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Internet usage, electricity consumption and economic growth in Australia: A time series evidence

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ABSTRACT

This study estimates the short- and long-run effects of the Internet usage and economic growth on electricity consumption using annual time series macro data for Australia for the period 1985–2012. ARDL bounds test for cointegration and Granger causality test for causal link are applied. Results from ARDL estimates indicate that the Internet use and economic growth stimulate electricity consumption in Australia. Internet usage and economic growth have no significant short-run relationship with electricity consumption. Multivariate Granger causality test confirms unidirectional causal link running from Internet usage to economic growth and electricity consumption. The findings are robust across different econometric specifications. The findings imply that Australia is yet to achieve electricity efficiency gains from ICT expansion and that it may pursue energy conservation policy without any adverse effect on its economy. Australia needs to promote its existing carbon capture and storage facilities, significantly boost investment in the renewable energy sector, in particular, in solar energy and build nuclear power plants for electricity generation to reduce CO_2 emissions. Also promoting green IT and IT for green might be potential means to curb environmental damage from Internet usage. A coordination between ICT policy, energy policy and growth policy is also recommended.

1. Introduction

Information and communication technologies (ICTs) have a wide array of effects on key global systems (Moyer and Hughes, 2012). The rapid use and expansion of these technologies have proved to contribute towards increasing productivity, boosting economic growth (Shahiduzzaman and Alam, 2014a,b) and reducing energy intensity (Moyer and Hughes, 2012). As such, the study on environmental impacts of ICT has drawn special attention since the early 1990s. Ever since, the studies investigating the energy impacts of ICTs have been profoundly researched in a macro framework. Although the rapid expansion of ICT usage is believed to improve productivity and energy efficiency, there is no consensus as yet on its effect on the environment. Some of the studies support the positive role of ICT in mitigating greenhouse gas emissions while others conclude that ICT use exerts pressure on energy use (Moyer and Hughes, 2012) hence leading to an increase in electricity consumption – one of the key sources of global CO_2 emissions (Hamdi et al., 2014).

Since 1970s, there was a general interest in how to reduce energy consumption and CO_2 emissions in economies through the expansion of ICTs. Schumpeter (1934, cited in Walker, 1985) coined the idea that it was possible to reduce energy

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demand while allowing the economy to grow by the expansion of ICTs that potentially contribute towards energy saving gains. The widespread expansion of ICTs has caused dramatic rise in the demand for electricity in the last two decades. ICT related electricity consumption has increased significantly both in the workplaces and households (IEA, 2009). The combined electricity consumption related to ICT equipments such as communication networks, personal computers and data centers is growing at a rate of nearly 7% per year (i.e., doubling every 10 years). The relative share of these ICT products and services in the global electricity consumption has increased from about 3.9% in 2007 to 4.6% in 2012 (Heddeghem et al., 2014).

A significant percentage of domestic electricity consumption in Europe is linked to the use of ICT products and services (Faucheux and Nicolai, 2011). According to some estimates (Greenpeace International, 2014), ICT industry is responsible for 2% of global CO_2 emissions. Because all ICT products need electricity to operate, rapid expansion of ICT use leads to increasing demand for electricity threatening environmental sustainability through greenhouse gas emissions and Australia is no exception. But if energy efficiency could be achieved leading to energy saving gains, the positive effect of energy efficiency might outweigh the negative effect of increased electricity consumption.

Since the mid-1990s, the Internet usage has been increasing at a rapid speed in Australia (Fig. 1). An overwhelming majority of Australians are using the Internet. In 2011, 87% of the Australians had used the Internet up from 81% in 2009 and 73% in 2007. The vast majority of household connections are now through broadband (96%) while the proportion of Australians accessing the Internet through a mobile device more than doubled between 2009 and 2011 from 15% to 37% (Ewing and Julian, 2012). It is claimed that the Internet has been transforming the Australian economy for the last 10 years (Bowles, 2012; Deloitte Access Economics, 2011) and is anticipated to play even more significant role in the future as it looks forward to becoming a leading digital economy. In 2010, the direct contribution of the Internet to the Australian economy was AUS$ 50 billion or 3.6% of its Gross Domestic Product (GDP). The contribution of the Internet to the economy will further increase and is projected to be around AUS$ 70 billion by 2015 (Deloitte Access Economics, 2011). Not only these numeric figures reflect the Internet's recent role in Australian economy in growth and productivity, two most recent empirical studies (Shahiduzzaman and Alam, 2014a,b) support the persistent positive role of ICT capital in boosting its economic growth and productivity.

Nevertheless, in its bid to be a leading digital economy, Australia has been undergoing the construction of the largest ever broadband rollout project, the National broadband network (NBN) with a view to expanding high speed internet (broadband) to the regional and remote areas of the country. One of the key objectives of the NBN is to narrow the digital divide in the country (Lee, 2011) which is believed to be in the danger of widening (Bowles, 2012). While the NBN rollout is justified and is consistent with Australia's move to be a leading digital economy, the benefits reaped from the massive expansion of the broadband infrastructure is not expected to be without opportunity cost. In other words, the future energy impacts of this expansion cannot be ruled out. Australia is one of the top CO_2 emitters in the world alongside USA, Canada, Germany, the UK, Saudi Arabia and Qatar on a per capita basis (Shafiei and Salim, 2014). The same authors argue that 90% of the power generation in Australia is still sourced from non-renewable fossil fuels such as coal, gas and oil. As a result, there has been a sharp increase in CO_2 emissions. Nevertheless, the rapid expansion of ICT use in the region is likely to have significant energy impacts as ICT products and services cannot be operated without electricity.

Energy is largely sourced from electricity in Australia (Salahuddin and Khan, 2013) and it is one of the major industries of the country. Electricity generation is the single largest contributor to greenhouse gas (GHG) emissions producing 38% of total emissions in Australia and 90% of electricity was generated from the burning of fossil fuels dominated by coals, gas and oil in 2012 (Asafu-Adjaye and Mahadevan, 2013). Coal provided 68% of Australia's electricity needs in 2012. Per capita electricity consumption has been steadily rising in Australia for most of the period during the last four decades (Fig. 2). Although energy

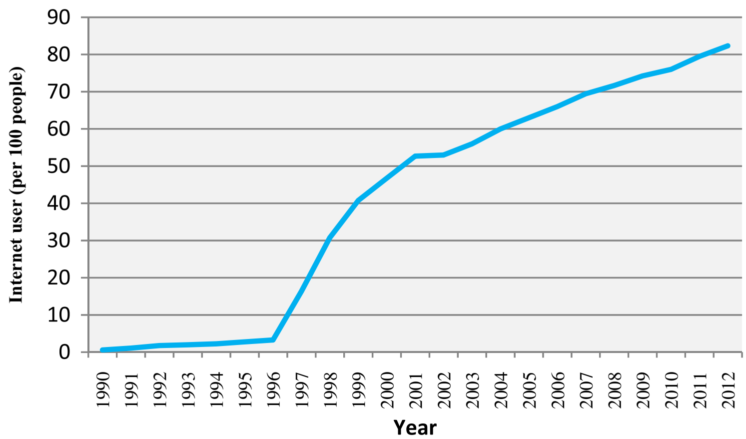

Fig. 1. Trend in the number of Internet users per hundred people (%) in Australia during 1990–2012. *Source:* World Development Indicators Database, The World Bank (2013).

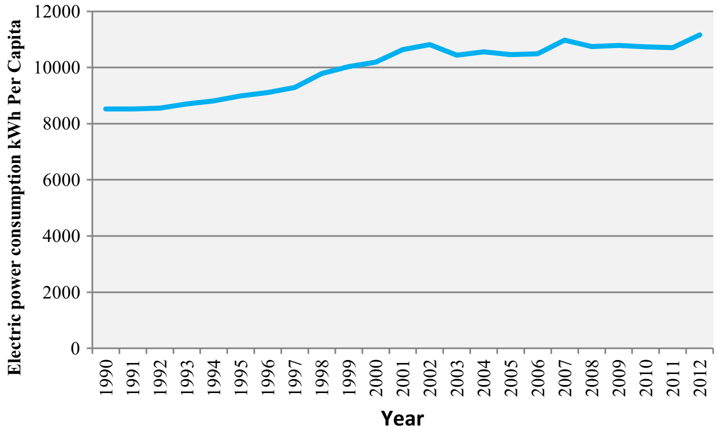

Fig. 2. Trend in per capita electricity consumption (kWh) in Australia during 1990–2012. *Source:* World Development Indicators Database, The World Bank (2013).

intensity has been on a declining trend (Fig. 3) during the same period and also for most of the period during 1970–2012, it is still struggling to embrace transition to a low carbon economy despite the fact that Australia also has some decoupling experiences. During the period 1971–2012, it experienced some extent of relative decoupling while it also performed absolute decoupling during 1970–72, 1981, 1985, 1992, 1994 and again during 2000–2002 and 2010–2012 (Fig. 4). Two key reasons for this declining trend in energy intensity and for enjoying some decoupling experiences are fuel efficiency gains from technological improvement and fuel switching and the rapid growth of less energy intensive service sector. However, despite these developments, to combat GHG emissions still remains a challenge for Australia.

