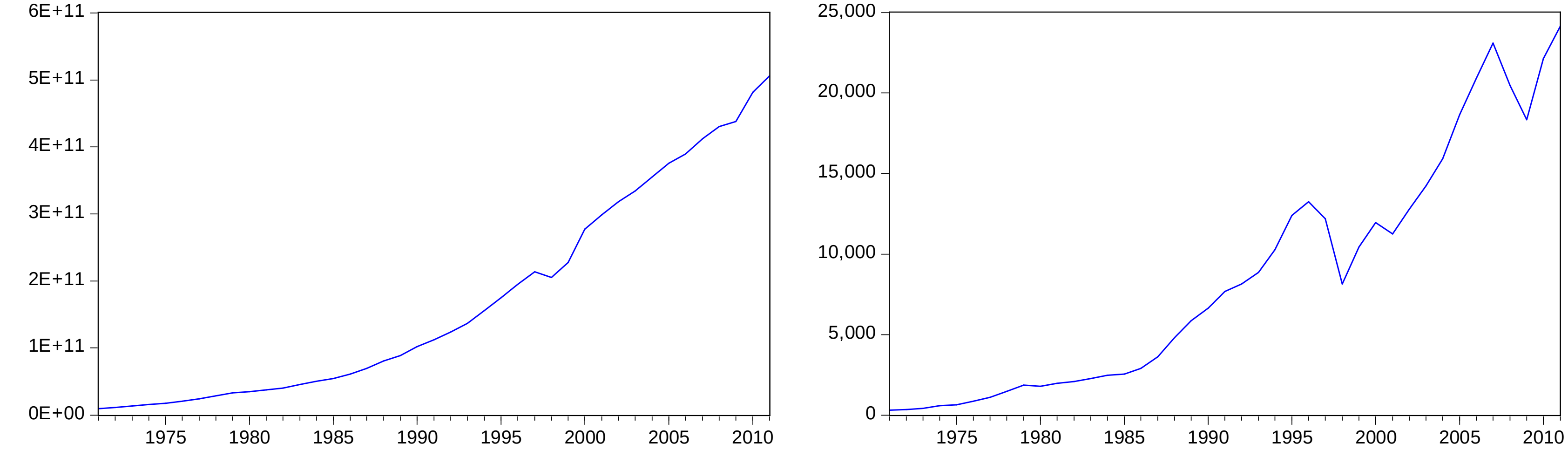


Figure 3-43: Electricity consumption and gross domestic product of Korea, Rep.

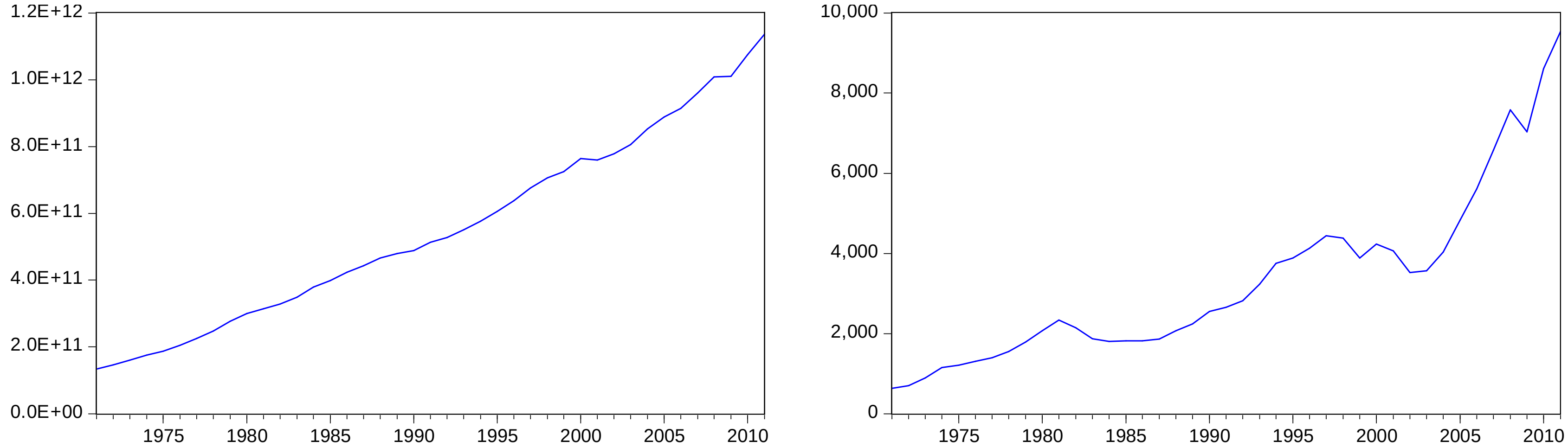


Figure 3-44: Electricity consumption and gross domestic product of Latin America & Caribbean (developing only)

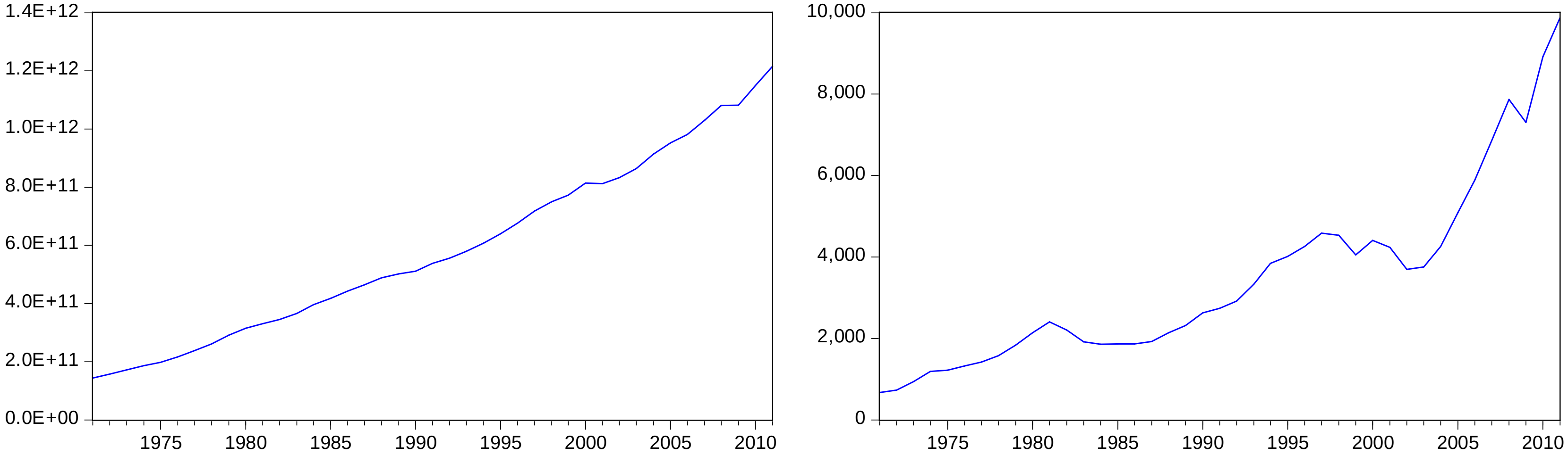


Figure 3-45: Electricity consumption and gross domestic product of Latin America & Caribbean (all income levels)

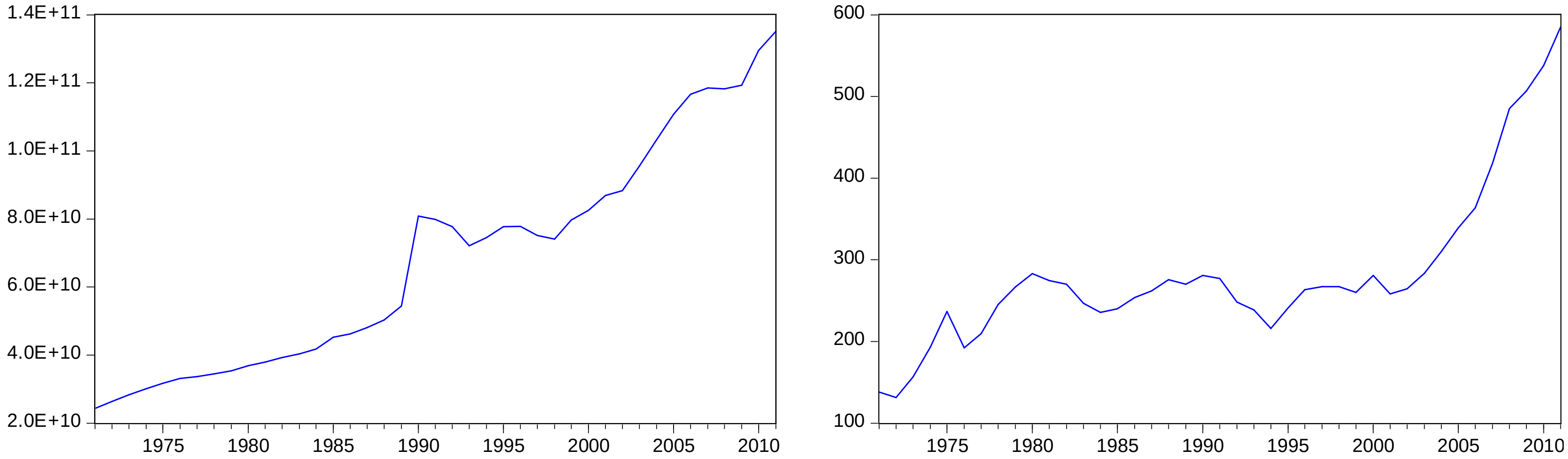


Figure 3-46: Electricity consumption and gross domestic product of Low income

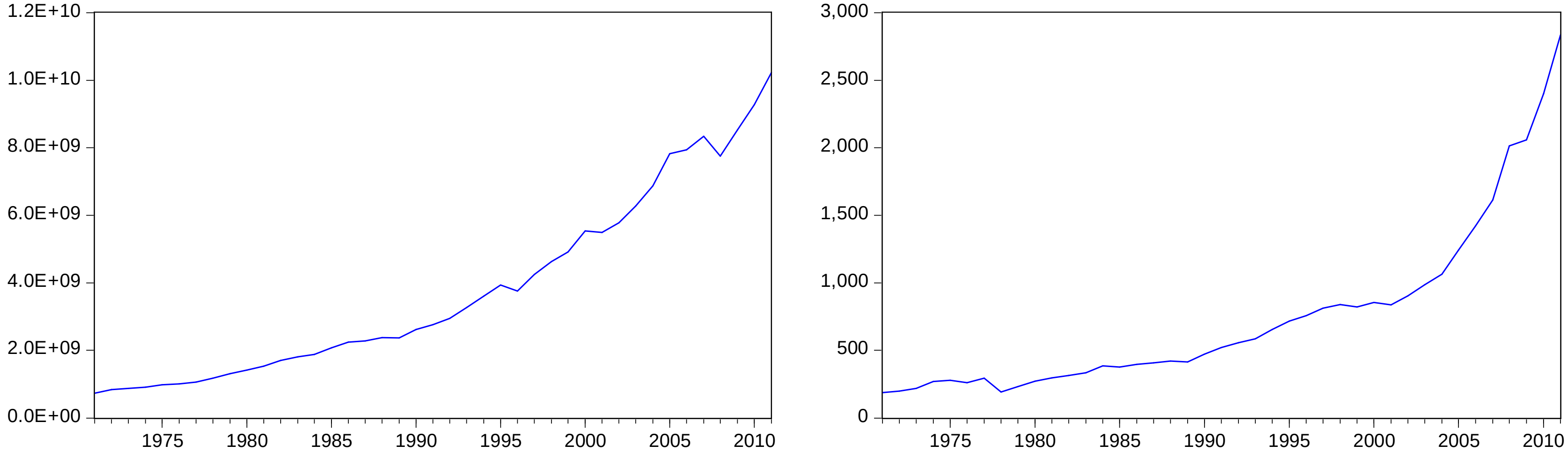


Figure 3-47: Electricity consumption and gross domestic product of Sri Lanka

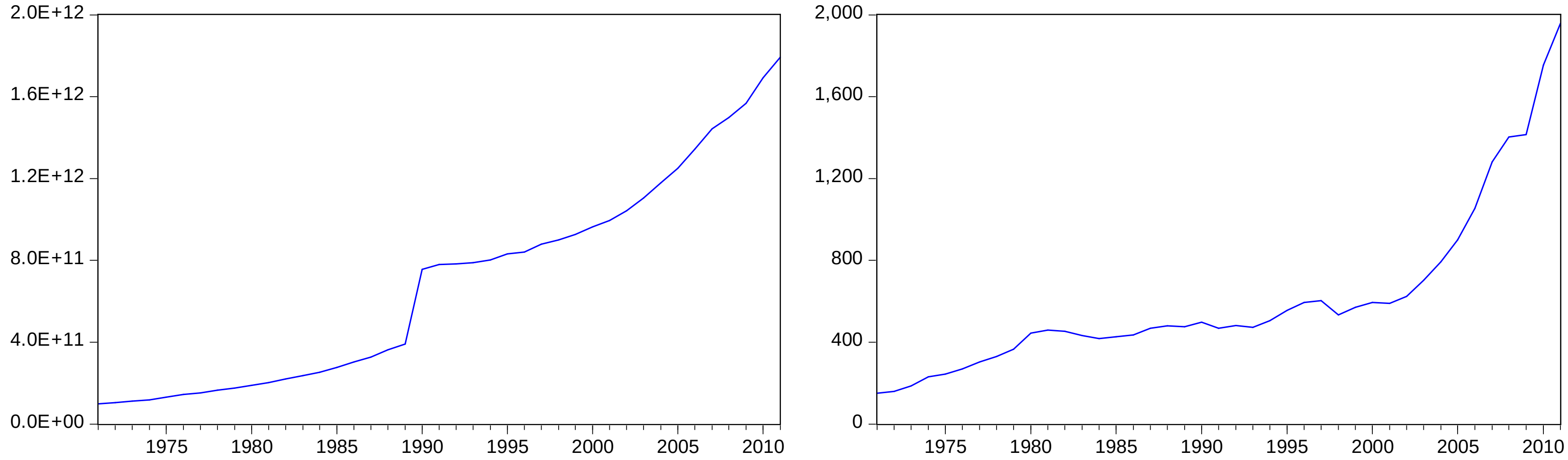


Figure 3-48: Electricity consumption and gross domestic product of Lower middle income

