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Dynamics between Power Consumption and Economic Growth at Aggregated and Disaggregated (Sectoral) Level Using the Frequency Domain Causality

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Abstract: We investigated the Granger causal relationship between the consumption of power both at the aggregate and sectoral level and economic growth in India using the frequency domain approach, which would help policy makers seek the efficient allocation of electricity via proper policy initiatives at different frequencies. We find that at the aggregate level, unidirectional causality runs from the total power consumption to economic growth, starting from the second up to the seventh quarter. In the sectoral context, the results are different. Since there is no causality between industrial power consumption and economic growth; therefore, an energy conservation policy can thus be implemented for the industrial sector. Moreover, since a bidirectional causality exists after 15 quarters for the commercial sector, a short-term policy but not an energy conservation policy could also be initiated for this sector. In the industrial and agricultural sectors, a promotional policy should be initiated because a unidirectional causality exists from sectoral power consumption to economic growth. Therefore, different and sector-specific policies would be more appropriate than a single policy for all power sectors in India in order to orient the efficient utilisation of power towards better economic development.

Keywords: power consumption; economic growth; seasonal unit roots; frequency domain causality

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1. Introduction

The road to better economic growth is paved with an efficient investment and better utilisation of infrastructure. Being one of the key infrastructural components, power (electricity) requires an efficient allocation of capital and other factor utilised in production. Otherwise, this sector would lead to mounting costs due to a lack of economic competitiveness. Further, as a factor of production, electricity directly or indirectly complements other factors of production such as labour and capital in the production process. Thus, any shortages of electricity will disrupt the manufacturing sector of an economy, which consequently may lead to the destabilisation of economic growth (Costantini and Martini 2010). Since India is an energy-led-growth economy with a perennial problem of power deficit, it is imperative on the part of policy makers to set out measures for the efficient consumption of electricity across the consuming sectors in order to boost economic development[1]. For instance, Chontanawat et al. (2008); Payne (2010); and Ozturk (2010) argue that inefficient use of energy may negatively impact economic growth. For this reason, it is essential to know how each consuming sector of electricity contributes to economic growth.

The study contributes to the existing literature in four key areas. (i) It is the first study that investigates the degree of short-run and long-run causality across different time scales for each consuming sector of electricity, in addition to the total power consumption in India.

(ii) It employs the novel frequency domain causality methodology developed by Breitung and Candelon (2006) to sectoral and total power consumption. At different frequencies, the causality between power consumption and economic growth is estimated, which is missing in the studies conducted in the time domain. (iii) The other studies have so far had an electricity supply-side focus (i.e., causality between different sources of supply of electricity and economic growth), but our focus in this study was on the demand-side of electricity (i.e., consumption of electricity sector-wise, including domestic, industrial, commercial, and agricultural sectors). (iv) This study has policy implications for the power sector in India[2], as country-specific studies would allow researchers to consider institutional, structural, and policy reforms undertaken in the economy (Chandran et al. 2010). In addition to this, it could help in prioritising the consumption of power across the consuming sectors.

Additionally, cross-country studies have some limitations which could be overcome through country-specific studies (Soytas and Sari 2009; Chang et al. 2001; Stern 2000). Our study finds a unidirectional causality from electricity consumption to economic growth at the aggregate level, starting after two quarters and continuing up to seven quarters during the period. However, the causality at the sectoral level diverges across the consuming sectors of electricity. A neutral effect exists between industrial (medium voltage (MV)) electricity consumption and economic growth. A bidirectional causality, in the long run, is found for both commercial electricity consumption and domestic electricity consumption, warranting an energy conservation policy for those two sectors in the short run only. Further, a unidirectional causality running from electricity consumption to economic growth is observed in the short run and the long run for the industrial (high voltage (HV)) and agricultural sectors, which supports the advancement of a promotional policy for energy consumption in these two sectors.

The remainder of the study is organised as follows: Section 2 reviews the literature on the causal relationship between electricity consumption and economic growth. Section 3 discusses the data and methodology. Section 4 analyses the empirical results. Section 5 concludes and provides policy implications.

2. Literature Review

The existing general literature on electricity consumption and economic growth can be presented in four different categories based on the corresponding individual hypotheses we put forth and the corresponding results they support. First, we present the feedback hypothesis, which states a bidirectional causality between the consumption of electricity and economic growth. This hypothesis states that a decline in the domestic consumption of electricity leads to a reduction in economic growth, and lower economic growth results in less power consumption. The empirical results validating this hypothesis are those supported by many studies, such as Masih and Masih (1996), Costantini and Martini (2010), Tang et al. (2013), Polemis and Dagoumas (2013), Bélaïd and Abderrahmani (2013), Nasreen and Anwar (2014), Mutascu (2016), and Sarwar et al. (2017), among others. The policy implication of this hypothesis suggests that any policy measures aiming at reducing the use of energy or promoting energy efficiency have a detrimental effect on economic growth and vice versa.