A recent study (Salahuddin and Khan, 2013) reports that energy consumption contributes towards CO_2 emissions in Australia and more than 20% of the total energy is sourced from electricity. Nevertheless, the rapid expansion of the Internet is expected to exert pressure on domestic demand for electricity consumption. Its further expansion in future due to the NBN rollout is likely to spark concerns for future environmental sustainability of Australia. As such, this study examining the impact of the Internet usage on electricity consumption in Australian context whose energy policies are already at the crossroads (Falk and Settle, 2011) is worth-investigation and also is likely to receive growing importance in energy and digital divide literature.

Also, since the mid-eighties and following the second oil shock, enormous literature investigating the relationship between economic growth and electricity consumption for different countries and regions evolved (Hamdi et al., 2014) but such relationship was rarely investigated in Australian context despite its important implications for energy policy. To fill this vacuum, the current study also examines the impact of economic growth on electricity consumption. Another reason for including economic growth is that usually simple bivariate models may fail to appropriately capture empirical relationship between the series (Karanfil, 2009; Bartleet and Gounder, 2010). Therefore, the extension of our model with the inclusion of economic growth is further justified.

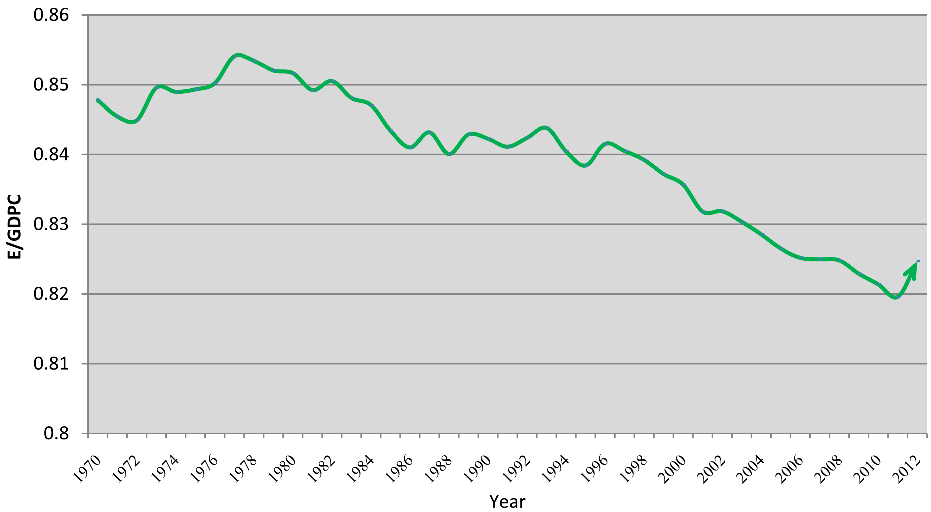

Fig. 3. Trend in energy intensity in Australia during 1970–2012. *Source:* International Energy Agency (2013).

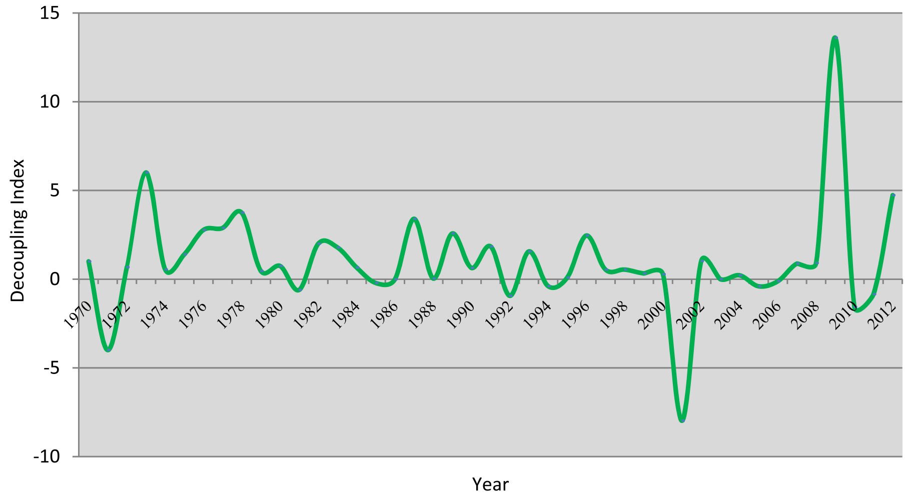

Fig. 4. Decoupling index values of CO_2 emissions from economic growth in Australia during 1970–2012.

There are a number of contributions of this study to the existing energy, Internet and growth literature. First, the most important contribution is that the Internet usage and electricity consumption relationship is being investigated for the first time ever for Australia. Second, although literature on the electricity–growth relationship is abundant, the economic growth-led electricity consumption hypothesis was never examined in the Australian context. Third, the current study uses the most recent data, the analysis of which, is expected to offer policy-oriented findings. Fourth, it also makes a methodological contribution by employing a couple of sophisticated and potentially suitable time series econometric techniques, the autoregressive distributive lag (ARDL) model and Innovation Accounting Approach (IAA) that have never been used before to estimate the Internet usage and electricity consumption relationship for any previous time series study, let alone for Australia and fifth, unlike other works, the findings of the study are expected to provide important implications at a time for ICT policy, energy policy and economic growth policy for Australia.

The rest of the paper is structured as follows: Section 2 discusses literature review, and methodology is presented in Section 3. Section 4 presents estimation results and finally the paper ends up in Section 5 with conclusions and policy implications of the research.

2. Literature review

2.1. ICT and electricity consumption

Environmental impact of the ICT use especially the impact of the astonishing increase in the Internet use and subsequently the energy intensity of the Internet has recently been one of the rising concerns. The electricity mix used for data centers is an issue of increasing importance (Coroama and Hilty, 2014). ICT-electricity consumption nexus is relatively an under-investigated area of research despite its potential implications for environmental sustainability. Most of the studies that have so far been conducted for developed economies are at the country level time series studies or at industry level cross-sectional studies (Sadorsky, 2012).

Arguably in one of the most cited studies on energy impacts of ICT so far, Romm (2002) labels the US economy characterized by the astonishing growth of the Internet use as the ‘Internet economy’. His findings suggest that the use of the Internet does not cause a rise in electricity demand rather it drives electricity efficiency. Thus, the study found that the Internet use has resulted in the decline in electricity intensity as well as in energy intensity in all the sectors of the USA economy. The study concludes that the Internet use potentially leads to economic growth with less energy consumption calling it a ‘New Energy Economy’ which is expected to have profound environmental implications. Schefer et al. shows that the share of total energy consumption of German mobile telephone sector is only 7% when it did not include electricity use for charging of the handsets. When charging of the handsets is accounted for, the share stands at 45%. Collard et al. (2005) estimate a factor demand model to assess the impact of IT investment on capital goods on the electricity intensity of production in the French service sector. Using panel data combining time series and cross sectional dimensions, they find that during the period 1986–1998, electricity intensity of production has declined with the diffusion of communication devices while it increased with the use of computers and software.

Cho et al. (2007) use time series data for South Korea to examine the effects of ICT investment and energy price on industrial electricity demand. They employ logistic growth model for analysis of data. Their findings indicate that ICT investment increases electricity intensity in the service sector and in those manufacturing sectors that consume relatively higher amount of electricity. The study further suggests that more efforts are required to achieve electricity efficiency in the service sector. It concludes that ICT investment in some of the manufacturing sectors have the potential for reduction in electricity consumption through energy efficiency. The European Commission e-Business Watch (2006) conducts a comprehensive study on the effects of ICT on electricity in Austria, Germany, Denmark, Finland, France, Italy, Spain and the UK as well as a number of company case studies. The findings indicate that at the aggregate level, ICT use increases electricity consumption while at the micro level, it enhances energy efficiency. Heddeghem et al. (2014) in a study examine the trend in worldwide electricity consumption and show that the absolute electricity consumption of three key ICT categories, namely, communication networks, personal computers and data centers, has increased in 2012 from its level in 2007.

