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# The causal relationship between Indian energy consumption and the GDP: A shift from conservation to feedback hypothesis post economic liberalisation

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**Abstract.** *Fossil fuels are the main source of energy generation, which on one hand induces development and on the other hand increases emissions. This creates a dissonance between energy consumption and economic growth. In the recent years, liberalisation and policy transformations took place in India rapidly particularly after the 1990s. Therefore we developed relationship between per capita energy consumption and economic growth (Gross Domestic Product as an indicator) for this era (1991-2014). Toda-Yamamoto causality test framework of vector autoregressive model was used to test the relationship between the two. In contrast to earlier studies, our results present a bidirectional causality which shows that economic growth demands energy vis-a-vis energy consumption induces economic growth. Harmonized implications of these results are crucial input to policy purposes for inclusive development.*

**Keywords:** energy consumption, economic growth, Toda-Yamamoto causality test, VAR model.

**JEL Classification:** Q01, Q28, Q32, Q48, Q58.

## 1. Introduction

The world is dependent upon energy. Energy, in the form of electricity has become a necessity, rather than mere luxury. From lighting the house to cooking food, electricity is embedded into our lives and the need for it is growing more substantially as more and more electronic items are replacing conventional devices like gas cylinders for cooking by induction cook stoves or hand written mail delivery with electronic mail. With the advent in such electronic devices and also the world population, the global demand for energy increased twenty-five times over the last century (Smil, 2017). In the 20$^{th}$ century when climate change was not making headlines, energy development policies also grew exponentially. However, in recent times the focus has shifted towards conserving the environment and since combustible electricity production accounts for almost 70% of world electricity production (IEA 2016), the dilemma lies between decreasing electricity supply to curb emissions (as per the directives of Kyoto Protocol) or continue increasing consumption to achieve inclusive growth. The solution lies in providing renewable energy to all but as long as that is not achieved; it will help in development of energy policy framework to find links between energy consumption and real economic growth so that countries can adopt policies on the basis of this relationship. However, this is actually not how these relationship studies first began.

The oil crisis of 1973 when the middle-eastern OPEC nations stopped exports to the western nations, the world saw an exponential increase in economic studies depicting relation between growth of an economy to energy consumption. The results of these studies showed conflicting results with some showing strong relationship between the energy consumption and GDP or what is known as bidirectional causality or feedback hypothesis, for example, Yang, 2000; Mukhtarov et al., 2017; Yasar, 2017; Osigwe and Arawomo, 2015; Pao et al., 2014; Oh and Lee, 2004; Fallahi, 2011; Jumbe, 2004; Soytas and Sari, 2003; Paul and Bhattacharya, 2004; Bowden and Payne, 2009, etc.

Conservation policy which suggests causality is unidirectional running from economic growth to energy consumption was established by Lise and Montfort (2007), Jumbe (2004), Cheng and Lai (1997), Mozumder and Marathe (2007), Cheng and Lai (1997), Ozturk et al (2010), Farhani and Rejeb (2012), Soytas and Sari (2009), Ghosh (2002), Armeanu et al. (2017), Aneja et al. (2017), Hasanov et al. (2017), Souhila and Kourbali (2012), etc.

Growth hypothesis is supported when unidirectional causality is running from energy consumption to economic growth. This indicates that energy conservation may reduce investment and negatively influence economic growth (Apergis et al., 2011). Narayan and Smyth (2008), Feng et al. (2009), Wolde-Rufael (2004), Aqeel and Butt (2001), Chen et al (2007), Al-Iriani (2006), Soytas et al. (2001), Stern (2011), Keppler (2006), Apergis and Danuletiu (2012), Abosedra et al. (2015), etc. are some of the studies supporting growth hypothesis.

Some studies also suggest complete absence of relationship, that is, neither energy consumption affects GDP nor does GDP affect energy consumption. This is popularly known as the neutrality hypothesis and is given by Ozturk and Acaravci (2010), Glasure and Lee (1998), Atinay and Karagol (1998), AsafuAdjaye (2000), etc. All these mentioned above use a variety of techniques like Granger Causality, Johansson

Multivariate Cointegration, Vector Autoregressive Models, Vector Error Correction Models, Cointegration and panel data technique, Toda-Yamamoto causality test, etc.