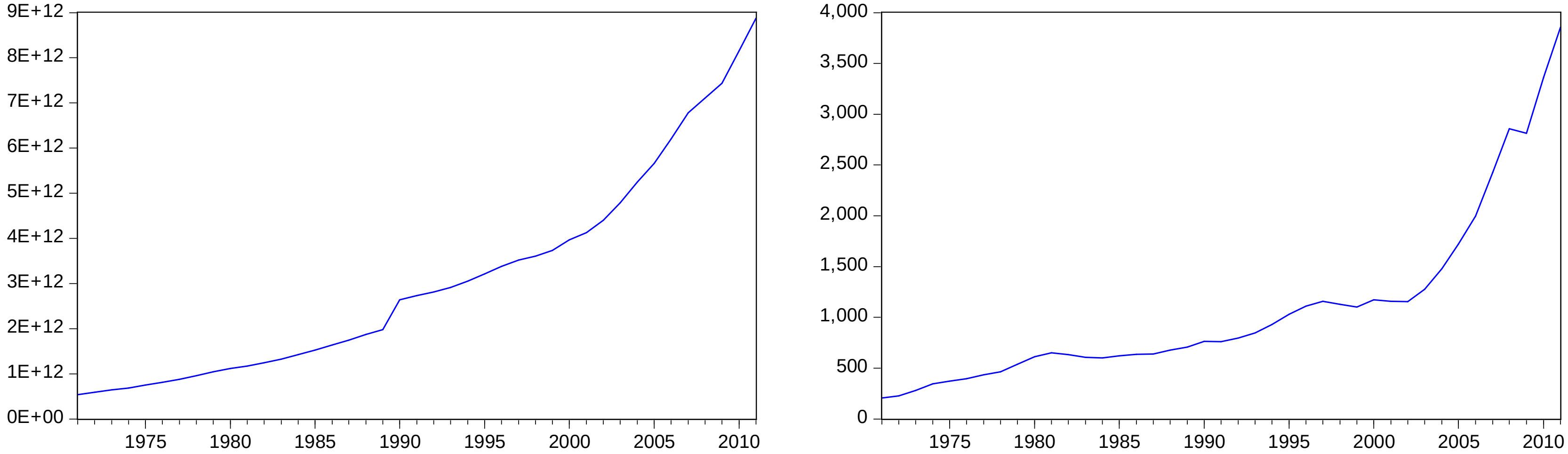


Figure 3-49: Electricity consumption and gross domestic product of Low & middle income