There is so far none but one panel study (Sadorsky, 2012) which estimated the empirical relationship between ICT investment and electricity consumption in emerging economies. Using a dynamic panel model, it employed the Generalized Methods of Moments (GMM) technique to investigate the link between the ICT and electricity consumption for a sample of emerging economies. The study found that ICT use increases electricity consumption in these countries. One limitation of homogeneous panel data approaches such as the GMM technique that was employed in this study is that it allows the intercept to differ while constraining all other parameters to be the same thus still imposing a high degree of homogeneity ignoring the potential cross-sectional heterogeneity in the panel. Such method of homogeneity has the potential risk of producing biased results. The current study overcomes this limitation by employing a panel estimation technique that allows for cross-country heterogeneity.

Moyer and Hughes (2012) use International Futures (IFs) integrated assessment system to explore the dynamic impacts of ICT on economic and energy systems including its impact on carbon emissions. They argue that ICT can have a downward impact on overall carbon emissions across a 50-year time horizon. However, they further caution that the net effect might be limited. The study recommends that ICT promotion must be coupled with a global price on carbon.

Despite the growing concern of the energy impacts of ICT expansion, there is so far none but only one panel study (Sadorsky, 2012) which estimated the empirical relationship between ICT investment and electricity consumption in emerging economies. Using a dynamic panel model, it employed the Generalized Methods of Moments (GMM) technique to investigate the link between the ICT and electricity consumption in emerging economies. Moyer and Hughes (2012) use International Futures (IFs) integrated assessment system to explore the dynamic impacts of ICT on economic and energy systems including its impact on carbon emissions. They argue that ICT can have a downward impact on overall carbon emissions across a 50-year time horizon. However, they caution that the net effect might be limited. The study further recommends that ICT promotion must be coupled with a global price on carbon.

An overview of the above literature review suggests that energy literature suffers from an absolute vacuum of any Australian study that directly examines the impact of the Internet usage on electricity consumption. The rapid increase of the Internet usage since mid-1990s and the ongoing NBN rollout to expand the Internet infrastructure further have obviously been exerting some pressure on domestic electricity demand and Australia may already be experiencing possible environmental consequences through CO_2 emissions from this rollout. This study will dig into depth this possibility and is expected to provide with a fine-grained understanding of this burning issue.

2.2. Electricity consumption and economic growth

Literature investigating the relationship between electricity consumption and economic growth is enormous. Since the pioneering work of Kraft and Kraft (1978) that examined this relationship in the USA, plenty of literature in the area have emerged. Basically four main streams of literature evolved that investigated this relationship: (i) the electricity consumption-led growth hypothesis (growth hypothesis) (ii) the growth-led electricity consumption hypothesis (conservation hypothesis), (iii) feedback hypothesis and (iv) neutrality hypothesis.

Most of the empirical studies tested the growth hypothesis and supported its validity (Hamdi et al., 2014). Literature testing conservation hypothesis dealt with both time series and panel data. Different time series techniques such as error correction mechanism (ECM), autoregressive distributed lag model (ARDL), variance autoregression (VAR), ordinary least squares-augmented group (OLS-AG), Dynamic Ordinary Least Squares (DOLS), fully modified ordinary least squares (FMOLS) and panel techniques such as panel cointegration, panel Granger causality and panel vector error correction model (VECM) were used to test the hypotheses.

In a study, Yoo (2006) investigates the causal link between real GDP and electricity consumption in Indonesia, Malaysia, Singapore and Thailand over the period 1971–2002. Findings indicated a bi-directional relationship for Malaysia and Singapore and a unidirectional relationship for Indonesia and Thailand. Overall, for all these countries, the growth hypothesis was found to hold meaning that economic growth causes increase in electricity consumption. Wolde-Rufael (2006) undertook the massive time series estimation for 17 African countries to examine the long-run relationship between real GDP per capita and electricity consumption per capita as well as determining the causal direction of the relationship over the period 1971–2001. He employed unrestricted error correction model (UECM) to assess cointegrating relationship and Toda-Yamamoto Granger causality for the determination of the direction of causal link between the variables. For 9 of the 17 countries, cointegrating or long-run relationship between real GDP per capita and electricity consumption per capita was found while for 5 countries, long-run relationship was found with real GDP per capita as the dependent variable. For 4 countries, a cointegrating relationship was found when electricity consumption per capita was used as a dependent variable. For 6 of the countries, no long-run relationship was observed. The findings further showed that GDP per capita Granger causes electricity consumption for six countries and electricity consumption Granger causes GDP for three countries. A bi-directional relationship was also observed for three countries. For the rest four countries, he found no causal relationship.

Squalli (2007) used time series data for the Organization of Petroleum Exporting Countries (OPEC) to estimate the long-run relationship and the direction of the causal link between electricity consumption and economic growth for the period of 1980–2003. He employed autoregressive distributed lag model (ARDL) to estimate the long-run relationship and modified Wald test (MWT) to identify the causal direction of the relationship. The study found long-run relationship between the variables for all the OPEC countries. A unidirectional relationship was found for 6 of the countries while a strong bi-directional relationship was evident in the rest five countries.

Chen et al. (2007) estimate the cointegrating and the causal relationship between GDP and electricity consumption for 10 rapidly growing Asian countries over the period 1971–2001. This is one of the unique studies that employ both time series and panel data techniques for estimation of the relationship. Both time series and panel unit root tests were conducted to assess the stationarity of data. Both time series cointegration and panel cointegration tests reveal long-run steady-state relationship between GDP and electricity consumption. Time series causality results suggest different causal directions for different countries. The panel causality test based on the error correction model finds significant bi-directional causality between the variables. A unidirectional short-run causality running from economic growth to electricity consumption was also found.

Narayan and Prasad (2008) conducted causality tests to investigate the causal relationship between electricity consumption and real GDP for 30 OECD countries. They employed a bootstrapped causal testing method and found that electricity consumption causes real GDP in Australia, Iceland, Italy, the Slovak Republic, Korea, Portugal and the UK. For the rest of the countries, no evidence of causal relationship was found. They also carried out a regression analysis for each of the 30 OECD countries and obtained positive relationship between real GDP and electricity consumption.

Narayan et al. (2010) investigate the long-run causality between electricity consumption and real GDP for seven panels consisting of a total of 93 countries. They conduct Canning and Pedroni long-run causality test for the first time in energy literature. They find long-run bi-directional causality for all panels except where only GDP Granger causes electricity consumption. There exist positive relationship between these variables in all the significant panels except in the then G6 countries which means that an increase in electricity consumption will reduce GDP. Acaravci and Ozturk (2010) examine the long-run relationship and causality issues between electricity consumption and economic growth for a panel of 15 transition economies. It is one of the very few studies, findings of which, do not indicate any cointegrating relationship between electricity consumption and economic growth implying that policies aiming to reduce electricity consumption would have no effect on real GDP in these countries.

Yoo and Kwak (2010) investigate the causal relationship between electricity consumption and economic growth for seven South American countries for the period of 1975–2006. They find unidirectional, bi-directional and no causal link for different countries across the region. Ciaretta and Zarraga (2010) use annual data to investigate the long-run and causal relationship between electricity consumption and real GDP for a panel of 12 European countries for the period of 1970–2007. They estimate a trivariate VECM by GMM. The results show evidence of a long-run equilibrium and a negative short-run relationship between the variables. The findings further confirm bi-directional causality between energy prices and GDP and between electricity consumption and energy prices.

Apergis and Payne (2011) in a multivariate panel of 88 countries categorized into four panels based on the World Bank income classifications (i.e., high, upper-middle, lower-middle and low income) over the period of 1990–2006. The results reveal long-run equilibrium relationship between real GDP, coal consumption, real gross fixed capital formation and the labor force for the high, upper-middle and lower-middle income country panels. They also find bi-directional causal relationship for high-income and the upper middle-income country panels in both the short- and the long-run. Their findings further indicate unidirectional causal link in the short-run and bi-directional causal link for the lower middle-income country panel and unidirectional causality from electricity consumption to economic growth for the low-income country panel.