As already mentioned, quite a few conflicting theories have emerged for several nations. The most inconsistent result was found for Turkey as it followed bidirectional, conservation and growth hypotheses for almost the same time period. The most consistent result is observed in case of the United States following bidirectional causality. Asian countries in general followed growth hypothesis and East Asian countries in particular are observed to be following conservational hypothesis.

Indian economy is growing at a fast pace and so are greenhouse gas emissions. A need to determine a causal link between energy consumption and growth is the need of the hour. There is a gap of such studies in recent years in India. Even studies conducted until 2014 (which is the latest such study) are highly conflicted in results where most cases of bidirectional causality were observed (Paul and Bhattacharya, 2004; Govindaraju and Tang 2013; Mallick, 2009; Ozturk and Uddin, 2012, and Bildirici and Bakirtas, 2014), a few cases of growth hypothesis (Fatai et al., 2004 and Wolde-Rufael, 2004), conservation hypothesis (Ghosh, 2002 and Keppler, 2006) and neutrality hypothesis (Alan et al., 2011 and Tiwari, 2011) were also observed. However it is also observed that studies which include data prior to the 1990s, which was the economic liberalisation period for India, showed a causal relationship running from GDP to energy consumption. Granger causality, VECM and Granger cointegration approach are the most popular methods used and no study has been conducted which includes data after 2011. This study therefore also includes data till 2014, which may not appear much as it is only three years more than the latest study; however the increase in installed thermal electricity capacity over a period of six years between 2005-2006 and 2010-2011 was only 36% compared to a 50% increase in four years between 2010-2011 to 2013-2014 (CEA, 2006-2014). This enormous change in capacity over a small period can be very consequential not only on emissions but also on the economy's rate of growth which is why this study has been undertaken.

## 2. Methodology and data

Previous similar studies conducted mostly employed Autoregressive distributed lag bounds testing approach of cointegration and vector error correction approach to test for causality. Toda-Yamamoto causality test is an alternative procedure to causality test which is based on modified granger non causality test. This procedure was proposed by Toda and Yamamoto (1995) to overcome the shortcomings of the conventional granger causality tests. The conventional granger causality test is based on F statistics and F statistics follows a standard normal distribution which means that when variables are integrated the granger causality test becomes fragile and may not be able to generate robust results since the resulting test statistics do not follow standard normal distribution. So Toda and Yamamoto, in order to overcome these challenges proposed a simple procedure which requires an estimation of an augmented VAR (vector autoregressive model) which generates the asymptotic VAR statistics in the form of Chi square distribution. Toda-Yamamoto (1995) test does not require knowledge of the integration and cointegration properties of the system. It can be applied even when there is no integration or stability, and when rank conditions are not satisfied 'so long as the order of integration of the process does not exceed the true lag length of the model' (Toda and Yamamoto, 1995).

Firstly the maximum order of integration of the series denoted by *dmax* was determined followed by determining the optimal lag length of the Vector Autoregressive (VAR) model denoted by k. Modified Wald statistic was used to test the significance of the parameters of the model where first, *(k+dmax)th* order of VAR was estimated. The estimation of *VAR(k+dmax)* guarantees the asymptotic chi-square distribution of the Wald Statistic. Finally the hypothesis is tested using a standard Wald Statistic test which has an asymptotic chi square distribution with m degrees of freedom.

The following tests were also done:
Augmented Dickey Fuller (ADF) Test to test the unit root.
Kwiatkowski–Phillips–Schmidt–Shin (KPSS) test to test for stationarity.
Lagrange Multiplier (LM) test to test for autocorrelation.
Inverse roots of AR characteristic polynomial were found to test for VAR model stability.
White test to determine the presence or absence of heteroscedasticity in the model.
Toda-Yamamoto causality test to determine the presence/absence/direction of relationship.