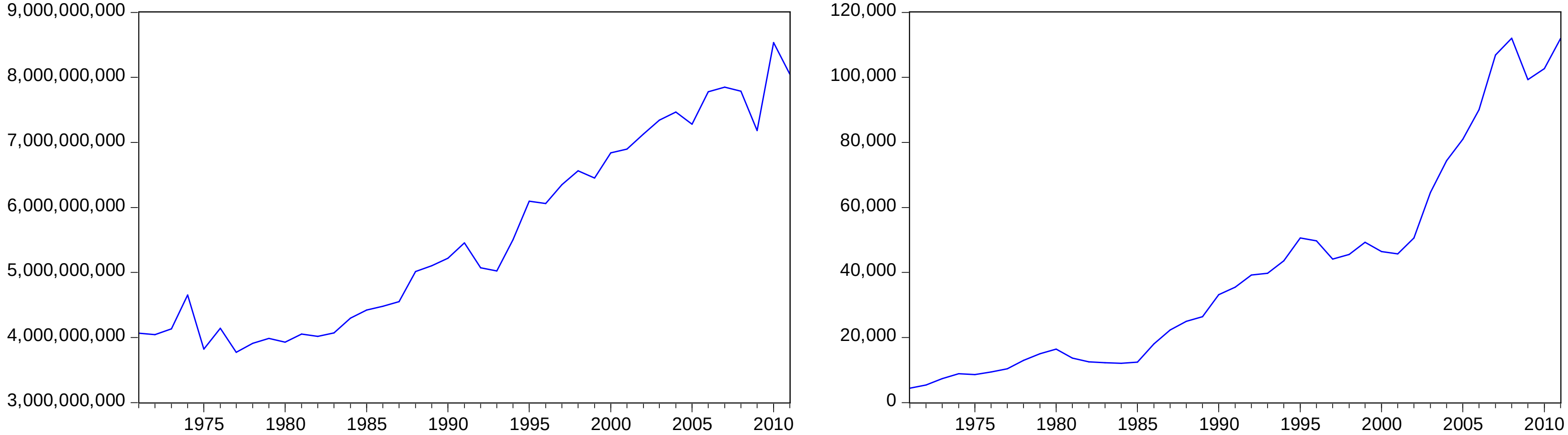


Figure 3-50: Electricity consumption and gross domestic product of Luxembourg

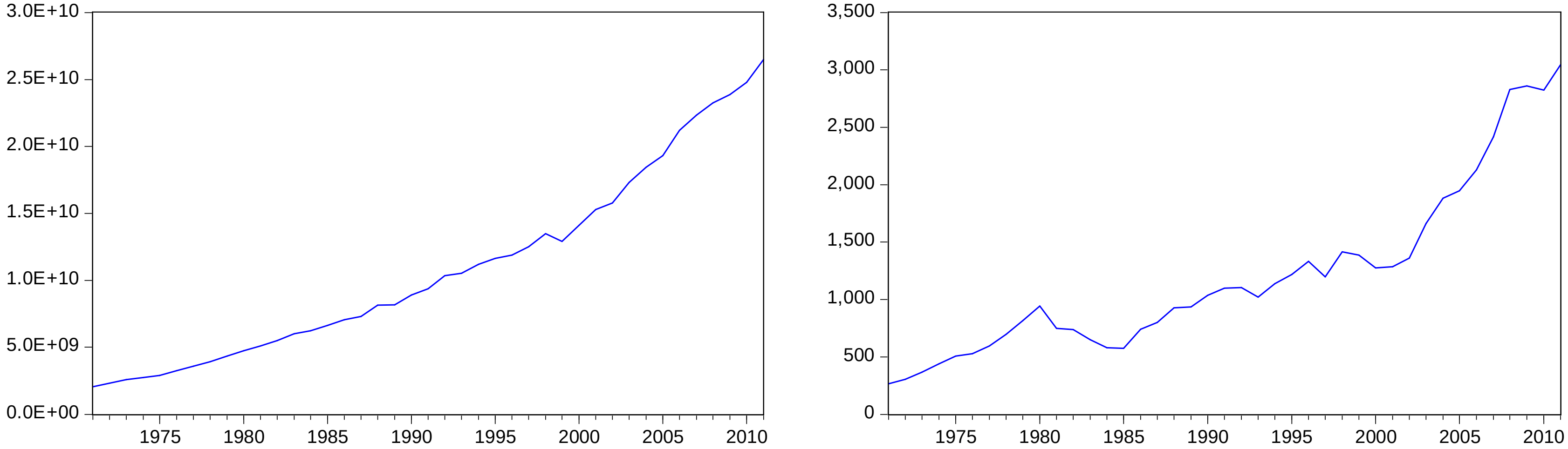


Figure 3-51: Electricity consumption and gross domestic product of Morocco

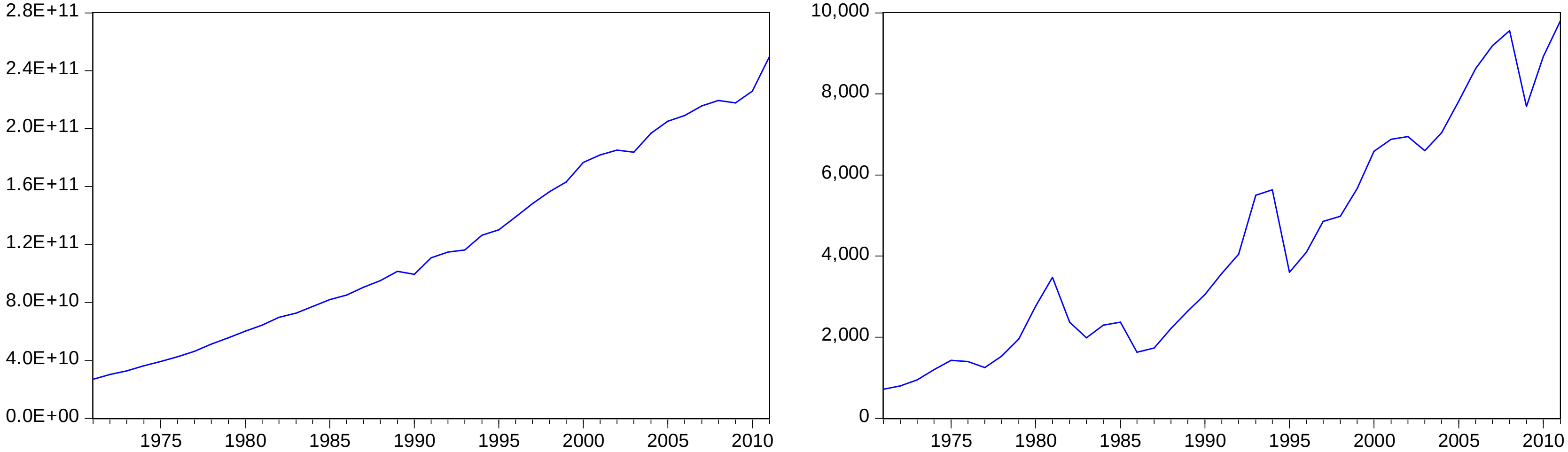


Figure 3-52: Electricity consumption and gross domestic product of Mexico

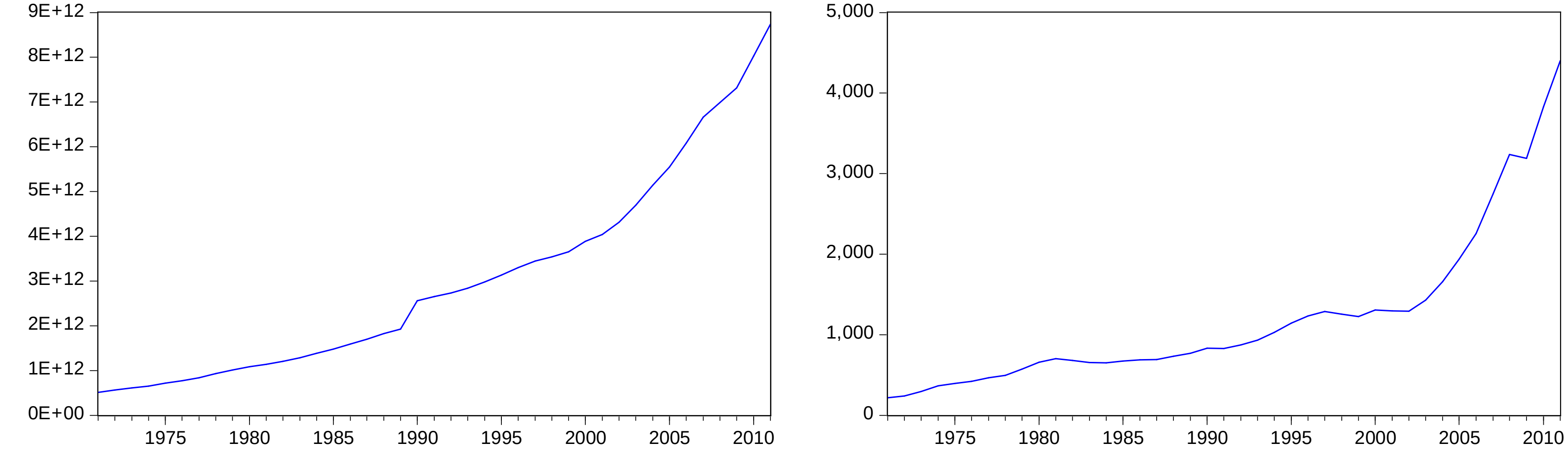


Figure 3‑53: Electricity consumption and gross domestic product of Middle income

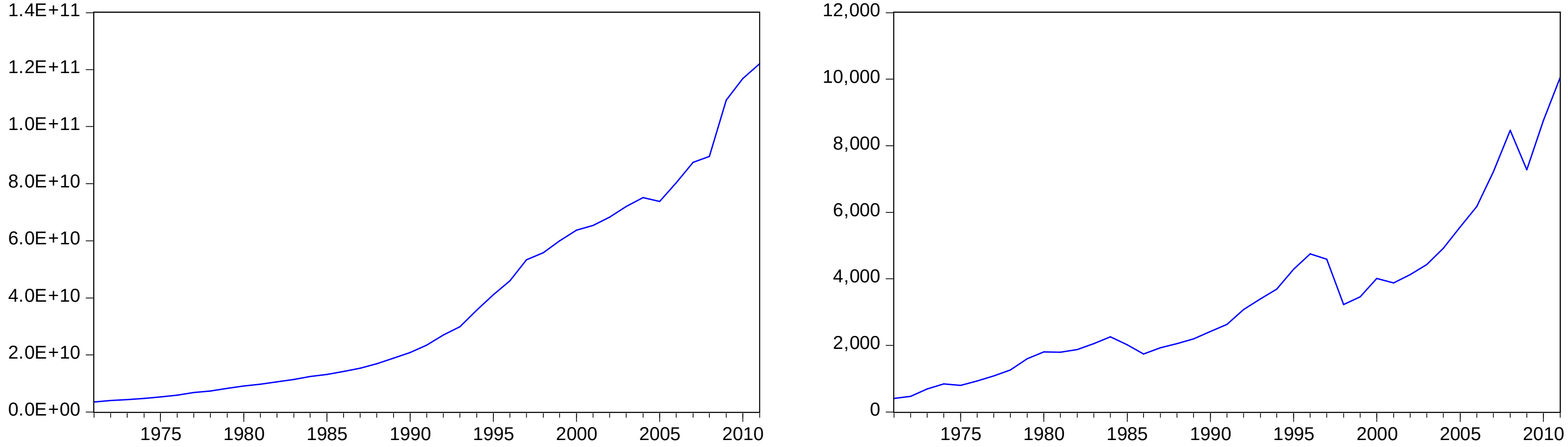


Figure 3‑54: Electricity consumption and gross domestic product of Malaysia

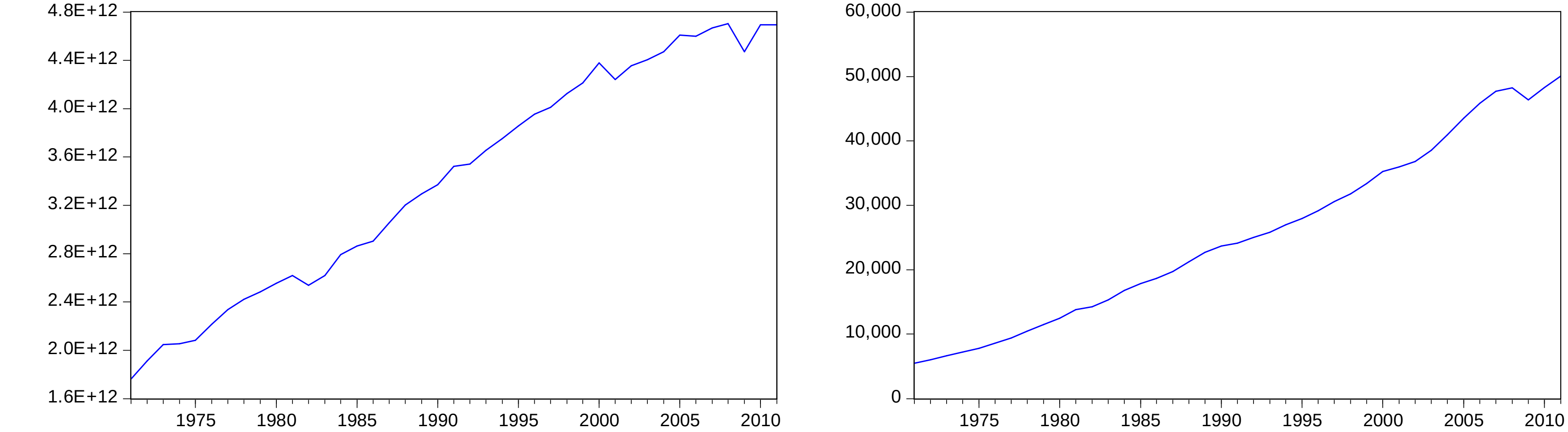


Figure 3-55: Electricity consumption and gross domestic product of North America

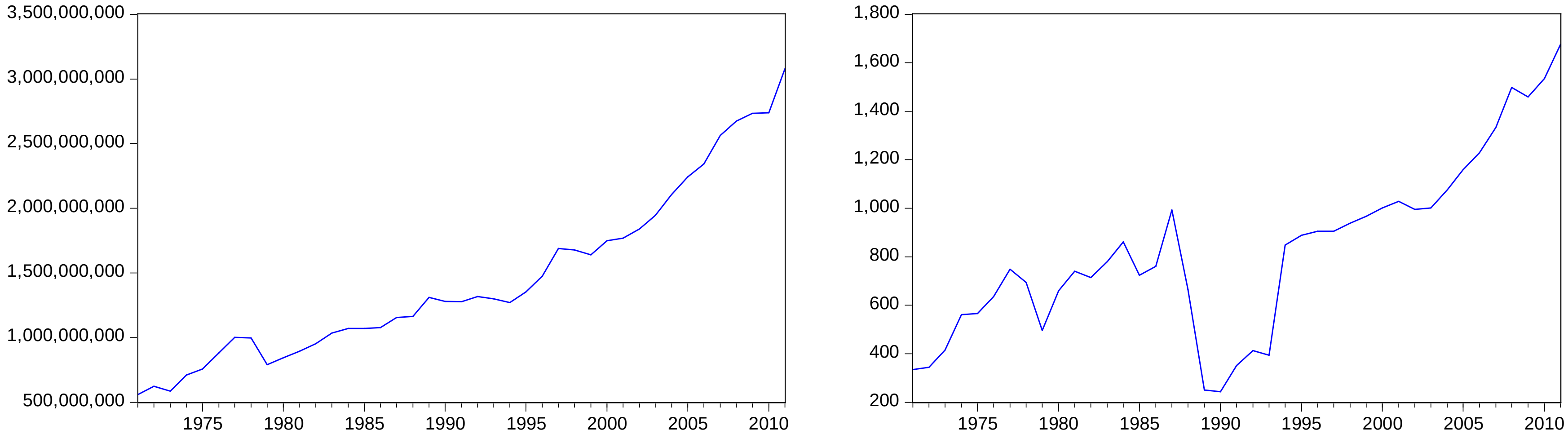