Bildirici and Kayikci (2012) in a study of 11 Commonwealth Independent States (CIS) apply panel ARDL and the FMOLS methods to examine the causal relationship. They divide the panel of CIS countries into three sub-panels based on income levels. Their empirical findings confirm a cointegrating relationship between the variables in all groups. The results further indicate a unidirectional causal link running from electricity consumption to economic growth for all groups in the long-run. FMOLS and ARDL estimations show that the effect of electricity consumption on GDP is negative for the second group of countries while it is positive for the first group of countries supporting the growth hypothesis.

Cowan et al. (2014) in a study use data on BRICS (Brazil, Russia, India, China and South Africa) for the period 1990–2010 and conduct panel causality analysis which accounts for cross sectional dependence and the potential heterogeneity across countries. They do not find any support for causal link between electricity consumption and economic growth for Brazil, India and China. However, a unidirectional causal relationship running from electricity consumption to economic growth in Russia and South Africa is found. Since findings of the causal direction between variables are different for different countries, the study fails to recommend any unique prescription for policy implications for these countries. Wolde-Rufael (2014) uses a similar method and analyzes the empirical relationship between electricity consumption and economic growth in 15 transition economies for the period 1975–2010. He employs a bootstrap panel causality technique that takes into account both cross sectional dependence and cross country heterogeneity. The findings offer limited support for electricity-led growth hypothesis. As expected, evidence of diverse directions of causality is found. The study concludes that these countries are yet to achieve energy efficiency as they are lagging behind according to international standard.

Several studies have examined the relationship between energy or electricity consumption and economic growth at country level. Wolde-Rufael (2006) investigates the relationship between per capita electricity consumption and real GDP per capita in Algeria, Zambia and Zimbabwe. He employed Toda-Yamamoto causality test and found no causal link between electricity consumption and real GDP for Algeria. For Zambia and Zimbabwe, he found that economic growth Granger caused electricity consumption supporting the conservation hypothesis. Chen et al. (2007) examines electricity consumption-real GDP nexus in China using Johansen-Juselius cointegration technique. They also found no causal link between the variables.

Mojumder and Marathe (2007) employ the same method to estimate this relationship for Bangladesh. Their findings indicated unidirectional relationship running from real GDP to electricity consumption. Narayan and Singh (2007) employed ARDL bounds testing method and VECM to investigate the empirical link between electricity consumption, real GDP and labor force in the Fiji islands. Their findings supported that electricity consumption Granger caused real GDP and labor force. Pao (2009) examines the causal relationship between electricity consumption and economic growth for Taiwan for the period 1980–2007. The results indicate long-run cointegrating relationship between the variables. Also unidirectional short and long-run causal relationship running from economic growth to electricity consumption is found. The study further suggests that there was no structural change during the period of the study and that the estimated parameters of the error correction mechanism (ECM) were stable. Shahbaz and Lean (2012) investigate the empirical relationship between electricity consumption and economic growth in Pakistan using time series data for the period 1972–2009. They find significant positive long-run relationship between these variables. Also electricity consumption and economic growth are found to cause each other. Solarin and Shahbaz (2013) show a bi-directional causal link between electricity consumption and economic growth in Angola. Hamdi et al. (2014) employ ARDL technique to study the relationship between electricity consumption and economic growth in Bahrain. They use quadratic sum match method to convert annual data into quarterly frequency. Their findings support feedback hypothesis which means that there is bi-directional causality between electricity consumption and economic growth. Javid and Qayyum (2014) apply structural time series technique to examine the relationship among electricity consumption, real economic activity, real price of electricity and the underlying energy demand trend (UEDT) at the aggregate and sectoral levels, namely, for the residential, commercial, industrial and agricultural sectors. The study finds a non-linear and stochastic trend at the aggregate level. The UEDT for the residential, commercial, and agricultural sectors show upward slope which imply that these sectors are yet to gain energy efficiency and even if, there are some energy efficiency improvements due to technical progress, they are outclassed by other factors.

Another strand of literature has focused on the decoupling issue to assess how economic growth is faring with the CO_2 emissions in countries. OECD (2002) first proposed the concept of 'decoupling' which occurs when the growth of environmental pressure is slower than the economic growth. Ever since, OECD countries have attached great importance to the research on the decoupling theory and its application dividing the decoupling concept into relative decoupling and absolute decoupling. Relative decoupling occurs when emissions grow at a slower rate than economic growth while absolute decoupling happens when emissions decline with the economy growing. Jukneys (2003) proposed the concept of primary decoupling, secondary decoupling and double decoupling. According to him, primary decoupling refers to delinking natural resources consumption from economic growth while secondary decoupling is decoupling of environmental pollution from consumption of natural resources. Double decoupling occurs when primary decoupling and secondary decoupling occur simultaneously.

Empirical research focusing on decoupling issue is scarce. Zhang and Wang (2013) examines the occurrence of decoupling between growth rates in economic activity and CO_2 emissions from energy consumption during 1995–2009 in Jiangsu province which is one of the most developed regions in China. They show that during the study period, Jiangsu experienced weak decoupling and strong decoupling except during 2003–2005. The decoupling states for the secondary and tertiary industries are similar to that of the whole economy. Wang et al. (2013) in another study in the same region show that economic activity is the critical factor in the growth of energy related CO_2 emissions and the energy intensity effect plays vital role in reducing CO_2 emissions. Andreoni and Galmarini (2012) use decomposition analysis to assess the progress in decoupling economic growth from CO_2 emissions in Italy. They split data for the periods of 1998–2002 and 2002–2006. The study considers five key sectors and four explanatory variables, CO_2 emissions, CO_2 intensity, energy intensity, structural changes and economic activity. The findings indicate that Italian economy did not perform absolute decoupling during both the periods in terms of economic growth and CO_2 emissions and that economic growth and energy intensity are mostly responsible for CO_2 emissions. The highest level of decoupling is observed in 2009.

Ren and Hu (2012) investigates the trend of decoupling effects in non-ferrous metal industry in China. The study observes four decoupling stages in the industry; strong negative decoupling stage (1996–1998), weak decoupling stage (1999–2000), negative decoupling stage (2001–2003) and weak decoupling stage (2004–2008). The study further suggests that the rapid growth of the industry is the most important factor responsible for the increase of CO_2 emissions. The increase in electric energy consumption contributed to increased CO_2 emissions. Freitas and Kaneko (2011) examine the state of decoupling of growth and CO_2 emissions from energy consumption during the period 2004–2009 in Brazil. Using decomposition analysis based on Log-mean Divisia Index (LMDI), the study finds that carbon intensity and energy mix are the two factors that need to be addressed to curb CO_2 emissions. They also observe several periods of relative decoupling in the country. Kveilborg (2004, 2007) and Kveilborg and Fosgerau (2005) found that use of larger vehicles, increased average loads and empty running were the key factors that contributed towards the decoupling of traffic growth from economic growth in Denmark.

Mckinon (2007) and Sorrell et al. (2010) had similar findings for the United Kingdom. So far, there is no study that estimated the decoupling index values for Australia. This study is the first attempt to do it for an assessment of the current environmental situation of Australia.

Although energy sector is one of the major industries in Australia, time series studies in the area of electricity consumption and economic growth is relatively scanty. Fatai et al. (2004) conducted a study examining the link between electricity consumption and economic growth in Australia and found support for the conservation hypothesis that is, economic growth Granger caused electricity consumption. This finding was further corroborated by Narayan and Smith (2005). In another study, Narayan and Prasad (2008) found unidirectional causality running from electricity consumption to economic growth in case of Australia. Salahuddin and Khan (2013) found bidirectional causal link between energy consumption and economic growth in Australia. They employed cointegration, vector autoregression (VAR), Granger causality and generalized impulse response functions to estimate the relationship using annual macro data for the period 1965–2007. Their findings also indicate that energy consumption in Australia has persistent positive effects on CO_2 emissions.

From the above literature review, it is evident that there is no recent study which investigated the empirical relationship between electricity consumption and economic growth in Australian context although such a topic is worth-investigation given the strong empirical evidence of such relationship in the literature and its subsequent environmental implications especially for a country like Australia which is one of the top CO_2 emitters in the world and that its major source of energy is electricity which is a key factor for CO_2 emissions. This study also uses the most recent data and the findings are thus expected to provide significant policy implications.