According to Toda and Yamamoto (1995) causality test model can be written as follows:

$$Y_t = \alpha_0 + \sum_{i=1}^{k} \alpha_{1i} Y_{t-i} + \sum_{j=k+1}^{d_{max}} \alpha_{2j} Y_{t-j} + \sum_{i=1}^{k} \varphi_{1i} EC_{t-i} + \sum_{j=k+1}^{d_{max}} \varphi_{2j} EC_{t-j} + v_{1t}$$

$$EC_t = \beta_0 + \sum_{i=1}^{k} \beta_{1i}\, EC_{t-i} + \sum_{j=k+1}^{d_{max}} \beta_{2j}\, EC_{t-j} + \sum_{i=1}^{k} \delta_{1i}\, Y_{t-1} + \sum_{j=k+1}^{d_{max}} \delta_{2j}\, Y_{t-j} + v_{2t}$$

Where,
Y – GDP per capita;
EC – Energy consumption (kg of oil equivalent per capita);
$k$ – optimal lag order;
$d$ – maximum order of integration of the series;
$v_{1t}$& $v_{2t}$ – error terms.

Annual data of per capita GDP and kg of oil equivalent per capita energy consumption between 1991 and 2014 was used. In this study, per capita energy consumption is denominated with kg oil equivalent and per capita GDP is denominated at constant 2011 U.S Dollar Purchasing Power Parity. The data was obtained from the World Bank Database under the code name SL.GDP.PCAP.EM.KD for GDP per capita and EG.USE.PCAP.KG.OE for energy consumption.

## 3. Empirical results

Before conducting the Toda-Yamamoto causality test, the order of integration of the series (*dmax*) and the optimal lag length (*k+dmax*) is determined so that there is no spurious or invalid causality or absence of such causality. Also unit root test, stationarity test, test for autocorrelation, test for stability of VAR model and test for heteroscedasticity was conducted before performing the causality test.

Using Augmented Dickey-Fuller (ADF) unit root test, it was found that GDP per capita (yper_capita) and Energy consumption (kg of oil equivalent per capita) has a unit root at maximum order of integration 2. This is also confirmed by Kwiatkowski-Phillips-Schmidt-Shin (KPSS) stationarity test where the series were found stationary at order of integration 2. Therefore, *dmax* or the maximum order of integration for the time series is 2. The results of ADF and KPSS tests are given in Table 1, Table 2, Table 3 and Table 4.

**Table 1.** *Augmented Dickey Fuller test results for Energy Consumption (kg of oil equivalent per capita)*

| Level of Significance | Panel A: Level | Panel B: 1st difference | Panel C: 2nd difference | *Dmax* |
|---|---|---|---|---|
| 1% | -3.75 | -3.89 | -3.79* | 2 |
| 5% | -2.99 | -3.05 | -3.01** | 2 |
| 10% | -2.63 | -2.67 | -2.65*** | 2 |
| t-statistic | 3.15 | -1.79 | -8.15 | |

*, ** and *** indicates we cannot reject null hypothesis at 1%, 5% and 10%, respectively.
Null hypothesis: D(ECper_capita) has a unit root.

**Table 2.** *Augmented Dickey Fuller test results for GDP per capita*

| Level of Significance | Panel A: Level | Panel B: 1st difference | Panel C: 2nd difference | *Dmax* |
|---|---|---|---|---|
| 1% | -3.75 | -3.76 | -3.81* | 2 |
| 5% | -2.99 | -3.00 | -3.02** | 2 |
| 10% | -2.64 | -2.64 | -2.65*** | 2 |
| t-statistic | 5.31 | -1.73 | -5.54 | |

*, ** and *** indicates we cannot reject null hypothesis at 1%, 5% and 10%, respectively.
Null hypothesis: D(GDPper_capita) has a unit root.

**Table 3.** *Kwiatkowski-Phillips-Schmidt-Shin test results for Energy Consumption (kg of oil equivalent per capita)*

| Level of Significance | Panel A: Level | Panel B: 1st difference | Panel C: 2nd difference | *Dmax* |
|---|---|---|---|---|
| 1% | 0.74* | 0.73* | -0.74* | 0/1/2 |
| 5% | 0.46 | 0.46 | -0.46** | 2 |
| 10% | 0.34 | 0.35 | -0.35*** | 2 |
| KPSS test statistic | 0.67 | 0.49 | 0.39 | |

*, ** and *** indicates we cannot reject null hypothesis at 1%, 5% and 10%, respectively.
Null hypothesis: D(ECper_capita) is stationary.