Figure 3-56: Electricity consumption and gross domestic product of Nicaragua

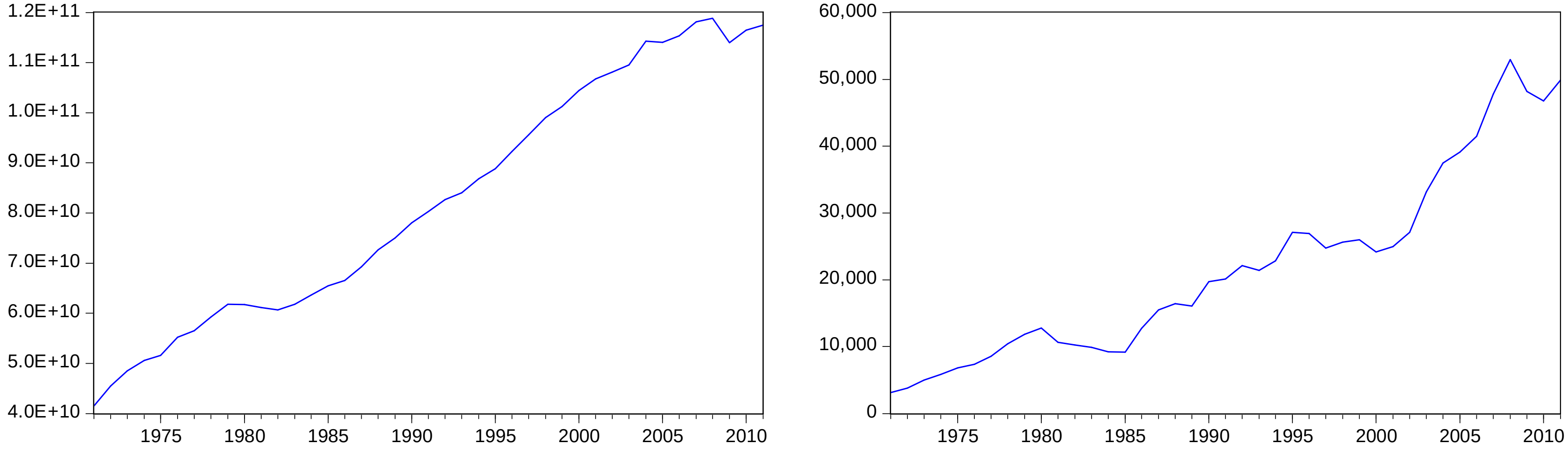


Figure 3-57: Electricity consumption and gross domestic product of Netherlands

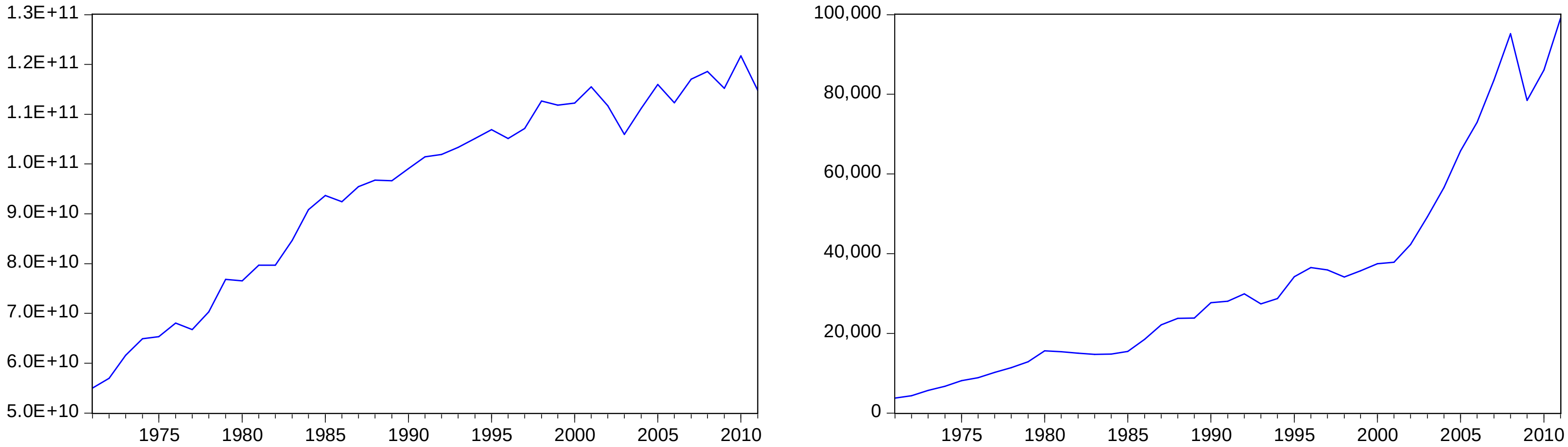
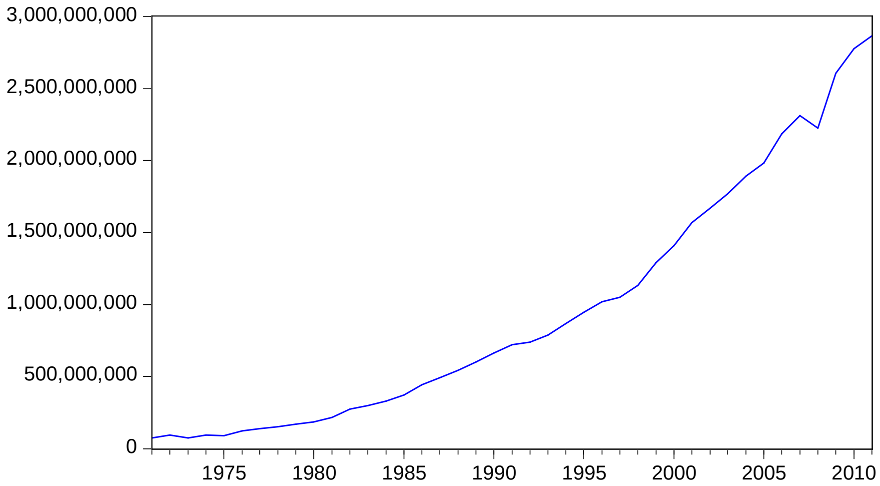


Figure 3-58: Electricity consumption and gross domestic product of Norway



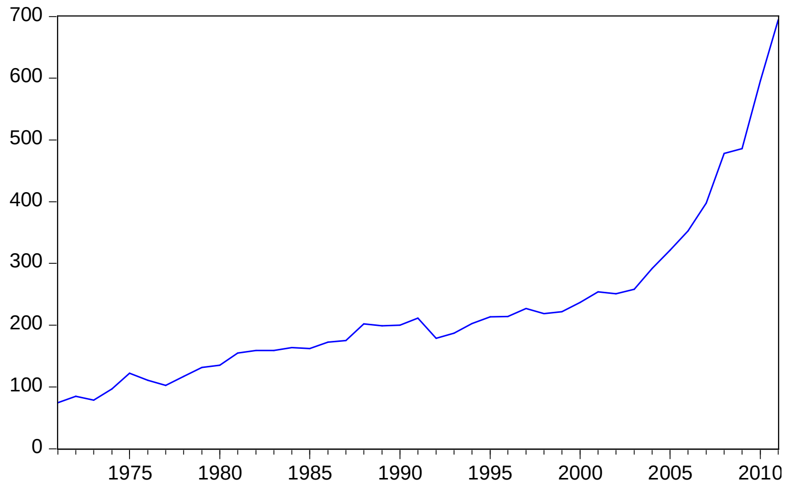
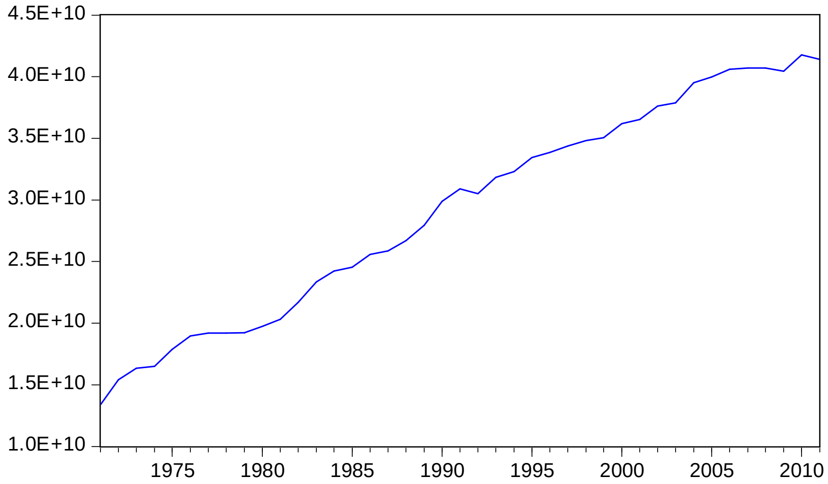


Figure 3‑59: Electricity consumption and gross domestic product of Nepal



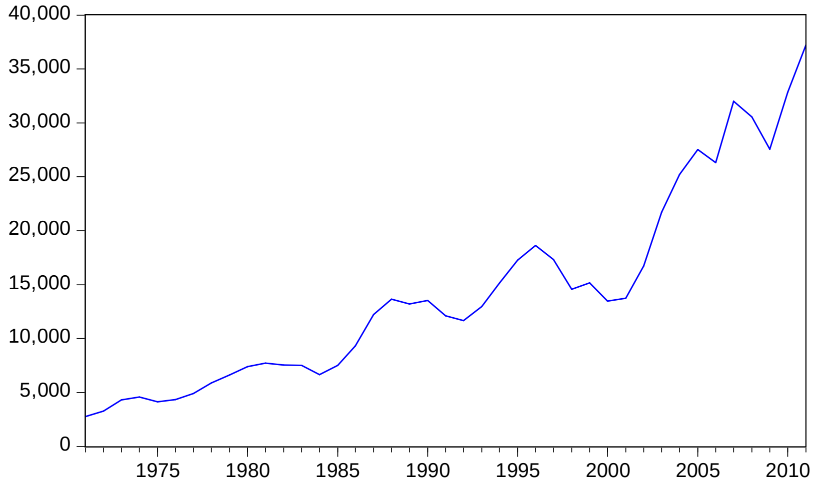


Figure 3‑60: Electricity consumption and gross domestic product of New Zealand

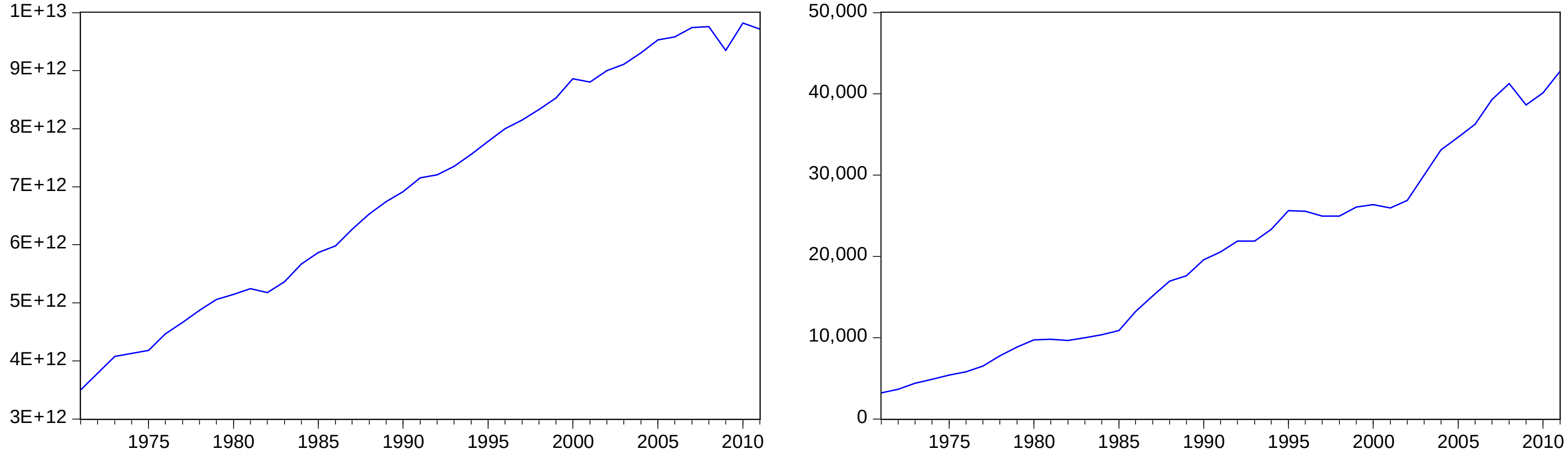


Figure 3-61: Electricity consumption and gross domestic product of High income: OECD