3. Data and methodology

3.1. Data

We employ historical data from the International Energy Agency (IEA, 2013) on per-capita CO_2 emissions and per capita energy consumption over the period from 1970–2012 to estimate the decoupling effects in order to report the overall emissions scenario of Australia. Annual time series data on electricity consumption per capita, real GDP per capita, internet users per 100 people for the period of 1985–2012 were obtained from the World Data Bank, (previously, World Development Indicators database, The World Bank, 2013) for econometric investigation of the relationship between variables. A few missing values were observed in the internet users per 100 people series which were replaced by 3-year moving average values. The variable per capita electricity consumption (EC) is measured by electric power consumption (kWh per capita) per capita, real GDP per capita (GDPC) is measured at constant 2005 US$ and the number of internet users per 100 people (NET) are considered for the study. All variables are expressed in natural logs.

3.2. Methodology

3.2.1. The model

Following Sadorsky (2012) and Narayan et al. (2010), we propose and estimate an econometric model where electricity consumption is assumed to be a function of Internet usage and economic growth in Australia. Therefore, the functional form of the model is:

$$\mathrm{EC} = F(A, \mathrm{NET}, \mathrm{GDPPC}) \tag{1}$$

or

$$\mathrm{EC}_t = A.(\mathrm{NET}_t)^{\beta 1}(\mathrm{GDPPC}_t)^{\beta 2} \tag{2}$$

Log-linearizing both sides of the equation, we obtain:

$$\ln E_t = \beta_0 + \beta \ln \mathrm{NET}_t + \beta_2 \ln \mathrm{GDPPC}_t + \varepsilon_t \tag{3}$$

The subscript t represent the time period.

3.3. Estimation procedures

3.3.1. Estimation of decoupling effects in Australia during 1970–2012

Following Bithas and Kalimeris (2013), we estimate decoupling index for energy and GDP per capita ratio for Australia. The decoupling index (DI) refers to the ratio of the change in the rate of consumption of a given resource, to the change in the rate of economic growth (in terms of GDP), within a certain time period (typically one year). The DI for Australia is estimated from the following formula;

$$\mathrm{DI} = \frac{E_t - E_{t-1}/E_{t-1}}{\mathrm{GDP}_t - \mathrm{GDP}_{t-1}/\mathrm{GDP}_{t-1}} \tag{4}$$

When DI > 1, no decoupling is taking place.

When DI = 1, it is the turning point between absolute coupling and relative decoupling is represented.

When 0 < DI < 1, relative decoupling is taking place.

When DI = 0, it is implied that the economy is growing while resource consumption remains constant. This is the turning point between relative and absolute decoupling.

When DI < 0, the relationship can be described as absolute decoupling.

3.3.2. Unit root tests

Since unit root test helps us with a robust causality assessment, we employ the DF-GLS (Dickey Fuller – Generalized Least Squares) test proposed by Eliott et al. (1996) to determine the order of integration of variables as this test is more powerful than other conventional tests such as ADF (Dickey and Fuller, 1979), PP (Phillips and Peron, 1988) and KPSS (Kwiatkowski et al., 1992). However, despite its superiority over other tests, it fails to identify the presence of structural break, if any, in the series (Baum, 2004). Therefore, we also conduct Zivot and Andrews (1992) unit root test which accommodates a single structural break point in the level. If we consider our series as X, the structural tests take the following form;

$$\Delta X_t = \alpha + \alpha X_{t-1} + bT + cD_t + \sum_{j=1}^{k} d_j \Delta X_{t-j} + \varepsilon_t \tag{5}$$

$$\Delta X_t = \beta + \beta X_{t-1} + ct + bD_t + \sum_{j=1}^{k} d_j \Delta X_{t-j} + \varepsilon_t \tag{6}$$

$$\Delta X_t = \gamma + \gamma X_{t-1} + ct + dDT_t + \sum_{j=1}^{k} d_j \Delta X_{t-j} + \varepsilon_t \tag{7}$$

$$\Delta X_t = \Omega + \Omega X_{t-1} + ct + dD_t + dDT_t + \sum_{j=1}^{k} d_j \Delta X_{t-j} + \varepsilon_t \tag{8}$$

where D is a dummy variable and shows the mean shift at each point and DT_t is a trend shift variable. The null hypothesis in Zivot and Andrews (1992) is $c = 0$ meaning the presence of unit root in the absence of structural break hypothesis against the alternative that the series is trend stationary with an unknown time break. Then, this unit root test selects that time break which reduces one-sided t-statistic to test $c(=c-1)=1$.

3.3.3. ARDL bounds testing approach

Since conventional cointegration techniques have certain limitations with their findings in the presence of structural break in macroeconomic dynamics (Uddin et al., 2013), we employ ARDL (Autoregressive Distributed Lag model) bounds testing approach developed by Pesaran (1997) and Pesaran et al. (2001) to estimate the long-run relationship between the variables. The ARDL technique has several advantages over other conventional cointegration techniques; first of all, this method can be applied to a small sample size study (Pesaran et al., 2001) and therefore conducting bounds testing is justified for the present study. Secondly, it can be applied even in case of mixed order of integration of variables [both for $I(0)$ and $I(1)$ variables]. Thirdly, it simultaneously estimates the short-run dynamics and the long-run equilibrium with a dynamic unrestricted error correction model (UCEM) through a simple linear transformation of variables. Fourth, it estimates the short- and the long-run components simultaneously potentially removing the problems associated with omitted variables and autocorrelation. In addition, the technique generally provides unbiased estimates of the long-run model and valid t-statistic even when the model suffers from the problem of endogeneity (Harris and Sollis, 2003). The empirical formulation of ARDL equation for our study is specified as follows:

$$\begin{aligned}\Delta \ln \mathrm{EC}_t = {} & \beta_0 + \beta_1 T + \beta_2 D + \beta_3 \mathrm{EC}_{t-1} + \beta_4 \ln \mathrm{GDPC}_{t-1} + \beta_5 \mathrm{NET}_{t-1} + \sum_{i=1}^{p} \beta_6 \Delta \ln \mathrm{EC}_{t-j} \\ & + \sum_{j=1}^{q} \beta_7 \Delta \ln \mathrm{GDPC}_{t-k} + \sum_{k=0}^{r} \beta_8 \Delta \ln \mathrm{NET}_{t-1} + \varepsilon_t \end{aligned} \tag{9}$$

$$\begin{aligned}\Delta \ln \mathrm{GDPC}_t = {} & \beta_0 + \beta_1 T + \beta_2 D + \beta_3 \ln \mathrm{GDPC}_{t-1} + \beta_4 \mathrm{EC}_{t-1} + \beta_5 \mathrm{NET}_{t-1} \\ & + \sum_{i=1}^{p} \beta_7 \Delta \ln \mathrm{GDPC}_{t-j} + \sum_{j=0}^{q} \beta_9 \Delta \ln \mathrm{NET}_{t-k} + \sum_{k=0}^{r} \beta_{10} \Delta \ln \mathrm{EC}_{t-l} + \varepsilon_t \end{aligned} \tag{10}$$

$$\begin{aligned}\Delta \mathrm{NET}_t = {} & \beta_0 + \beta_1 T + \beta_2 D + \beta_3 \mathrm{NET}_{t-1} + \beta_4 \ln \mathrm{GDPC}_{t-1} + \beta_4 \mathrm{EC}_{t-1} + \sum_{i=0}^{p} \beta_8 \Delta \ln \mathrm{NET}_{t-j} \\ & + \sum_{j=0}^{q} \beta_9 \Delta \ln \mathrm{GDPC}_{t-k} + \sum_{k=0}^{r} \beta_{10} \Delta \ln \mathrm{EC}_{t-l} + \varepsilon_t \end{aligned} \tag{11}$$

where lnGDPC, lnEC and lnNET indicate log values for real GDP per capita, electricity consumption per capita and internet users per 100 people, respectively. Δ is the difference operator. T and D denotes time trend and dummy variable, respectively. The dummy variable is included in the equation to capture the structural break arising from the series. ε_t is the disturbance term.

To examine the cointegrating relationship, Wald Test or the F-test for the joint significance of the coefficients of the lagged variables is applied with the null hypothesis, H_0: $\beta_3 = \beta_4 = \beta_5$ indicating no cointegration against the alternative hypothesis of the existence of cointegration between variables. F statistics are computed to compare the upper and lower bounds critical values provided by Pesaran et al. (2001).