**Table 4.** *Kwiatkowski-Phillips-Schmidt-Shin test results for GDP per capita*

| Level of Significance | Panel A: Level | Panel B: 1st difference | Panel C: 2nd difference | *Dmax* |
|---|---|---|---|---|
| 1% | 0.74* | 0.74* | -0.74* | 0/1/2 |
| 5% | 0.46 | 0.46 | -0.46** | 2 |
| 10% | 0.34 | 0.35 | -0.35*** | 2 |
| KPSSteststatistic | 0.67 | 0.57 | 0.28 | |

*, ** and *** indicates we cannot reject null hypothesis at 1%, 5% and 10%, respectively.
Null hypothesis: D(ECper_capita) is stationary.

The second step is to determine the optimal lag length chosen by LR, AIC, FPE, SC and HQ criteria. In order to do this, firstly a VAR model containing all dependant variables was estimated with a randomly selected lag interval. Table 5 depicts the optimal lag length of 1 (k = 1) by LR and SC criteria and 2 (k=2) by FPE, AIC and HQ criteria out of a maximum of 2 lag lengths since the data is annual.

**Table 5.** *Lag interval tests*

| Lag | LogL | LR | FPE | AIC | SC | HQ |
|---|---|---|---|---|---|---|
| 0 | -275.77 | NA | 3.17e+08 | 25.25147 | 25.35065 | 25.27483 |
| 1 | -214.0935 | 106.5255* | 1683126 | 20.00850 | 20.30606* | 20.07859 |
| 2 | -209.1823 | 7.589988 | 1569184.* | 19.92566* | 20.42159 | 20.04249* |

*indicates optimal lag length.

In order to determine which of the two lag lengths is to be used as the optimal lag length, test for autocorrelation problem in the VAR model is performed. Table 6 and Table 7 depict the test for autocorrelation at Lag 2 and Lag 1 respectively and both the lag lengths accept the null hypothesis of no serial correlation.

**Table 6.** *Lagrange Multiplier test results at lag length 2*

| | | | |
|---|---|---|---|
| Dependant Variable: GDP per capita | | | |
| Null Hypothesis: No Serial Correlation up to 2 lags | | | |
| F-statistic | 0.35890 | Prob.F(2,20) | 0.7028 |
| Obs*R-Squared | 0.83160 | Prob. Chi-Square(2) | 0.6598 |
| Dependant Variable: Energy Consumption (kg of oil equivalent per capita) | | | |
| F-statistic | 0.332377 | Prob.F(2,20) | 0.7211 |
| Obs*R-Squared | 0.772043 | Prob. Chi-Square(2) | 0.6798 |

**Table 7.** *Lagrange Multiplier test results at lag length 1*

| | | | |
|---|---|---|---|
| Null Hypothesis: No Serial Correlation up to 1 lag | | | |
| Dependant Variable: GDP per capita | | | |
| F-statistic | 0.613902 | Prob.F(1,21) | 0.4421 |
| Obs*R-Squared | 0.681675 | Prob. Chi-Square(1) | 0.4090 |
| Dependant Variable: Energy Consumption (kg of oil equivalent per capita) | | | |
| F-statistic | 0.561175 | Prob.F(1,21) | 0.4621 |
| Obs*R-Squared | 0.624650 | Prob. Chi-Square(1) | 0.4293 |

The model has no autocorrelation indicating the error terms of the equations are not correlated. However, it is still not determined which optimal lag length is to be used and therefore the test for stability of the VAR model was conducted and the results are given in Figure 1 and Figure 2. Figure 1 depicts that the VAR model is not stable at lag length 1 and therefore the optimal lag length for the model is found to be 2 (k = 2). Figure 2 depicts that the VAR model is stable at lag length 2 as all the inverse roots are in the unit circle.