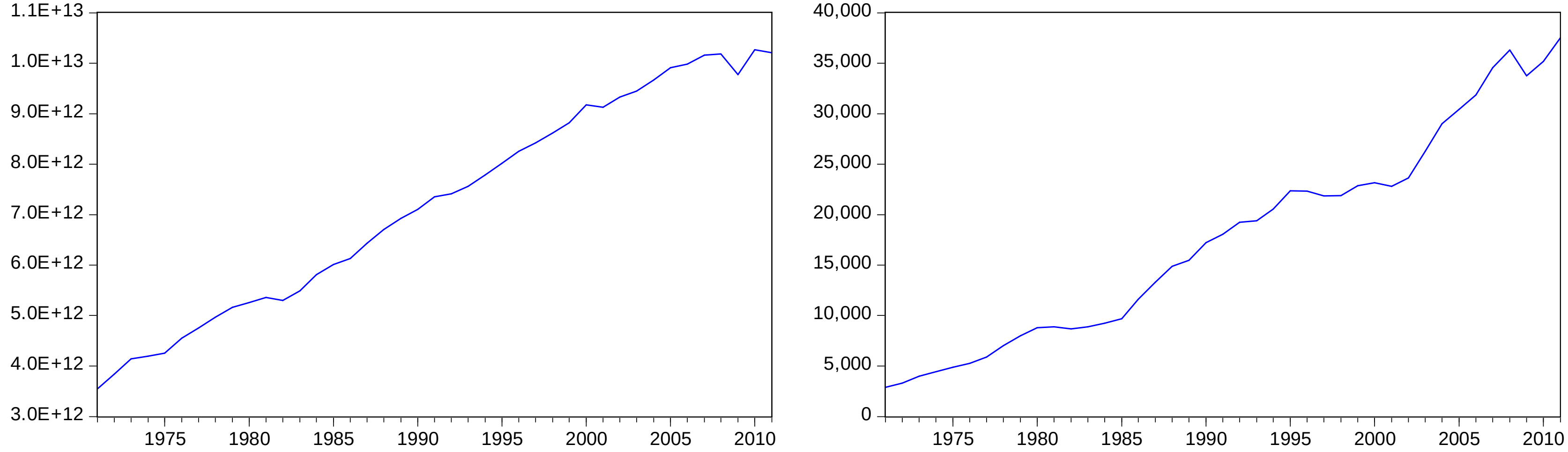


Figure 3-62: Electricity consumption and gross domestic product of OECD members

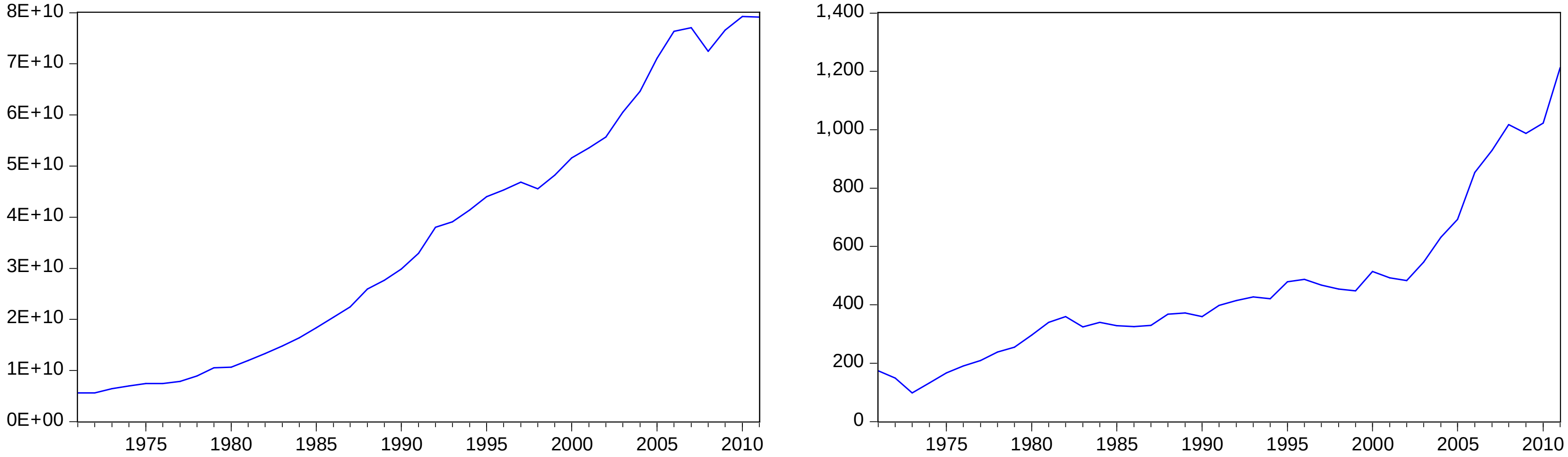


Figure 3-63: Electricity consumption and gross domestic product of Pakistan

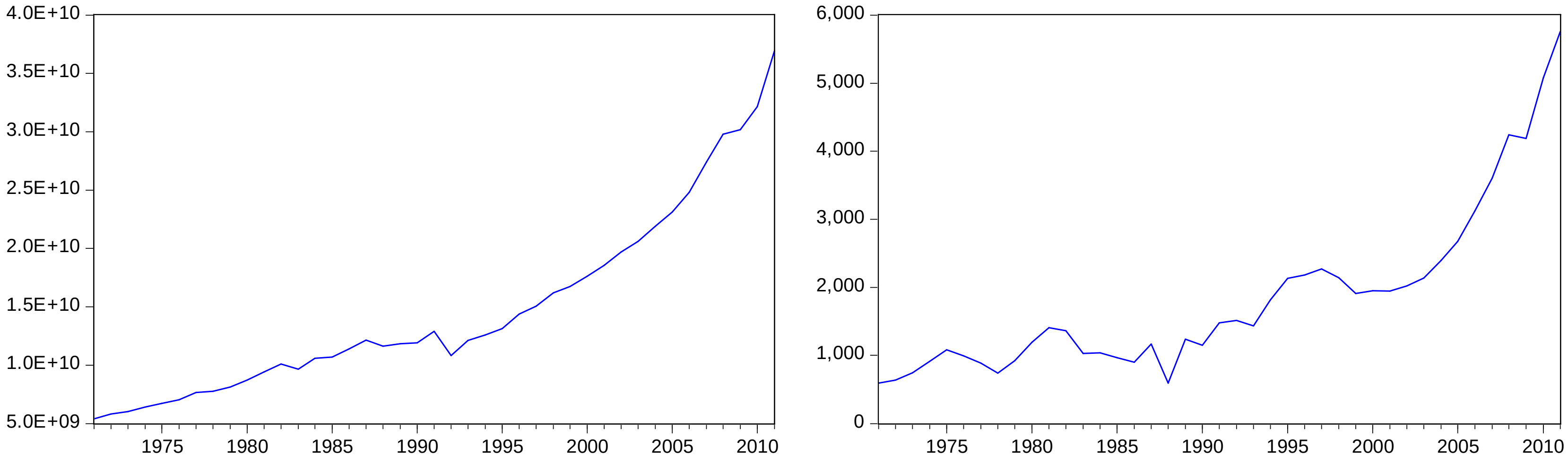


Figure 3-64: Electricity consumption and gross domestic product of Peru

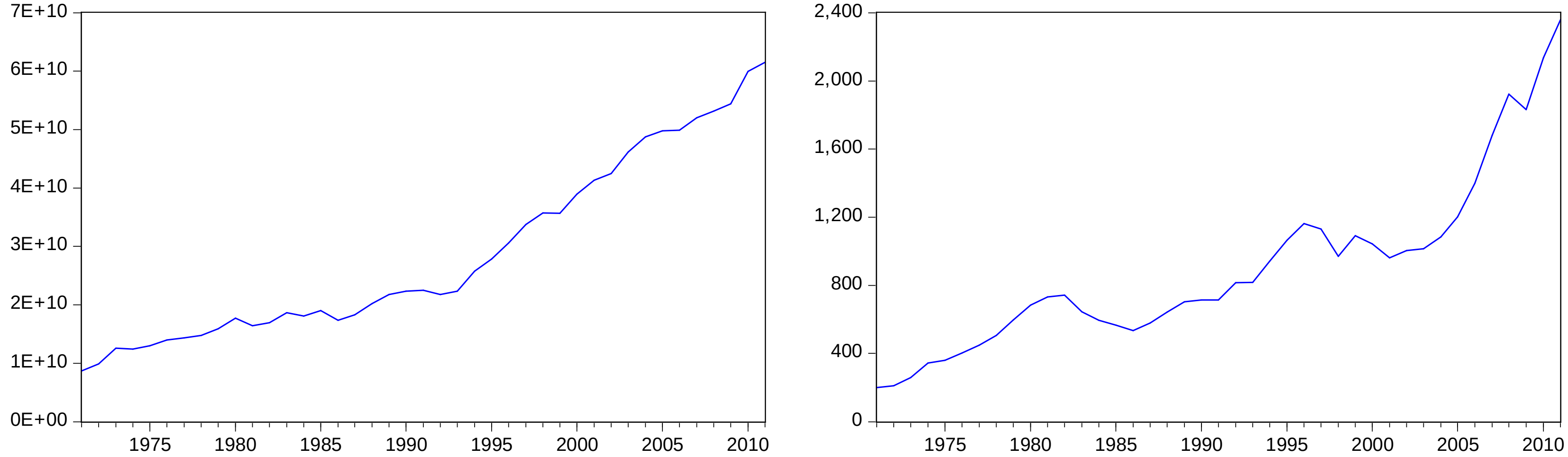


Figure 3-65: Electricity consumption and gross domestic product of Philippines

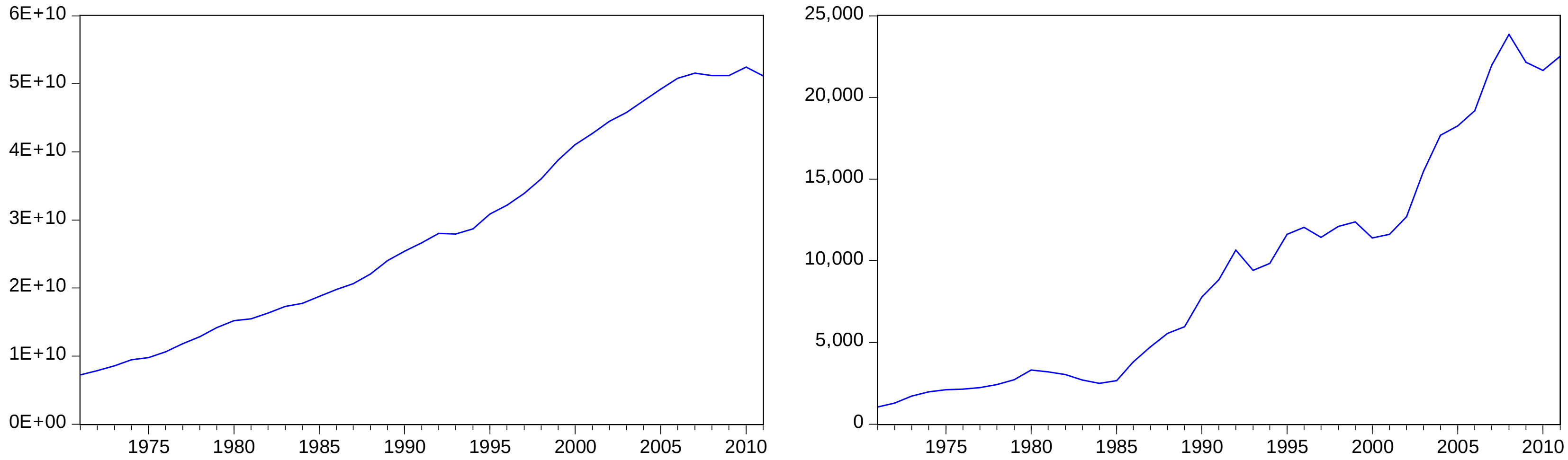


Figure 3-66: Electricity consumption and gross domestic product of Portugal

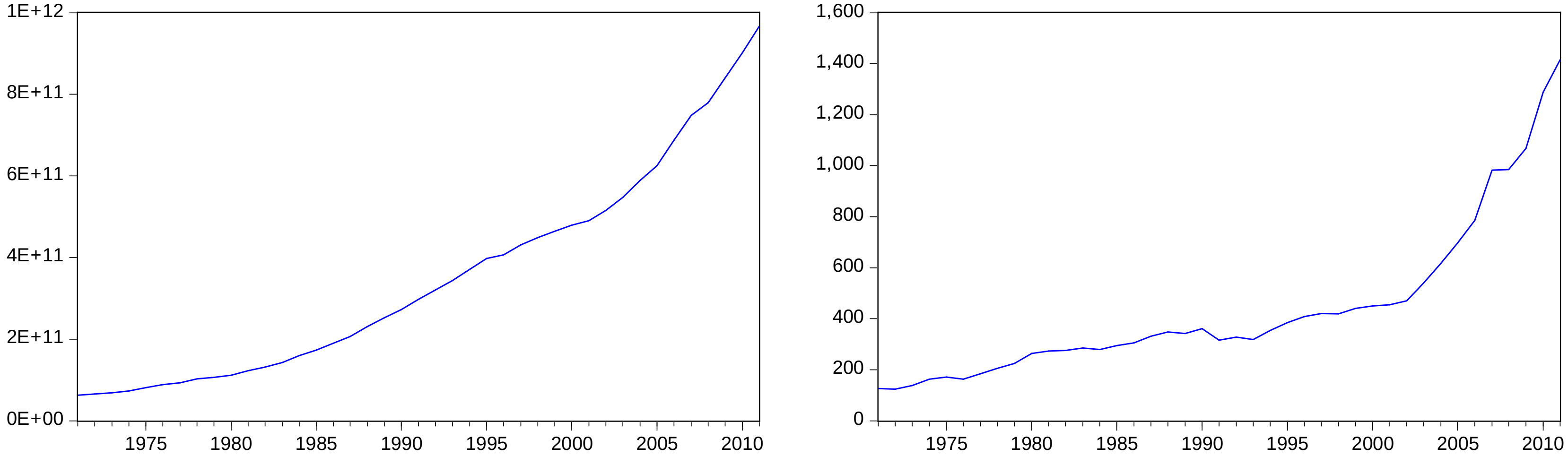


Figure 3-67: Electricity consumption and gross domestic product of South Asia

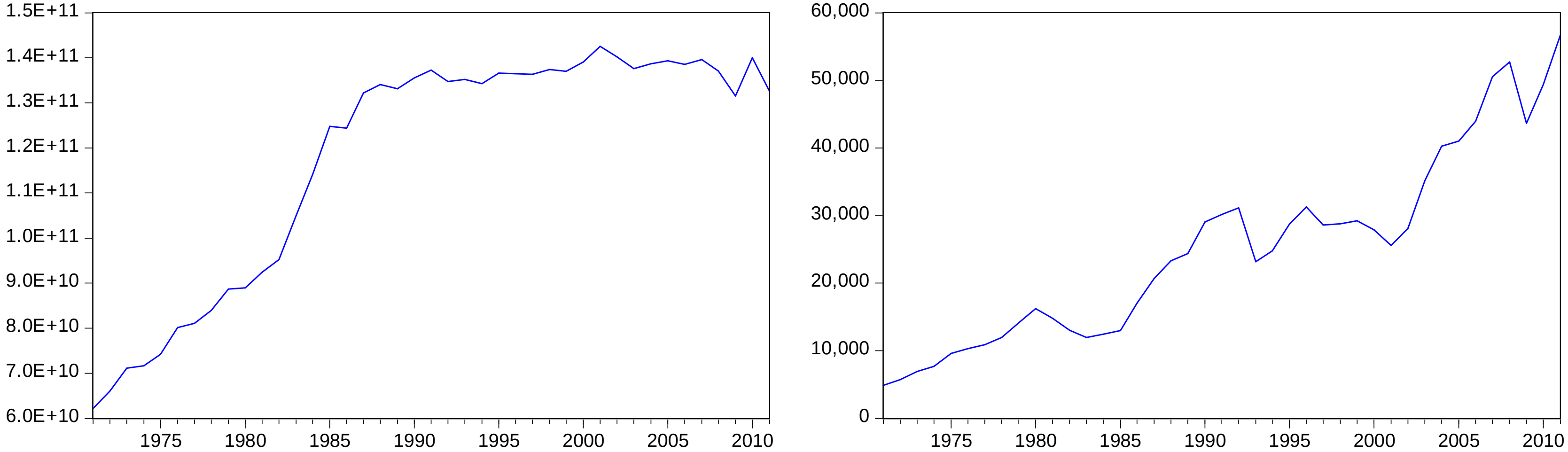


Figure 3-68: Electricity consumption and gross domestic product of Sweden

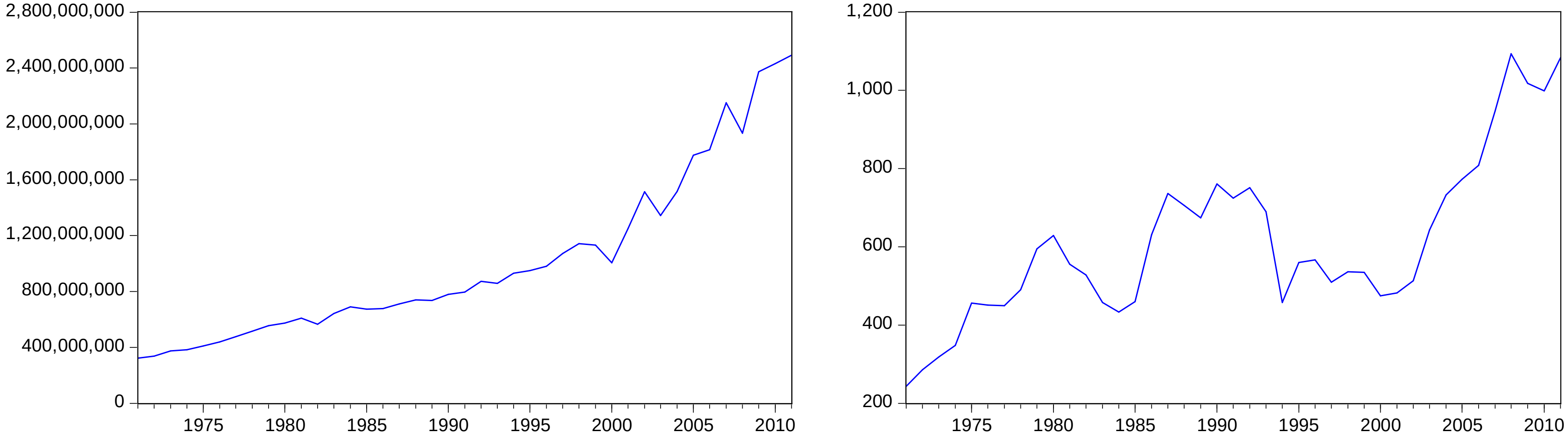


Figure 3-69: Electricity consumption and gross domestic product of Senegal

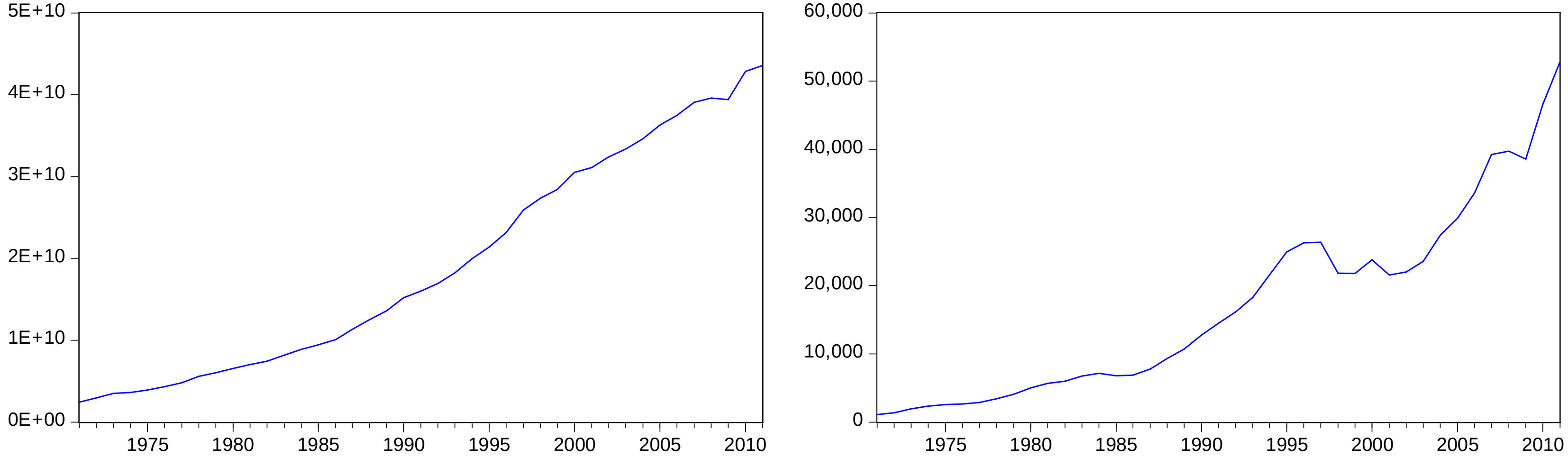


Figure 3-70: Electricity consumption and gross domestic product of Singapore

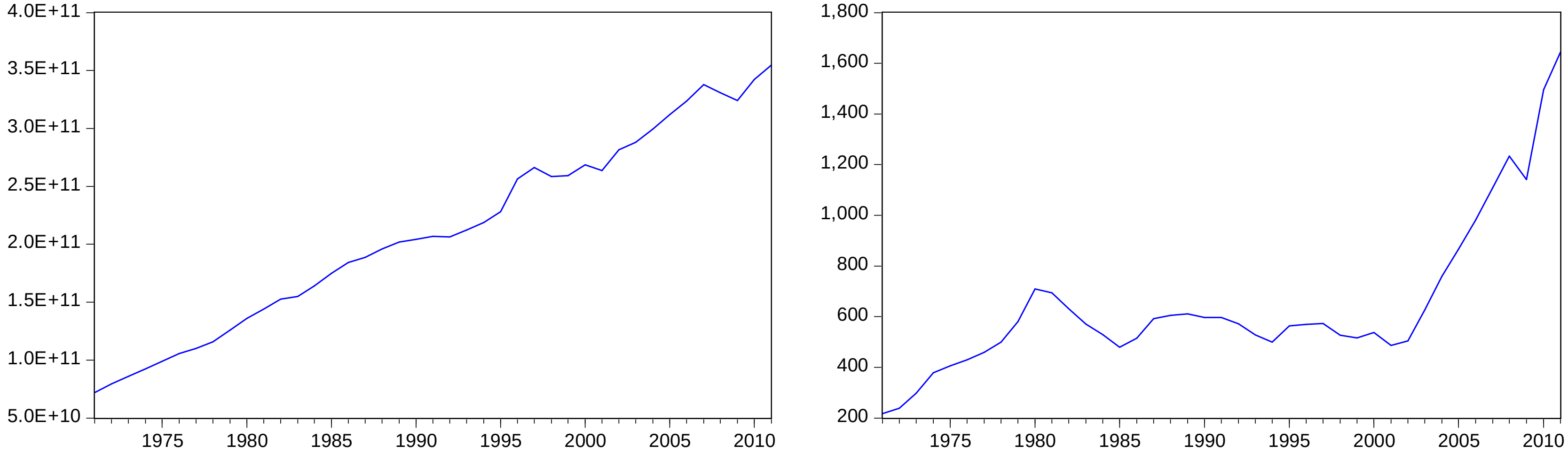


Figure 3-71: Electricity consumption and gross domestic product of Sub-Saharan Africa (all income levels)