3.4. The vector error correction model (VECM) Granger causality test

According to Granger (1969), once the variables are integrated of the same order, the VECM Granger causality test is appropriate to estimate their causal link. Since all the variables in our study are first difference stationary [$I(1)$], this study proceeds further to determine the causal direction between them. Knowledge about the exact direction of causal link helps with better policy implications of the findings (Shahbaz et al., 2013). The potential causality pattern for our study is represented by the following VAR specification in a multivariate framework;

$$\Delta \ln \mathrm{EC}_t = \beta_{0i} + \sum_{i=1}^{p} \beta_{1i} \Delta \ln \mathrm{EC}_{t-1} + \sum_{i=0}^{p} \beta_{2i} \mathrm{NET}_{t-i} + \sum_{i=0}^{p} \beta_{3i} \Delta \ln \mathrm{GDPC}_{t-i} + \varepsilon_t \tag{12}$$

3.4.1. Impulse response function (IRF) and variance decompositions

One major weakness of the VECM Granger causality is that it is unable to provide reliable estimates of the causal strength of relationship between variables beyond the selected sample period. Another limitation is that it provides only the direction of the relationship, not the corresponding sign. To overcome these limitations, this study applies Innovation Accounting Approach (IAA) which consists of variance decomposition and generalized impulse response functions. The generalized impulse response function is preferred over the simple Choleski fractionalization impulse response analysis as the generalized impulse response function is insensitive to the order of the VECM (Shahbaz et al., 2013). It also indicates whether the impacts of innovations are positive or negative or whether they have short-run or long-run effect. The general representation of this procedure is available in the seminal works of Sims (1980, 1986) and Bernanke (1986). Although impulse response function traces the effect of a one standard deviation shock on the current and future values of all the endogenous variables through the dynamic structure of VECM, it doesn't provide the magnitude of such effect. Consequently, variance decomposition method is employed to examine this magnitude.

Variance decomposition (Pesaran and Shin, 1999) measures the percentage contribution of each innovation to h-step ahead forecast error variance of the dependent variable and provides a means for determining the relative importance of shocks in explaining the variation in the dependent variable. Engle and Granger (1987) and Ibrahim (2005) argued that variance decomposition approach produces more reliable results as compared to those from other traditional approaches.

3.4.2. Dynamic Ordinary Least Squares (DOLS)

Finally, we apply the Dynamic Ordinary Least Squares (DOLS) method (Stock and Watson, 1993) and estimate the long-run coefficients between the variables in order to check for the robustness of the findings from the ARDL estimates. The application of this method for robustness check is appropriate in that this estimator is robust to small sample bias and eliminates simultaneity problem. Moreover, the obtained co-integrating vectors from DOLS estimators are asymptotically efficient.

4. Estimation results

Table 1 reports descriptive statistics. The standard deviations in all the series are quite low implying that the data are evenly dispersed around the mean. Hence it was convenient for us to proceed with the datasets for further estimation.

The DF-GLS unit root results are reported in Table 2 which shows all the series in our study are first difference stationary, i.e., $I(1)$. The weakness of this test is that it does not consider the presence of structural break (Baum, 2004) in the series. Due to different types of internal and external shocks, it is expected that there will be some structural breaks in the data. To overcome this shortcoming, we employ Zivot and Andrews (1992) unit root structural break test. The results of this test are presented in Table 3 which detects a number of break points in the early and late 1990s as well as in the late 2000s. The results further confirm that all the series are first difference stationary, i.e., $I(1)$, in the presence of structural break.

Next we proceed with the estimation of short-run and the long-run relationship among the variables. Since ARDL is sensitive to lag order, for calculating the F statistic, first of all, we need to identify the appropriate lag order. To do this, we choose AIC (Akaike Information Criterion) as it provides better results than other lag length criteria (Lutkepohl, 2006). The reported ARDL results in Table 4 suggests that the calculated F statistic of 4.689 is higher than the upper bound critical value generated by Pesaran et al. (2001) at the 1% level of significance. Therefore, there is highly significant cointegrating

Table 1
Descriptive statistics.

Variable	Obs	Mean	Std. Dev.	Min	Max
LEPU	23	9.174	0.118	8.926	9.320
LGDPC	23	10.300	0.160	10.044	10.525
NET	23	2.540	1.968	−0.634	4.410

Table 2
Unit-root test DF-GLS.

Log levels (Z_t)		Log 1st difference (Z_t)		
Variable	DFGLS stat	Variable	DFGLS stat	$I(d)$
LEPU	−0.460	ΔLEPU	−3.855[a]	$I(1)$
NET	0.796	ΔNET	−3.267[a]	$I(1)$
LGDPC	−2.518	ΔFD	−3.277[b]	$I(1)$

Note: a, b, and c indicate 1%, 5%, and 10% significance level respectively.

Table 3
Zivot–Andrews structural break unit root test.

Variable	Z & A test for level			Z & A test for 1st difference		
	T-Statistic	TB	Outcome	*T*-Statistic	TB	Outcome
LEPU	−3.675	2002	Unit Root	−4.594[a]	1992	Stationary
NET	−12.545[a]	1997	Stationary	−4.891[c]	1998	Stationary
LGDPC	−3.747	2008	Unit Root	−6.010[a]	1993	Stationary

Note: a, b, and c indicate 1%, 5%, and 10% significance level respectively.

Table 4
Results from bounds test.

Dep. Var.	*F*-stat.	95% Lower bound	95% Upper bound	Outcome
F_{LEPU}(LEPU|GDPC, NET)	7.249	4.5690	5.7521	Cointegration
F_{LGDPC}(LGDPC|LEPU, NET)	4.743	4.5690	5.7521	No cointegration
F_{NET}(NET|LGDPC, LEPU)	2.919	4.5690	5.7521	No cointegration

Table 5
Estimated long run coefficients using the ARDL approach (1,0,1) based on AIC, dependent variable is EPU.

Regressor	Coefficient	Standard Error	*T*-Ratio[Prob]
GDPC	0.889[a]	0.005	167.962[0.000]
NET	0.002[a]	0.767	−2.750[0.012]
DT	0.005	0.004	1.352[0.191]

Note: a, b, and c indicate 1%, 5%, and 10% significance level respectively.

relationship between per capita electricity consumption and the predicted variables – the Internet users per 100 people and economic growth.

Table 5 reveals that the Internet usage and economic growth stimulate Australia's per capita electricity consumption in the long-run. The findings are consistent with expectations. This means that an increased usage of the Internet leads to an increase in electricity consumption of Australia. Also higher level of income causes more consumption of electric appliances and thus cause higher consumption of electricity.

Table 6 reports the short-run effects of the independent variables on growth. The findings indicate that there is highly significant (at 1% level of significance) positive short-run effects of the Internet usage and economic growth on per capita electricity consumption in Australia. The coefficient of the error correction term, ECT_{t-1} is −0.3 and has the expected sign. It also implies a relatively speedy convergence (the short-run deviations being corrected at the speed of 53% towards the long-run equilibrium each year).

Table 7 demonstrates results from the diagnostic tests carried out from the ARDL lag estimates. The LM test confirms no serial correlation while Ramsey's RESET test suggests that the model (Eq. (1)) has the correct functional form. The normality

Table 6
Error correction representation for the selected ARDL model (1,0,1) selected based on AIC, dependent variable is dLEPU.

Regressor	Coefficient	Standard error	*T*-Ratio[Prob]
dGDPC	0.488	0.125	3.885[0.001]
dNET	0.013	0.005	2.351[0.029]
DT	−0.006	0.001	−3.601[0.002]
ecm(−1)	−0.536	0.139	−3.854[0.001]

Table 7
Diagnostic test.

Test statistics	LM version
R^2 0.97	Adjusted R^2 0.97
Serial correlation $\chi^2(1) = 0.449[0.503]$	Normality $\chi^2(2) = 1.001[0.606]$
Functional form $\chi^2(1) = 2.218[0.136]$	Heteroscedasticity $\chi^2(1) = 4.617[0.032]$

test reveals that the disturbance terms are normally distributed and are homoscedastic as supported by the heteroscedasticity test. The stability of parameters over time is reflected in the graphical plots of CUSUM and CUSUM of Squares (Figs. 5 and 6 respectively).