**Figure 1.** *AR roots graph at lag length 1*

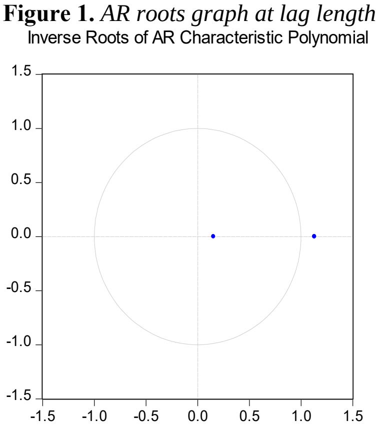
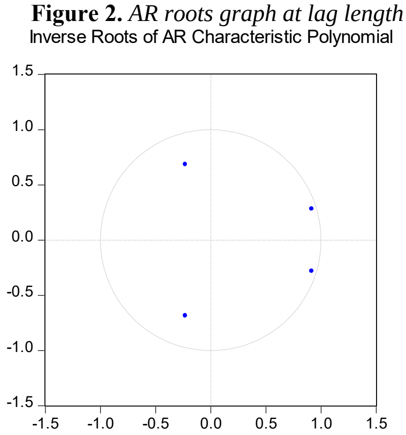



**Figure 2.** *AR roots graph at lag length 2*




Heteroscedasticity refers to the circumstance in which the variability of a variable is unequal across the range of values of a second variable that predicts it. White test is used to determine the presence of heteroscedasticity. Table 8 depicts the results of white test which accepts the null hypothesis of homoscedasticity.

**Table 8.** *Test for heteroscedasticity*

| Null Hypothesis: Homoscedasticity | | | |
|---|---|---|---|
| Dependant Variable: GDP per capita | | | |
| F-statistic | 1.415609 | Prob.F(1,22) | 0.2468 |
| Obs*R-Squared | 1.450939 | Prob. Chi-Square(1) | 0.2284 |
| Dependant Variable: Energy Consumption (kg of oil equivalent per capita) | | | |
| F-statistic | 0.979046 | Prob.F(1,22) | 0.3332 |
| Obs*R-Squared | 1.022545 | Prob. Chi-Square(1) | 0.2110 |

The final step of this study is to verify the direction of causality between energy consumption (ECper_capita) and economic growth (GDPper_capita) using the Toda-Yamamoto causality test. The empirical results of Granger Causality test based on methodology is estimated through MWALD test and reported in Table 9.

**Table 9.** *Toda-Yamamoto test results*

| Null Hypothesis | Lag (k) | k+dmax | Chi-square test | Conclusion |
|---|---|---|---|---|
| *ECper_capita* does not Granger Cause *GDPper_capita* | 2 | 4 | 6.088627 (0.0476)* | Reject |
| *GDPper_capita* does not Granger Cause *ECper_capita* | 2 | 4 | 11.21656 (0.0037)* | Reject |

*Significance at 5% level.

According to Toda-Yamamoto causality test, the null hypothesis that ECper_capita (Energy Consumption, kg of oil equivalent per capita) does not Granger Cause GDPper_capita (GDP per capita) is rejected and GDPper_capita does not Granger Cause ECper_capita is also rejected. Therefore, a bidirectional causality is observed between energy consumption and economic growth. This result is similar to that of Yasar (2017) for upper middle income and high income countries, by Mukhtarov et al. (2017) for Azerbaijan, by Osigwe and Arawomo (2015) for Nigeria and by Pao et al. (2014) for Brazil.

## 4. Discussion

Since the beginning of the human civilization, energy has been one of the most vital resources being used initially for the purpose of keeping warm or cooking food by burning firewood. The Romans used water power to grind corn, cut wood, make music and even tell the time. The Romans and the Greeks are even known for using passive solar power to keep the rich warm during the winters. In recent times, through and post industrialisation era, energy has evolved exponentially to become the most demanded resource on the planet, be it in the form of people still using firewood after thousands of years of evolution to keep warm and cook food or to have a face-to-face conversation with someone living as far as the next room or thousands of kilometres away.