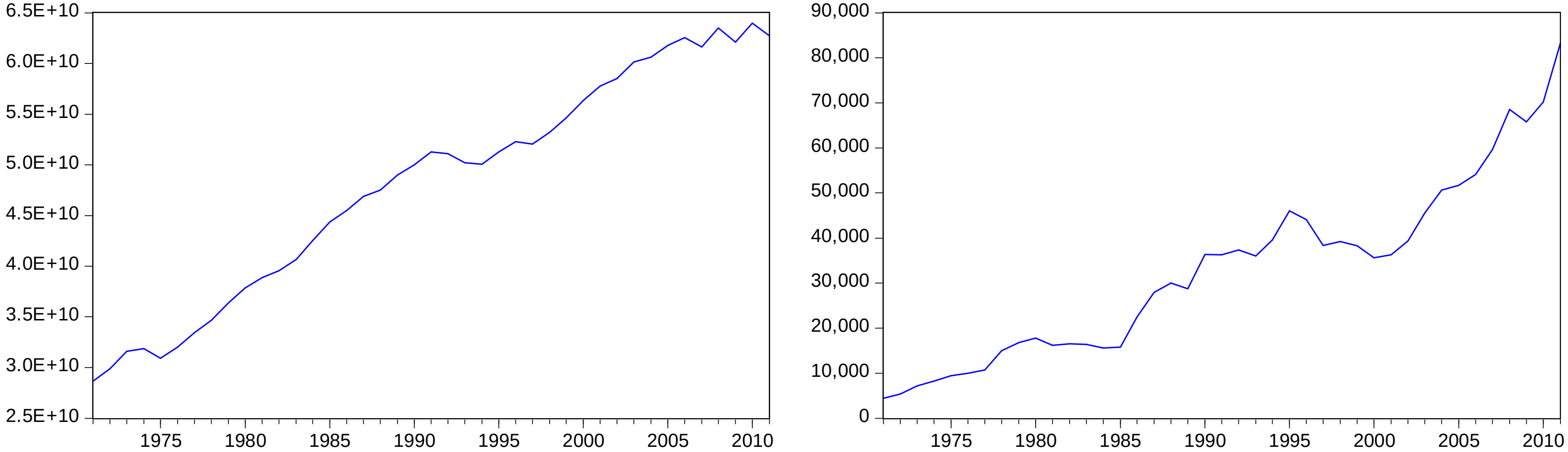


Figure 3-72: Electricity consumption and gross domestic product of Switzerland

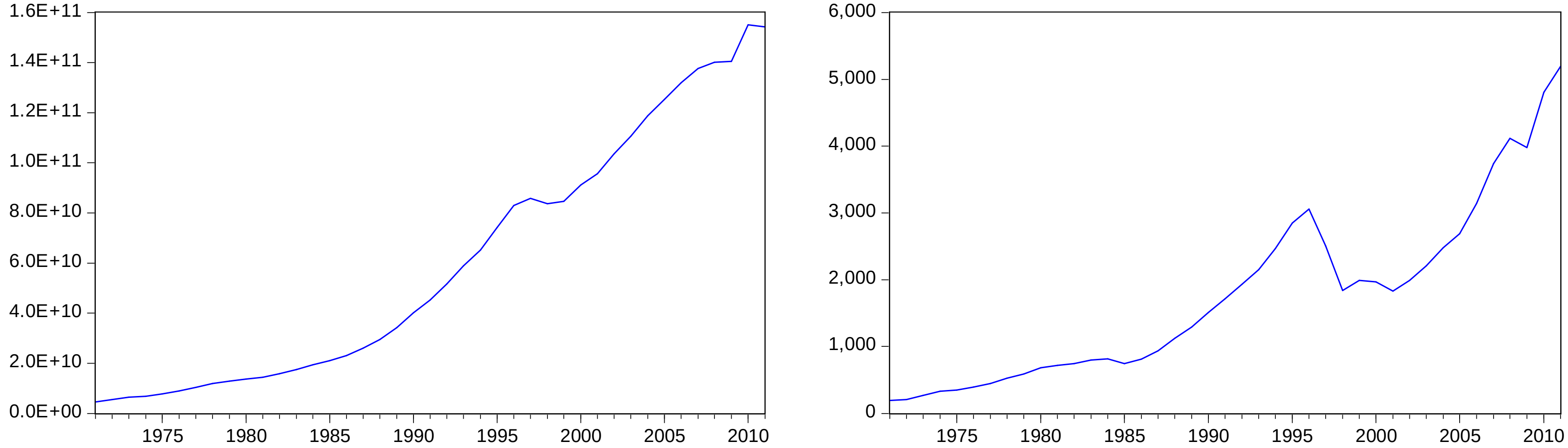


Figure 3-73: Electricity consumption and gross domestic product of Thailand

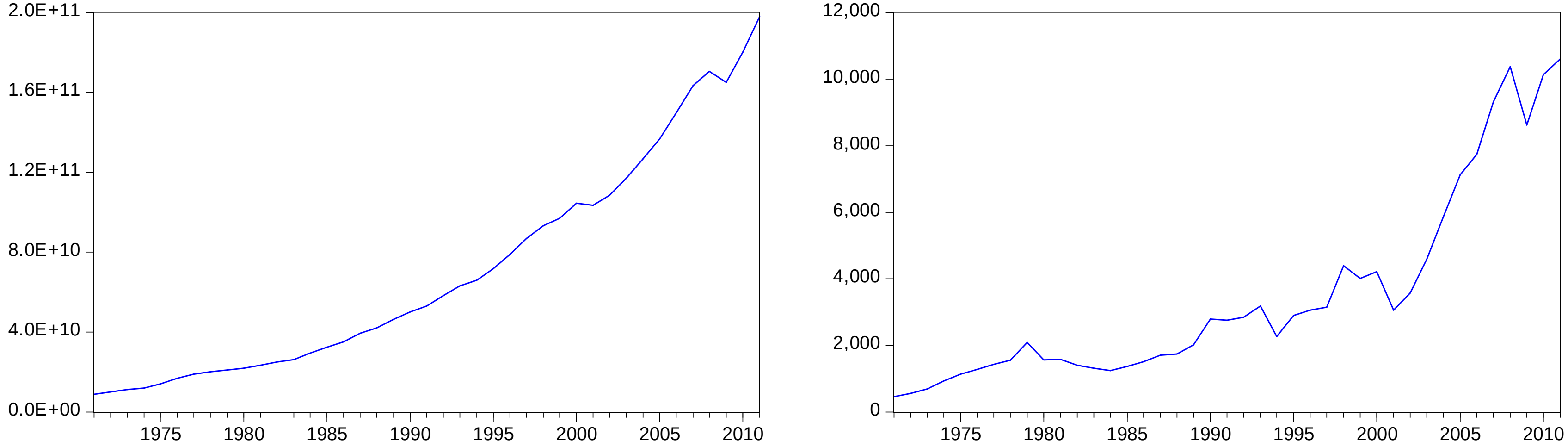


Figure 3-74: Electricity consumption and gross domestic product of Turkey

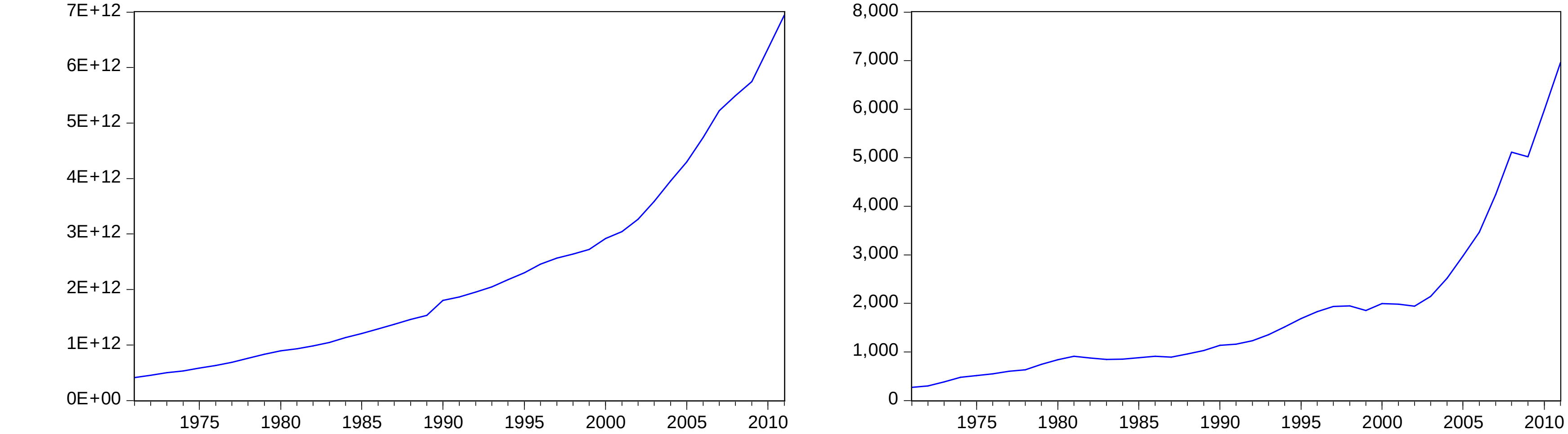


Figure 3-75: Electricity consumption and gross domestic product of Upper middle income