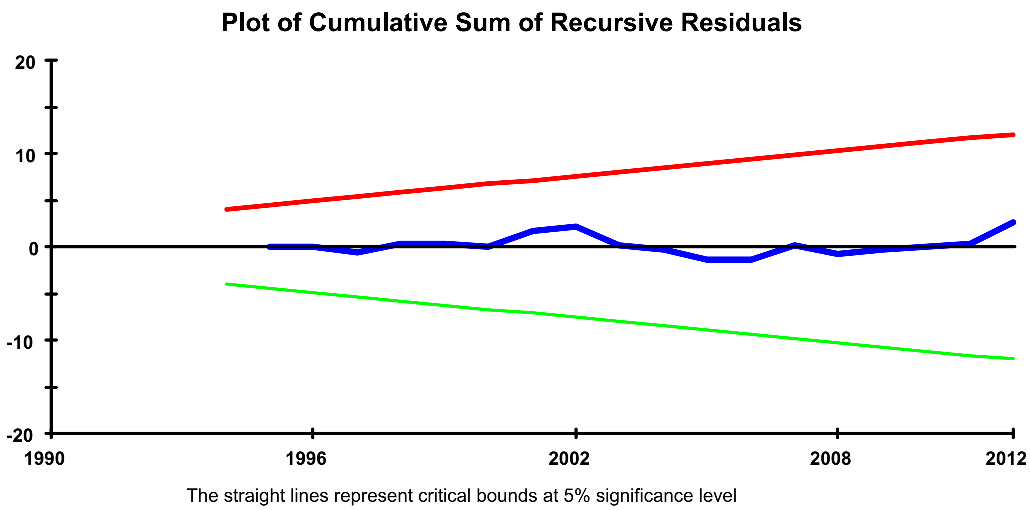

Fig. 5. Plot of Cumulative Sum of Recursive Residuals.

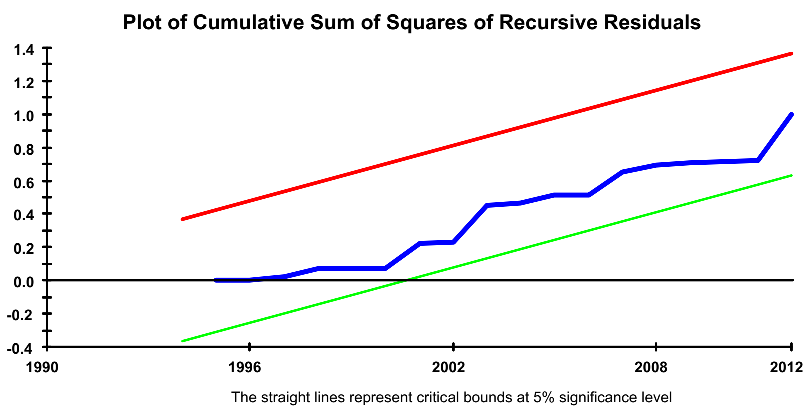

Fig. 6. Plot of Cumulative Sum of Squares of Recursive Residuals.

From Fig. 7, we see that the standard deviation of per capita electricity consumption leads to positive increase in future per capita electricity consumption in Australia. The response of per capita electricity consumption to the shocks in the Internet users per 100 people and per capita GDP demonstrates expected signs but with different magnitudes. The accumulated response of per capita electricity consumption to a shock in the Internet users per 100 people is positive and significant. The accumulated response of per capita electricity consumption to future shocks in GDP per capita is also positive and significant. Thus the findings are supportive of the earlier ARDL estimates of this study.

Results from the variance decomposition analysis are reported in Table 8. The study allows a 27 year forecasting horizon. Interestingly, at the 5-year forecasting horizon, about 75% of the one-step forecast variance in per capita electricity consumption is accounted for by its own innovations and altogether 25% is accounted for by economic growth and Internet users per 100 people. In the long-run after a period of 27 years, the response to own innovative shocks declines to around 60% while

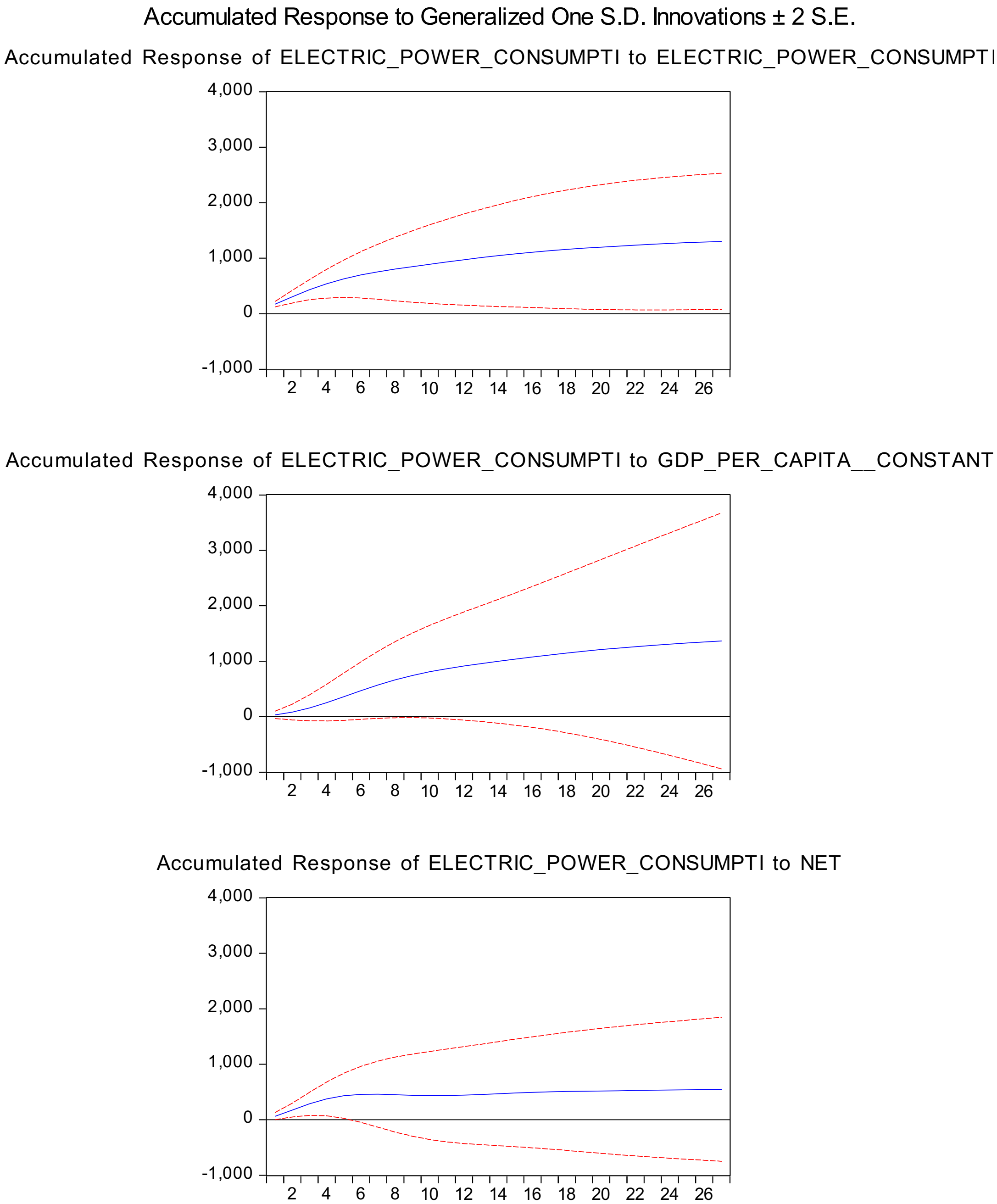

Fig. 7. Impulse response of per capita electricity consumption in Australia during 1990–2012.

Table 8
Variance decomposition of per capita electricity consumption in Australia during 1990–2012.