Now this energy is being produced either by conventional means, that is, fossil fuels or by renewable energy like solar, hydro and wind power. The world has witnessed the impacts of climate change since the 50’s but have very recently started to actually pay attention to the destruction it has already caused and the destruction that we shall face if we do not change our ways. In 1992 at the Rio Earth Summit the world saw the very first international agreements starting to take place with an ultimate goal of stopping the warming climate globally. The United Nations Framework Convention on Climate Change is the main international agreement on climate action and it mainly handles two issues: the Doha amendment to the Kyoto Protocol and the Paris Agreement. In 1997 the participating countries, as part of the Kyoto Protocol, signed an agreement to reduce emissions at least 18% below the 1990 levels. However, the problem now arises is that of reducing emissions affecting energy growth and reducing energy growth affecting the economy's growth. This is the reason why most researchers conduct studies on relationships between the energy and the economy for one nation or a group of nations. Determination of these linkages will determine which policy is most suitable for an economy keeping in mind the goals laid down by the Kyoto Protocol. If the results of the study indicate unidirectional relationship, that is, if causality runs from economic growth to energy consumption and not vice versa, then there may be no harm in adopting conservation measures or reducing energy growth from fossil fuels to reduce emissions, as it will not hamper the economy's growth. However, when causality runs from energy consumption to economic growth then conservation policies will lead to a decline in the nation's economic growth. But when an economy shows bidirectional causality, the question that arises for the policymakers is whether they should decrease energy production to limit emissions that will eventually lead to a reduction in rate of growth or increase energy production to increase the economy's growth and cause an increase in emissions, as opposed to the goals of Kyoto Protocol.

In India, almost 65% of electrical energy comes from fossil fuels (CEA, 2019) and it is growing at an annual rate of 105 MW, leading to an increase in emissions rather than a decrease. India has ratified the 2$^{nd}$ commitment period of Kyoto Protocol as well as the Paris agreement and is measuring up to the targets. India is already producing 30% of its energy from renewable sources and it is likely that this value will be 40% by the end 2030, more than a decade earlier than targeted. Even then, the economy witnessed a 4.8% (27 million tone) increase in coal consumption in 2017 along with a coal subsidy of USD 2.3 billion which suggested a rather conflicted strategy.

The results of this study establish bidirectional causality in India which indicates that economy will be impacted by change in energy consumption and vice versa. The policy makers, therefore, have a difficult choice to make between reducing emissions and increasing growth. An equilibrium needs to be achieved between the two and although renewable energy is the obvious answer, yet its immediate implementation across the nation is not possible. The following recommendations are made to achieve this equilibrium:

- Even though the coal tax has doubled three times since 2010, the removal of subsidies is extremely essential to ensure the effectiveness of the tax.
- There is a need to harness the highly unutilized solar energy potential in the nation, of which the solar PV systems are the easiest to install and the government has in-fact introduced national and state level policies in this respect. However, the problem arises at awareness level; people in remote and rural locations do not have any knowledge about the schemes introduced by the government and efforts must be made to make information available.
- Pico hydro projects and individual wind mills to provide decentralised off-grid electricity are becoming economically and environmentally efficient means to generate and deliver power and here, the government lacks on policy initiatives which needs to be improved upon.

- The Indian Himalayan Region stores a massive amount of renewable energy (246 GW, excluding large hydro power) of which only 5% has been installed (CEA, 2019). The unutilised small hydro potential (82%, CEA 2019) and solar potential (99%, CEA 2019) can enormously benefit the renewable energy targets eventually leading to emission reductions.
- More coordination must be achieved between central and state governments to formulate required policies and renewable energy targets and proper implementation of policies and regulations.
- Inject higher funding and foreign investment into Research and Development activities as well as into private sector with a focus on energy innovation and upgrading the obsolete and dysfunctional renewable energy equipment.

## Summary

The relationship between energy consumption and economic growth plays a vital role in determination of policies on the energy sector. This study tested the causal relationship between energy consumption and economic growth for India for the period of 1991-2014 with the help of a Vector Autoregressive Framework. A modified version of Granger Causality test introduced by Toda and Yamamoto, bidirectional causality was determined between energy consumption and economic growth. Bidirectional causality, in this sense, indicates that economic growth induces energy consumption and energy consumption leads to further economic growth. Also, any energy conservation policies for the purpose of reducing greenhouse gas emissions can negatively affect economic growth. Therefore it is important to recommend policies that promote energy consumption and economic growth simultaneously.

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