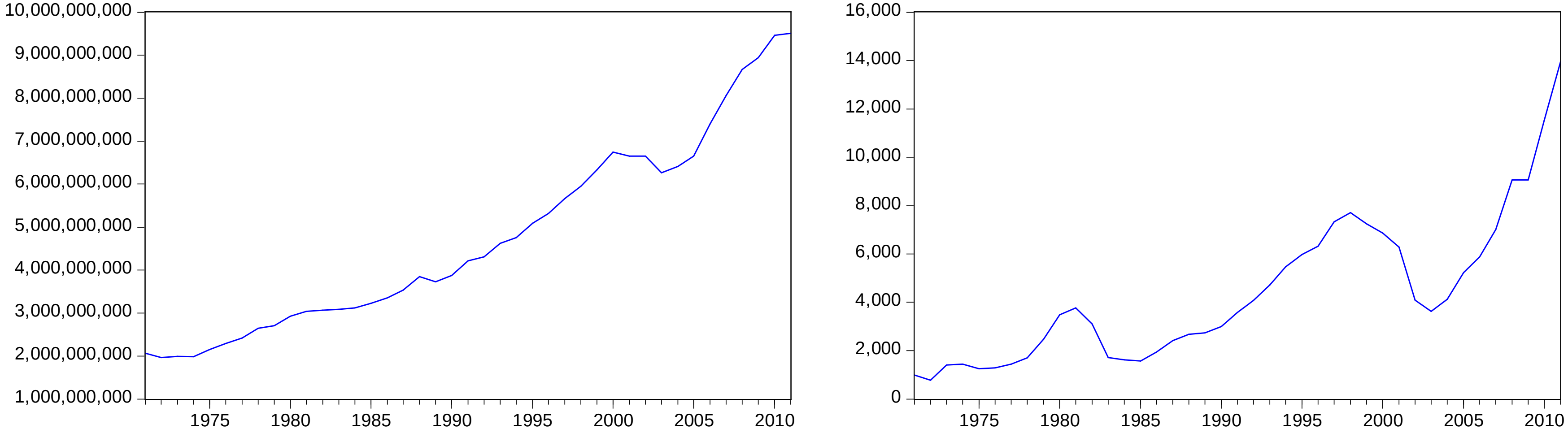


Figure 3-76: Electricity consumption and gross domestic product of Uruguay

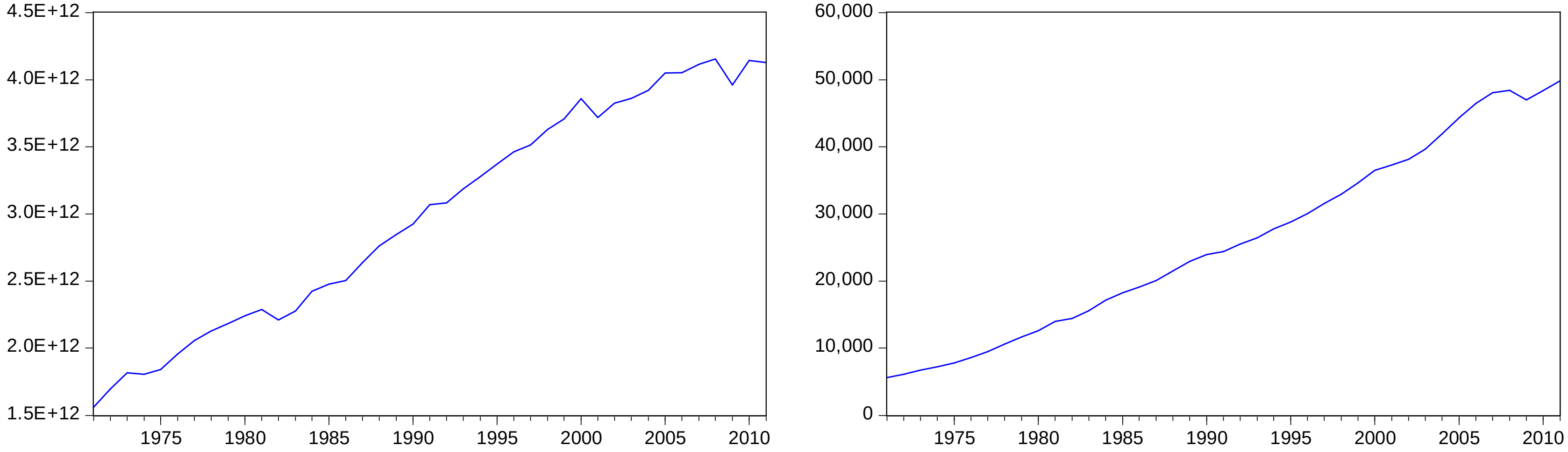


Figure 3-77: Electricity consumption and gross domestic product of United States

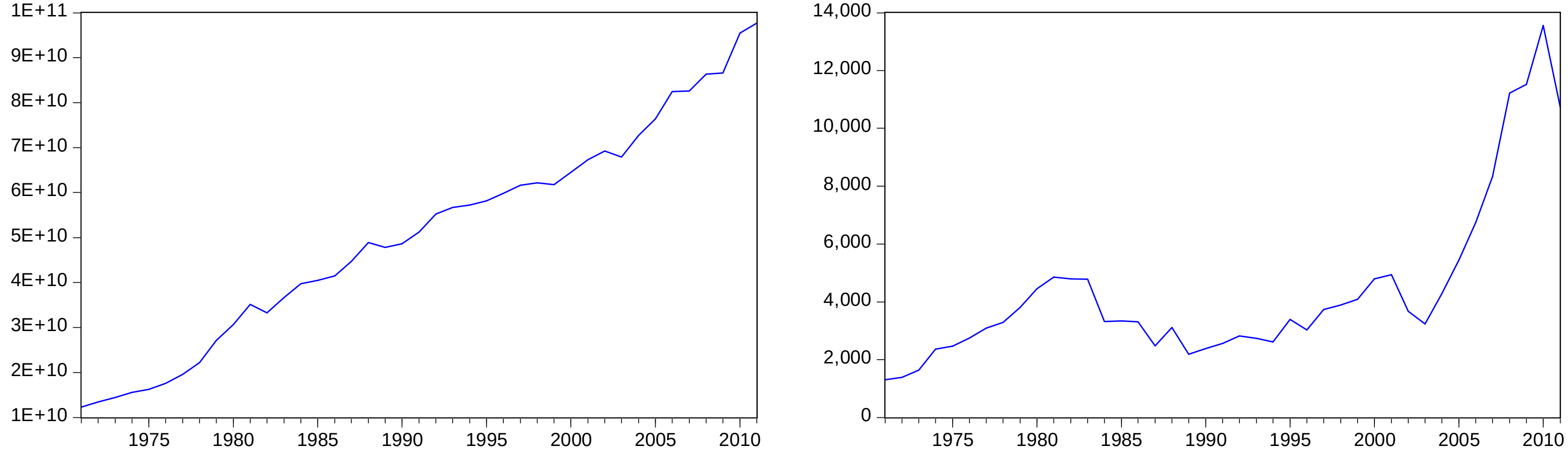


Figure 3-78: Electricity consumption and gross domestic product of Venezuela, RB

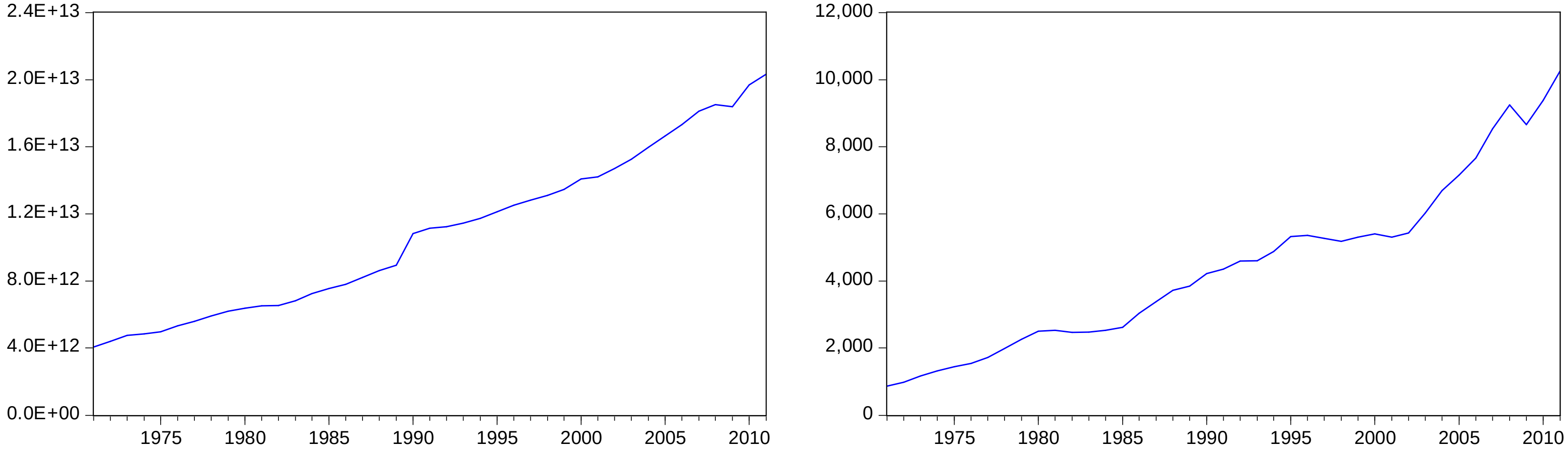


Figure 3-79: Electricity consumption and gross domestic product of World

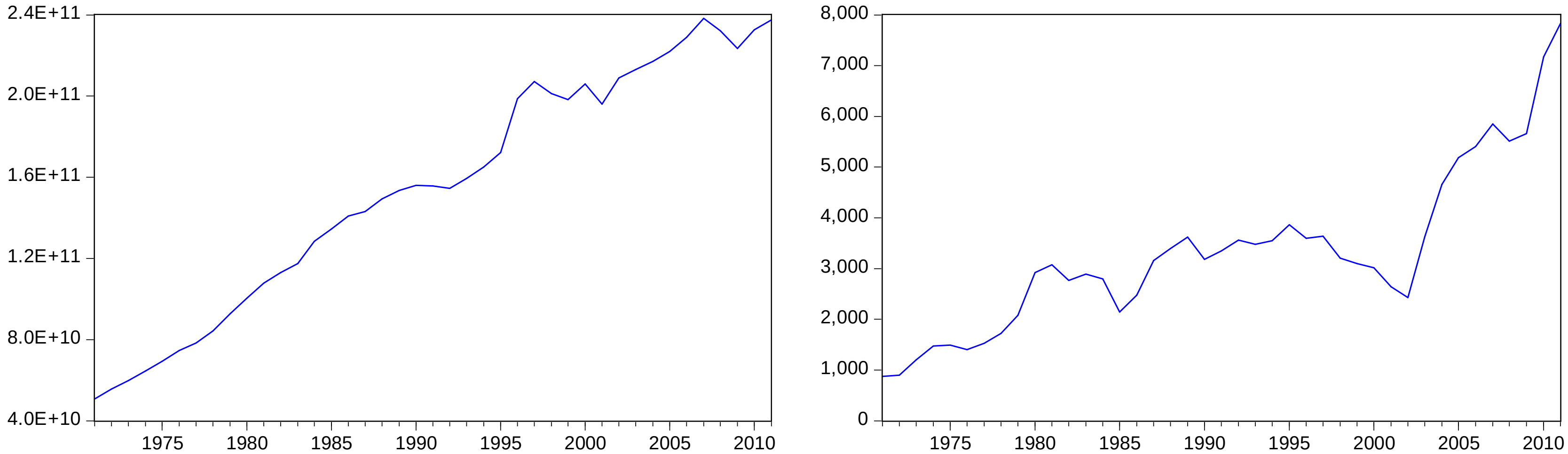


Figure 3-80: Electricity consumption and gross domestic product of South Africa

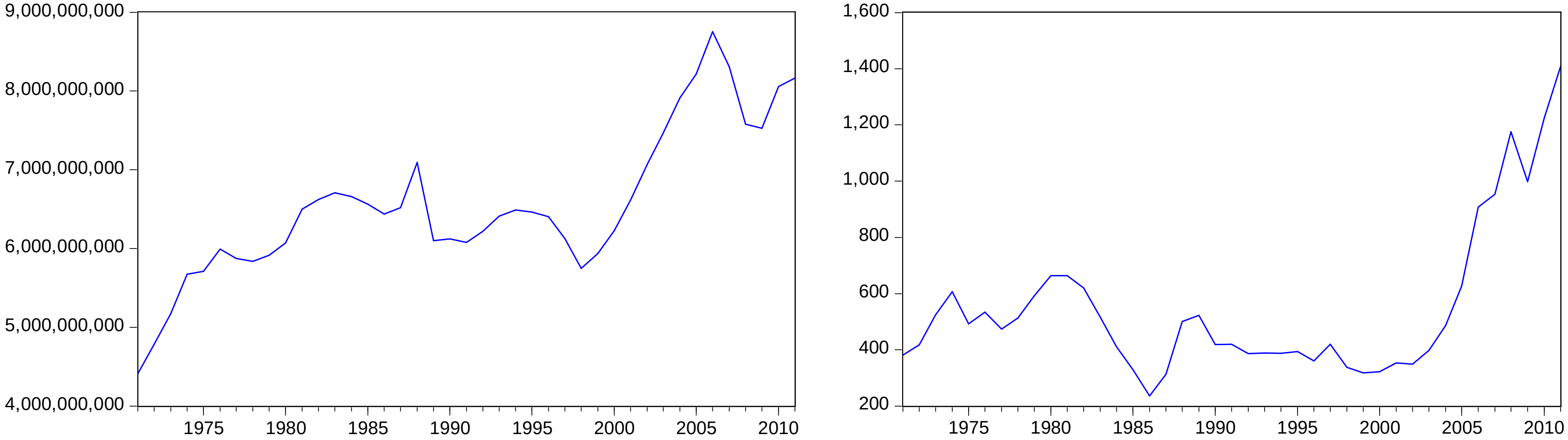


Figure 3‑81: Electricity consumption and gross domestic product of Zambia

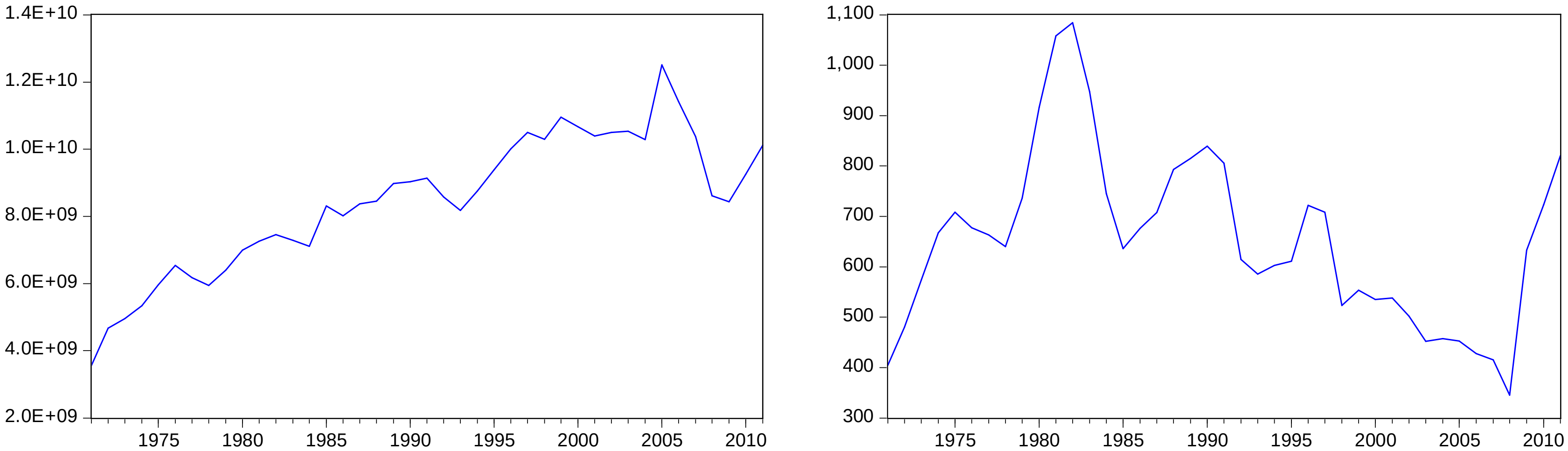


Figure 3‑82: Electricity consumption and gross domestic product of Zimbabwe

According to Toda and Yamamoto (1995) the Wald statistic converges in a χ^2 random variable distribution with degrees of freedom equal to the number of the excluded lagged variables, regardless of whether the process is stationary, possibly around a linear trend or whether it is cointegrated. The advantage of this approach is that it does not require pre-testing in order to determine the cointegrating properties of the system although testing for unit root. This ensures that the usual test statistic for Granger causality has the standard asymptotic distribution were valid inference can be made according to Wolde and Rufael (2006). The modified Wald test is valid for series being stationary, I(1) or I(2) or cointegrated of an arbitrary order as long as the order of integration does not exceed the true lag length of the model.

This approach minimizes the risks associated with misidentification of the integration order while at the same time it diminishes the possibility of a distorted sized test which often in pre-testing. Kuzozumi and Yamamoto (2000) find out that in the presence of a small sample the asymptotic distribution might be a poor approximation to the distribution of the test statistic however the distortion remains lower than other and it may still be preferable when the sample size is small (Tsani 2009).

According to the approach of Toda and Yamamoto the electricity consumption and economic growth model employed in the present task is described below in the following VAR system:

$$ELC_{it} = a_0 + \sum_{i=1}^{k} a_{1i} ELC_{it-i} + \sum_{j=k+1}^{d_{max}} a_{2j} ELC_{it-j} + \sum_{i=1}^{k} \gamma_{1i} GDP_{t-i} + \sum_{j=k+1}^{d_{max}} \gamma_{2j} GDP_{t-j} + \varepsilon_{1t} \quad (1)$$

$$GDP_{it} = b_0 + \sum_{i=1}^{k} b_{1i} GDP_{t-i} + \sum_{j=k+1}^{d_{max}} b_{2j} GDP_{t-j} + \sum_{i=1}^{k} \delta_{1i} ELC_{it-i} + \sum_{j=k+1}^{d_{max}} \delta_{2j} ELC_{it-j} + \varepsilon_{2t} \quad (2)$$

where ELC is the electricity consumption and GDP is the real domestic product. In Eq. (1) Granger causality runs from GDP to ELC if $\gamma_{1i} \neq 0$ for every i-value whereas in Eq. (2) Granger causality runs from ELC to GDP if $\delta_{1i} \neq 0$ for every i-value.

The first step towards the investigation of the existence of the Granger causality between energy consumption at aggregate levels and real GDP is the identification of the order of integration of the series under consideration (d max). For this purpose the

Augmented Dickey and Fuller (1981) (ADF) unit root test is employed. This test is based on the null hypothesis that the considered series has a unit root against the alternative of the series being stationary.

Although severely criticized for poor performance this test is very commonly used by researchers in order to assess the integration order of a series. Apparently the implementation of further tests like Phillips and Perron (1988) could provide the researcher with more sound results but this is considered beyond the scope of this task.

The test is being performed at levels and at first differences of the variables with intercept as well as with intercept and trend. The results of the ADF are presented in Table 4.1. Both Electricity consumption and Real GDP appear to be integrated of order one at levels with intercept as well as with intercept and trend, in most cases. However at some countries or aggregates it comes out that these series are integrated of order 2 which is attributed partly on the magnitude of the sample and partly to the power of the incorporated test. As such the maximum order of integration (d max) based on the results of the ADF unit root test is order 2.

In order to identify the optimal lag order of each VAR two different criteria have been employed the Schwarz information criterion (SBIC), the Akaike information criterion (AIC). Based on the work of Lee (2006) estimation starts for a VAR (4) and continues by dropping one lag at a time and in accordance with Stock (1994), in the case of conflicting results between the different tests AIC is preferred.

The optimal lag length for each country/aggregate is being reported on Table 4.2. With the maximum order of integration of the series being known as well as the lag length of VAR being established the modified Wald test can be applied after augmenting each VAR order k by the maximum order (d max) of integration of the series. Results of the Granger causality tests are summarized in Table 4.2 where next to each country/region aggregate the one of the four aforementioned hypotheses that is valid is being reported.

Apart from that, the 61 countries under examination are being categorized according to the following characteristics:

- Income level
- Region and
- Oil/Natural gas Producers

Three equivalent scenarios are being considered and examined in order to investigate the existence of a possible correlation between one hypothesis of the four established and one characteristic of the three above. The method this examination is realized is based on a binary dependent variable model.

In this type of models, the dependent variable y may take on only two values, usually 0 and 1, representing the occurrence of an event, or a choice between two alternatives. The goal is to quantify the relationship between the individual characteristics of a country denoted as x, and the probability of a causality hypothesis being satisfied.

A simple linear regression of y on x is not appropriate, since the implied model of the conditional mean places inappropriate restrictions on the residuals of the model and the fitted value of y from a simple linear regression is not restricted to lie between zero and one.

A specification that is designed to handle the specific requirements of binary dependent variables is adopted with the probability of observing a value of one being:

$$\Pr = (y_i = 1 | x_i, \beta) = 1 - F(-x_i', \beta)$$

where F is a continuous, strictly increasing function that takes a real value and returns a value ranging from zero to one. The standard simplifying convention of assuming that the index specification is linear in the parameters is adopted so that it takes the form x_i', β .

The choice of the function F determines the type of binary model. It follows that:

$$\Pr = (y_i = 0 | x_i, \beta) = F(-x_i', \beta)$$

Given such a specification, we can estimate the parameters of this model using the method of maximum likelihood. The likelihood function is given by:

$$l(\beta) = \sum_{i=1}^{n} y_i \log(1 - F(-x_i \beta)) + (1 - y_i) \log(F(-x_i' \beta))$$

The first order conditions for this likelihood are nonlinear so that obtaining parameter estimates requires an iterative solution. A second derivative method for iteration and computation of the covariance matrix of the parameter estimates is used.

There are two alternative interpretations of this specification that are of interest. First, the binary model is often motivated as a latent variables specification. Suppose that there is an unobserved latent variable y_i^* that is linearly related to x:

$$y_i^* = x_i'\beta + u_i$$

where u_i is a random disturbance. Then the observed dependent variable is determined by whether y_i^* exceeds a threshold value:

$$y_i = \begin{cases} 1 \text{ if } y_i^* > 0 \\ 0 \text{ if } y_i^* \leq 0 \end{cases}$$

In this case, the threshold is set to zero, but the choice of a threshold value is irrelevant, so long as a constant term is included in x_i . Then:

$$\Pr = (y_i = 1 \mid x_i, \beta) = \Pr(y_i > 0) = \Pr(x_i'\beta + u_i > 0) = 1 - F_u(-x_i'\beta)$$

where Fu is the cumulative distribution function of u. Imposing that y can only be 0 or 1 implies that expected value of y is simply the probability that $y = 1$ as:

$$E(y_i \mid x_i\beta) = 1 \times \Pr = (y_i = 1 \mid x_i, \beta) + 0 \times \Pr = (y_i = 0 \mid x_i, \beta) = \Pr = (y_i = 1 \mid x_i, \beta)$$

With this convention the interpretation of the binary specification as a conditional mean specification can be made and the binary model can be written as a regression model:

$$y_i = (1 - F(-x'_i\beta)) + \varepsilon_i$$

where ε_i is a residual representing the deviation of the binary y_i from its conditional mean and:

$$\begin{aligned} &E(\varepsilon_i \mid x_i, \beta) = 0 \\ &\mathrm{var}(\varepsilon_i \mid x_i, \beta) = F(-x_i'\beta)(1 - F(-x_i'\beta)) \end{aligned}$$

Estimated coefficients from a binary model cannot be interpreted as the marginal effect on the dependent variable like in the case of a simple regression model. The marginal effect of on the conditional probability is defined as:

$$\frac{\partial E(y_i \mid x_i, \beta)}{\partial x_{ij}} = f(-x_i'\beta)\beta_j$$

Where $f(x) = dF(x)/dx$ the density function of F. Coefficient β_j is is weighted by a factor f that depends on the values of all regressors in x. The *direction* of the effect of a change in x_j depends only on the sign of the β_j coefficient. Positive values of β_j imply that increasing x_j will increase the probability of the response while negative values imply the opposite.

An alternative interpretation of the coefficients is that the ratios of coefficients provide a measure of the relative changes in the probabilities:

$$\frac{\beta_j}{\beta_k} = \frac{\partial E(y_i \mid x_i, \beta) / \partial x_{ij}}{\partial E(y_i \mid x_i, \beta) / \partial x_{ik}}$$

4 Empirical results

In this section the outcomes of the investigation of 61 countries and 21 area aggregates as far as the existence of causality between the electricity consumption and Gross Domestic Product is concerned are being reported. Further research has been made in order to examine the association between the four cases of causality and the countries characteristics according to income level, region and the oil/natural gas potential.

Although the results confirm the aspect that causality results are sensitive to many parameters like the period of study and varying with the choice of investigation technique, they reveal that in most of the countries under study, actually 32 there is no causality between electricity consumption and economic growth. Moreover the outcomes witness a connection between countries that produce electricity from oil/natural gas and the feedback hypothesis as well as a tendency to the neutrality hypothesis in countries of Europe and central Asia.

In table 4.1 results from the ADF tests for every country are being reported while in table 4.2 the optimal lag length and the causality outcome tests for each county/region aggregate are presented.