Period	S.E.	Electricity per capita	GDPC	NET
1	173.7531	100.0000	0.000000	0.000000
2	227.9662	90.94899	1.406215	7.644797
3	274.1514	84.89115	4.511362	10.59749
4	307.6305	79.62123	9.782656	10.59611
5	333.6356	74.66736	16.08726	9.245379
6	355.1638	69.82367	21.92443	8.251905
7	373.2043	65.60150	26.29822	8.100283
8	387.5592	62.42995	29.11257	8.457478
9	398.2287	60.37314	30.76351	8.863357
10	405.8273	59.21604	31.70109	9.082868
11	411.2985	58.64765	32.24687	9.105477
12	415.4926	58.39109	32.59284	9.016070
13	418.9596	58.25786	32.84996	8.892183
14	421.9721	58.14605	33.08246	8.771483
15	424.6403	58.01427	33.32139	8.664343
16	427.0068	57.85543	33.57171	8.572853
17	429.0916	57.67915	33.82227	8.498578
18	430.9075	57.50088	34.05734	8.441789
19	432.4678	57.33496	34.26514	8.399897
20	433.7914	57.19073	34.44095	8.368321
21	434.9051	57.07135	34.58605	8.342593
22	435.8415	56.97510	34.70510	8.319793
23	436.6333	56.89758	34.80375	8.298673
24	437.3097	56.83379	34.88719	8.279027
25	437.8936	56.77949	34.95949	8.261020
26	438.4019	56.73171	35.02347	8.244817
27	438.8467	56.68867	35.08086	8.230469

Table 9
Results from dynamic OLS.

	Coefficient	Robust Std. Err.	*P*-Value
LGDPC	0.055[a]	0.019	0.004
Internet use	0.050[a]	0.001	0.000
Intercept	8.490	0.196	0.000
R^2 0.999			

Note: a, b, and c indicate 1%, 5%, and 10% significance level respectively.

Table 10
VECM Granger causality.

Excluded	Chi-sq	df	Prob.
Dependent variable: D(EPU)			
D(GDPC)	1.523377	2	0.4669
D(NET)	4.972489	2	0.0832
All	7.831430	4	0.0980
Dependent variable: D(GDPC)			
D(EPU)	1.696555	2	0.4282
D(NET)	0.426328	2	0.8080
All	1.903370	4	0.7535
Dependent variable: D(NET)			
D(EPU)	0.436823	2	0.8038
D(GDPC)	1.187753	2	0.5522
All	1.551416	4	0.8175

the response of per capita electricity consumption to the shocks in GDP per capita and Internet users per 100 people rise to 43% from the first 5-year forecast horizon of 25%. Among the 43% of the variance, approximately 8% variance is due to the shocks in the variable of the Internet users per 100 people and around 35% variations are attributed to GDP per capita. The findings remind that while GDP per capita have strong forecasted impact on per capita electricity consumption, the impact of the Internet usage is also likely to be evident in the future. This leads to the justification that electricity efficiency policy in Australia needs to incorporate development and deployment of the Internet issues in its future policy framework to reduce the potential environmental damage from the expansion of Internet infrastructure.

Table 9 reports results from DOLS estimates. Although the coefficients vary, it confirms the robustness of the findings of ARDL long-run estimates. Multivariate Granger causality results are presented in Table 10. It shows a unidirectional causal link running from Internet usage to economic growth and electricity consumption.

5. Conclusions, policy implications and limitations

This study examines the empirical relationship among the Internet usage, electricity consumption and economic growth using Australian annual time series data for the period 1985–2012. Because of the long sample period, structural break unit root test is conducted. Having found the presence of structural break in the series, an ARDL bounds testing approach is applied taking into account the structural break. Granger causality test is performed to determine the causal link between the variables under study. The findings from the ARDL estimates suggest that the Internet usage and economic growth have long-run positive and significant effects on electricity consumption while these effects in the short-run are insignificant. Multivariate Granger causality test confirms unidirectional causal link running from the Internet usage to economic growth and electricity consumption. The causality of the relationship is robust as checked by impulse response functions and variance decomposition analysis. Another econometric technique Dynamic Ordinary Least Squares method (DOLS) also lends support to the long-run relationship between the variables. The baseline model used in the study succeeded all the conventional diagnostic tests.

The findings of the current study that both the Internet usage and economic growth stimulate electricity consumption in Australia in the long-run have important policy implications. The positive relationship between the Internet usage and electricity consumption suggest that Australia is yet to achieve energy efficiency gains from ICT expansion. Since 90% of electricity in Australia is still generated from non-renewable fossil fuels mostly from coal and gas, additional pressure on the demand for electricity will only worsen the environmental situation. Nevertheless, Australia is a coal abundant country and the largest exporter of coal in the world since 1986 (Falk and Settle, 2011). It may not be realistic for it to give up coal-fired generation of electricity that plays a significant role in Australian economy (The Gournot Report). Instead, it is recommended that Australia controls CO_2 emissions in the atmosphere through Carbon Capture and Storage facilities (CCS). CCS technology is not new in Australia and it is reported (Huaman and Jun, 2014) that Australia already has five large scale integrated CCS (LSIP) but this technology is yet to succeed in reducing CO_2 emissions significantly. For Australia, post combustion capture (PCC) is considered the only viable means of carbon capture (Qadir et al., 2013). Also Carbon pricing could be another option as it is argued that carbon pricing (emissions trading scheme) is a cost-effective method to reduce emissions which commenced in Australia from July, 2012. But it has just been abolished by the current Abbott government and whether it is gone for good or will be reinstated again remains to be seen. The abrogation of the emissions trading scheme (ETS) has put Australia in isolation from the international community in its efforts to reduce emissions.

Australia is also blessed with significant renewable resources such as wind, tidal energy, wave energy and geothermal energy although currently only 5% renewable energy is used for electricity production (Asafu-Adjaye and Mahadevan, 2013). Among the renewable resources, solar energy is the most valid option for reducing emissions as Australia is one of the sunniest countries in the world and that it is blessed with very strong wind (Byrnes et al., 2013). Queensland, one of the largest provinces of Australia is known as the sunshine state for its affluence in sunlight. Currently, there is no assistance to firms for investment in renewable energy sources even in solar energy. Aggressive investment for technological improvement in the renewable sector is important for Australia in order to achieve its target of producing 20% of electricity from the use of renewables by the year 2020. Apart from massive investment in the renewable sector, building nuclear energy is another potential option for Australia for power generation. Usually nuclear energy plants involve huge investment and the benefits are likely to be due only in the very long-run. Public investment in this sector is a preferred choice. Since Australia is one of the few developed countries whose economy remained stable for a long time now, large scale investment in nuclear energy is not very challenging. However, the success and sustainability of nuclear energy plants also depend on the consensus among the political parties.

Another finding of the study, the positive long-run relationship between economic growth and electricity consumption imply that Australia is in a position to pursue energy conservation policy without having its economic growth adversely affected (Hamdi et al., 2014). But energy conservation policy is not currently a good option for Australia given its enormous domestic demand for energy for its booming resources such as coal and mining which contribute towards huge export earnings. Energy efficiency gains should be the ultimate goal for significant reduction in its emissions.

This study also emphasizes on the Internet based electricity efficiency strategy to reduce environmental damage caused by CO_2 emissions as an inevitable consequence of additional electricity consumption due to massive increase in the Internet usage. Once energy efficiency gains from the growth in the Internet usage are achieved, this is expected to further promote the expansion of the Internet use and its accessories in the country as this will potentially reduce the cost of using the Internet services and the accessories which are likely to play an important role in reducing digital divide in Australia. Australia can in no way pursue or support a policy that may decelerate the growth of the Internet usage since digital divide is already in the danger of widening (Bowles, 2012). Electricity efficiency generated from various measures adopted for introducing and promoting green Internet is expected to encourage the various policies such as the ongoing rollout of the NBN for the growth of the Internet usage to continue. To achieve this goal of electricity efficiency, this study recommends that Australia promotes green Internet, green IT and IT for green that have the potential to substantially reduce CO_2 emissions through eco-efficiency and eco-design processes (Jenkin et al., 2011). Also the energy policy experts of Australia must recognize that electricity sector itself provides substantial opportunities for reducing emissions if measures such as fuel switching and generation efficiency improvement initiatives are taken (Ang et al., 2011). Finally, an effective coordination among ICT policy, energy policy and growth policy appears to be vital to address the climate change issue in Australia.

Despite important and significant findings, the current study suffers from a number of limitations. First, this study uses data for the period of 1990–2012 as the Internet data was available only from 1990. Future studies dealing with longer sample period are expected to provide more reliable results. Although, the robustness of the findings have been confirmed through a couple of other econometric techniques, still they might not be invariant across different other econometric methodologies. As the currently ongoing NBN rollout is expanding the Internet infrastructure across Australia, it is expected to lead to the increase in the Internet usage eventually resulting in a further increase in domestic electricity demand. The increase in electricity consumption is expected to cause a higher level of CO_2 emissions. Therefore, assessing the direct impact of the Internet usage on CO_2 emissions in Australia could be a potential topic for further investigation. This is left for future research.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.tele.2015.04.011.

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