After that in table 4.3, 4.4 and 4,5 that follow, the categorization of the 61 countries according to income level, region and electricity producing capability through oil/natural gas is summarized. Apart from that the connection between income level, region and oil/natural gas potential characteristics with the four causality hypotheses is reported.

Finally the probability of a hypothesis to be valid in a country with certain characteristics is provided, which is derived from the marginal effect of the estimated relationship. For the countries that a connection between a characteristic and a form of causality is realized, the potential of the equivalent hypothesis to be valid is being shown as a percentage.

Table 4.1: Empirical results from ADF test.

	Country	Integration order of ELC	Integration order of GDP
1	Hong Kong SAR, China	I(1)	I(1)
2	Singapore	I(1)	I(1)
3	Uruguay	I(1)	I(1)
4	Australia	I(1)	I(1)
5	Austria	I(1)	I(1)
6	Belgium	I(1)	I(1)
7	Canada	I(1)	I(1)
8	Chile	I(1)	I(1)
9	Denmark	I(1)	I(1)
10	Spain	I(2)	I(1)
11	Finland	I(2)	I(1)
12	France	I(1)	I(1)
13	United Kingdom	I(1)	I(1)
14	Greece	I(1)	I(1)
15	Ireland	I(2)	I(1)
16	Iceland	I(1)	I(1)
17	Israel	I(1)	I(1)
18	Italy	I(1)	I(1)
19	Japan	I(1)	I(1)
20	Korea, Rep.	I(1)	I(1)
21	Luxembourg	I(1)	I(1)
22	Netherlands	I(2)	I(1)
23	Norway	I(1)	I(1)
24	New Zealand	I(1)	I(1)
25	Portugal	I(2)	I(1)
26	Sweden	I(1)	I(1)
27	Switzerland	I(1)	I(1)
28	United States	I(1)	I(1)
29	Bangladesh	I(1)	I(1)
30	Kenya	I(1)	I(1)
31	Nepal	I(1)	I(2)
32	Zimbabwe	I(1)	I(1)
33	Bolivia	I(1)	I(1)
34	Cameroon	I(1)	I(1)
35	Congo, Rep.	I(1)	I(1)
36	Ghana	I(1)	I(1)
37	Guatemala	I(1)	I(1)
38	Honduras	I(1)	I(1)
39	India	I(2)	I(1)
40	Sri Lanka	I(1)	I(2)
41	Morocco	I(1)	I(1)
42	Nicaragua	I(1)	I(1)
43	Pakistan	I(1)	I(1)
44	Philippines	I(1)	I(1)
45	Senegal	I(2)	I(1)

Table 4.1 (continued): Empirical results from ADF test.

	Country	Integration order of ELC	Integration order of GDP
46	Zambia	I(1)	I(1)
47	Brazil	I(1)	I(1)
48	China	I(2)	I(2)
49	Colombia	I(1)	I(2)
50	Costa Rica	I(1)	I(1)
51	Dominican Republic	I(1)	I(1)
52	Algeria	I(2)	I(2)
53	Ecuador	I(2)	I(1)
54	Gabon	I(1)	I(1)
55	Mexico	I(1)	I(1)
56	Malaysia	I(1)	I(1)
57	Peru	I(1)	I(1)
58	Thailand	I(1)	I(1)
59	Turkey	I(2)	I(1)
60	Venezuela, RB	I(2)	I(1)
61	South Africa	I(1)	I(1)
62	Sub-Saharan Africa (developing only)	I(1)	I(1)
63	European Union	I(1)	I(1)
64	East Asia & Pacific (developing only)	I(2)	I(2)
65	East Asia & Pacific (all income levels)	I(2)	I(1)
66	Europe & Central Asia (all income lev-	I(1)	I(1)
67	Euro area	I(1)	I(1)
68	High income	I(1)	I(1)
69	Heavily indebted poor countries (HIPC)	I(1)	I(1)
70	Latin America & Caribbean (developing	I(1)	I(1)
71	Latin America & Caribbean (all income	I(1)	I(1)
72	Low income	I(1)	I(1)
73	Lower middle income	I(1)	I(2)
74	Low & middle income	I(1)	I(2)
75	Middle income	I(1)	I(2)
76	North America	I(1)	I(1)
77	High income: OECD	I(1)	I(1)
78	OECD members	I(1)	I(1)
79	South Asia	I(2)	I(2)
80	Sub-Saharan Africa (all income levels)	I(1)	I(1)
81	Upper middle income	I(2)	I(2)
82	World	I(1)	I(1)

As shown in table 4.1, the vast majority of the countries are characterized by variables integrated by order 1, both in electricity consumption and gross domestic product. This fact is expected it is common thing for such economic variables to be integrated of order 1. Although some countries show an integration order of 2, whether in electricity consumption time series or in GDP, this fact is considered to be sample specific and in the long run the same series will prove to be I(1).

Table 4.2: Optimal lag length and Granger Causality (Modified Wald test) results

	Country	Optimal lag length	Causality
1	Hong Kong SAR, China	4	ELC ≠ GDP
2	Singapore	4	ELC → GDP
3	Uruguay	4	ELC ≠ GDP
4	Australia	1	ELC ≠ GDP
5	Austria	1	ELC ≠ GDP
6	Belgium	2	ELC ≠ GDP
7	Canada	4	ELC ↔ GDP
8	Chile	3	ELC ↔ GDP
9	Denmark	1	ELC ≠ GDP
10	Spain	1	ELC → GDP
11	Finland	4	GDP → ELC
12	France	2	ELC → GDP
13	United Kingdom	1	ELC ≠ GDP
14	Greece	3	ELC ≠ GDP
15	Ireland	4	ELC ≠ GDP
16	Iceland	4	ELC ↔ GDP
17	Israel	4	ELC ≠ GDP
18	Italy	1	GDP → ELC
19	Japan	2	ELC ≠ GDP
20	Korea, Rep.	4	ELC ↔ GDP
21	Luxembourg	4	GDP → ELC
22	Netherlands	1	ELC ≠ GDP
23	Norway	3	GDP → ELC
24	New Zealand	1	ELC ≠ GDP
25	Portugal	3	ELC ≠ GDP
26	Sweden	1	ELC ↔ GDP
27	Switzerland	1	ELC ≠ GDP
28	United States	2	ELC → GDP
29	Bangladesh	1	ELC ≠ GDP
30	Kenya	2	ELC ≠ GDP
31	Nepal	4	ELC → GDP
32	Zimbabwe	2	ELC ≠ GDP
33	Bolivia	4	ELC → GDP
34	Cameroon	1	GDP → ELC
35	Congo, Rep.	1	ELC → GDP
36	Ghana	1	ELC ≠ GDP
37	Guatemala	1	ELC ≠ GDP
38	Honduras	2	ELC ≠ GDP
39	India	3	ELC → GDP
40	Sri Lanka	4	ELC ≠ GDP
41	Morocco	2	ELC ↔ GDP
42	Nicaragua	1	ELC → GDP

Table 4.2 (continued): Optimal lag length and Granger Causality (Modified Wald test) results

	Country	Optimal lag length	Causality
43	Pakistan	1	ELC → GDP
44	Philippines	1	ELC ≠ GDP
45	Senegal	4	ELC ≠ GDP
46	Zambia	1	ELC → GDP
47	Brazil	3	ELC ↔ GDP
48	China	4	ELC ↔ GDP
49	Colombia	2	ELC ↔ GDP
50	Costa Rica	1	ELC ≠ GDP
51	Dominican Republic	4	ELC → GDP
52	Algeria	4	ELC → GDP
53	Ecuador	2	ELC → GDP
54	Gabon	1	ELC → GDP
55	Mexico	3	ELC ↔ GDP
56	Malaysia	4	ELC ↔ GDP
57	Peru	4	ELC ↔ GDP
58	Thailand	4	ELC ≠ GDP
59	Turkey	3	ELC ≠ GDP
60	Venezuela, RB	4	ELC ≠ GDP
61	South Africa	1	ELC ≠ GDP
62	Sub-Saharan Africa (developing only)	1	ELC → GDP
63	European Union	2	ELC ↔ GDP
64	East Asia & Pacific (developing only)	4	ELC ↔ GDP
65	East Asia & Pacific (all income levels)	3	ELC → GDP
66	Europe & Central Asia (all income levels)	1	ELC → GDP
67	Euro area	2	ELC ↔ GDP
68	High income	1	ELC ≠ GDP
69	Heavily indebted poor countries (HIPC)	4	ELC ≠ GDP
70	Latin America & Caribbean (developing	2	ELC ≠ GDP
71	Latin America & Caribbean (all income	2	ELC → GDP
72	Low income	1	ELC → GDP
73	Lower middle income	1	ELC → GDP
74	Low & middle income	1	ELC → GDP
75	Middle income	1	ELC → GDP
76	North America	2	ELC → GDP
77	High income: OECD	2	GDP → ELC
78	OECD members	2	ELC → GDP
79	South Asia	3	ELC → GDP
80	Sub-Saharan Africa (all income levels)	1	ELC → GDP
81	Upper middle income	2	ELC → GDP
82	World	1	ELC → GDP

As seen in table 4.2 32 countries witness no causality between electricity consumption and GDP implying the neutrality hypothesis while 29 show a causal relationship running from electricity consumption to GDP, suggesting the Growth hypothesis. On the

Table 4.3: Connection between different regional characteristics and four causality hypotheses

	East Asia & Pacific	Europe & Central Asia	Latin America & Caribbean	Middle East & North Africa	North America	South Asia	Sub-Saharan Africa
Growth Hypothesis	NO	NO	NO	NO	NO	NO	NO
	-	-	-	-	-	-	-
Conservation Hypothesis	NO	NO	NO	NO	NO	NO	NO
	-	-	-	-	-	-	-
Feedback Hypothesis	NO	NO	NO	NO	NO	NO	NO
	-	-	-	-	-	-	-
Neutrality Hypothesis	NO	YES	NO	NO	NO	NO	NO
	-	14,64%	-	-	-	-	-

Table 4.4: Connection between different income level characteristics and four causality hypothses

	High income: nonOECD	High income: OECD	Low income	Lower middle income	Upper middle income
Growth Hypothesis	NO	NO	NO	NO	NO
	-	-	-	-	-
Conservation Hypothesis	NO	NO	NO	NO	NO
	-	-	-	-	-
Feedback Hypothesis	NO	NO	NO	NO	NO
	-	-	-	-	-
Neutrality Hypothesis	NO	NO	NO	NO	NO
	-	-	-	-	-

Table 4.5 Connection between different fossil fuel resources characteristics and four causality hypotheses

	Producing Electricity from oil/NG
Growth Hypothesis	**NO**
	-
Conservation Hypothesis	**NO**
	-
Feedback Hypothesis	**YES**
	23,75%
Neutrality Hypothesis	**NO**
	-

other hand 15 countries confirm bidirectional causality, namely the feedback hypothesis and 6 countries verify the conservation hypothesis showing causality running from GDP to electricity consumption.

In the tables 4.3, 4.4 and 4.5 the outcomes of the investigation by means of a dependent variable model of a possible connection between the causal relationship and a countries particular attributes are summarized. As seen, it is clear that no connection between regional characteristics and causality existence/direction is found with the exception of the neutrality hypothesis being correlated with countries in Europe and central Asia. In the same sense no correlation is found among the income level characteristics of countries and causality. Last but not least the feedback hypothesis is proved to be often in countries that produce electricity from oil and natural gas. In fact the possibility that the neutrality hypothesis is valid in countries at Europe and central Asia is 14,64% while the possibility the feedback hypothesis to be met in countries that produce electricity from oil and natural gas is 23,75%.

5 Policy implications and conclusions

In this thesis the causal relationship between the electricity consumption and the economic growth of 82 countries, namely 61 countries and 21 area aggregates, has been investigated. The technique engaged was a newly developed technique by Toda and Yamamoto that provides the user with the advantage of doing away with testing for cointegration and unit root tests while researching the causal effects between the associated variables. Moreover the findings of causality have been further studied so that a possible connection with a country’s characteristics like income level, region, and ability in producing electricity from fossil fuels can be found. Vehicle for this task was the use of a binary dependent variable model, something that is considered to be pioneering compared to relevant up to now studies.

The majority of the recent bibliography relative to the subject has been gone through and analyzed for its particularities in general and then the methodology and theoretical framework was deployed before the final empirical outcomes were reported. Apart from major differences, a point that different studies see eye to eye is the four different hypotheses for the casual relationship, each one with a different unique implication as it has been analyzed. The growth hypothesis according to which the reduction in electricity consumption can harm economic growth, conservation hypothesis stating that electricity conservation policies could hardly affect economic growth, neutrality hypothesis by which electricity conservation will have no effect on economy and feedback hypothesis which estimates that changes in electricity use may not affect economic growth.

As stated before the goal of this dissertation was to come up with a deeper and more concrete, if possible, conclusion for the existence and the direction of causality between electricity consumption and why not energy consumption and economic development. This goal was based on the number of countries studied as well as on the period of study that spans from 1971 to 2011 and which according to the data available at the World Bank was the biggest selection available both in time period and number of countries.

However the final outcomes fail to provide a clear conclusion confirming thus what seems to be the rule; there is no consensus in the existence or direction of causality between electricity consumption and economic growth, among the different countries. Even among studies for the same country or for different countries but for the same period the results can vary. This reveals the sensitivity of the different approaches to the different data set, the particular characteristics of countries, the advantages and disadvantages of each technique but also the differences in the connection between economy and energy in general from one country/region to another.

More analytically, most countries 32 actually, though with a slight difference, show no causality between electricity consumption and GDP confirming neutrality hypothesis while 29 witness a causal relationship running from electricity consumption to GDP, according to the growth hypothesis. 15 countries witness bidirectional causality, namely the feedback hypothesis and 6 countries verify the conservation hypothesis showing causality running from GDP to electricity consumption.

In order to go further and provide someone with something new and more interesting outcome, an attempt was made to combine these results with each country’s special characteristics such as income level, region and potential of producing electricity through oil or natural gas. Here the results show that the feedback hypothesis appears to match in countries that are able to produce electricity from fossil fuels while the neutrality hypothesis seems to be connected with countries in central Asia and Europe. The first finding sounds logical taking into account that an electricity independent country can manage its energy use without direct or definite, at least, impact on its economic situation. On the other supposing that economy may heavily rely on energy sector, especially if fossil fuel reserves are such, one cannot easily reject the possible interconnection in between but quite the contrary, which is what the feedback hypothesis presumes. In the same sense countries whose economy are already developed up to a level, such as those of Europe and central Asia, are expected to be unaffected in general terms by changes in the electricity sector, justifying the neutrality hypothesis. Apart from that no other connection between a certain hypothesis and a particular characteristic has been detected which is quite interesting information in the sense that causality between energy and economic growth does not have to do with even with income level characteristics.

Future studies that will incorporate more data that come from more countries will make use of even sounder econometric techniques involving even wider range of criteria or variables are to shed more light on this topic. Though difficult to cope with, understanding the causal relationship between electricity consumption and economies will always be challenging and its investigation worthwhile.

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