Second, the growth hypothesis sanctions a unidirectional causality running from electricity consumption to economic growth. That means an increase in the consumption of electricity will enhance economic growth via a higher level of production. The empirical results supporting this hypothesis are confirmed by studies such as Murry and Nan (1994), Khan et al. (2007), Pradhan (2010), Ahamad and Islam (2011), Das et al. (2012), Tang and Shahbaz (2013), Wolde-Rufael (2014), Iyke (2015), Acaravcı et al. (2015), and He et al. (2017), among others.

The feedback and growth hypotheses emphasize the role of the consumption of energy (electricity) in economic development. However, the flip side of energy consumption is its effect on environmental pollution, which is also a cause of concern for policy makers. In the case of the two hypotheses, any policy aiming at conserving energy will hurt economic growth on the one hand, and reduce environmental degradation on the other hand. However, the result also suggests that for an energy-led growth economy, such as in India, policy measures should be directed towards the promotion of the use of renewable energy, which will take care of economic growth and environmental concerns as well.

Third, the conservation hypothesis supports a growth-led economy. This hypothesis is revealed through a unidirectional causality running from economic growth to electricity consumption, which reinforces the fact that electricity consumption has no causation to the growth of the economy. The empirical studies that support the conservation hypothesis include Cheng and Lai (1997), Aqeel and Butt (2001), Narayan and Singh (2007), Ho and Siu (2007), Hu and Lin (2008), Narayan and Prasad (2008), Ghosh (2009), Narayan et al. (2010), Mahmoodi and Mahmoodi (2011), Dogan (2014), Kasman and Duman (2015), Fang and Chang (2016), etc. Thus, the policy implication of the conservation hypothesis entails that instead of focusing on economic growth, policy measures should be oriented toward energy conservation and efficiency, which brings about a reduction in CO_2 emissions and an improvement in the quality of the environment (Huang et al. 2008).

Fourth, the neutral hypothesis affirms no causality between power consumption and economic growth. The results of this empirical work which finds no causal relationship are found by Wolde-Rufael (2006), Chontanawat et al. (2008), Wolde-Rufael (2009), Yoo and Kwak (2010), Ozturk and Acaravci (2011), Jafari et al. (2012), Śmiech and Papież (2014), etc. The policy ramification of this hypothesis affirms that limiting the use of energy in those countries will not hurt their economic growth. Therefore, a desirable reconciliation between the protection of the climate and economic competitiveness could be achieved for those countries (Śmiech and Papież 2014).

In terms of the estimation techniques predominant in the existing literature, the energy-economic growth nexus is investigated by applying time series and panel data sets for the short-run and the long-run relationship via Granger causality and cointegration methods, respectively. A survey of the literature on the causal relationship between electricity consumption and economic growth is conducted by Payne (2010) and Tiba and Omri (2017), with a focus on the different model specifications, variables used, hypotheses tested, and methodological issues. Payne (2010) attributed the mixed results of the empirical studies to the time period, model specifications, variable selection, and econometric methods used by the authors. Moreover, Ozturk (2010) reported inconsistent empirical findings in the existing literature on the nexus between energy consumption and economic growth. These kinds of inconsistencies in the findings of empirical studies are not at all conducive for policy making to use energy consumption as an economic tool for sustainable economic development (Payne 2010).

Further, giving an extensive survey of the existing literature on the energy-environment-economic growth link for specific- and multi-country studies covering the period from 1978 to 2014, Tiba and Omri (2017) underscore the fact that there is a lack of consensus about the direction of causality between those three variables which those authors attribute to the data availability, modelling methodology, time span, chosen measures and sample used in the study. Thus, there is a need for a further study of the dependence between the variables, using a novel methodology with a new set of data and a new set of variables.

However, a few studies are found to be related to our study concerning the relationship between sectoral electricity consumption and economic growth but not for India. Zamani (2007) examines only two electricity-consuming sectors, including the industrial and agricultural sectors in Iran, using the Engle–Granger VEC model. This author finds a bidirectional causality between industrial electricity consumption and economic growth and a unidirectional causality running from agricultural electricity consumption to economic growth. In the US, Thoma (2004) examines the causality between four electricity consuming sectors and economic growth, apart from total electricity consumption. A unidirectional causality is also reported from industrial production (a proxy for economic growth) to total commercial and industrial electricity consumption, but no causality is found for residential electricity usage and other sectors. Soytas and Sari (2007) investigate the causal relationship between industrial electricity consumption and manufacturing value added in Turkey and report a unidirectional causality running from the former to the latter.

Looking at the summary of the literature presented in the Indian context in Table 1, the results show divergences across the studies on the causality between energy consumption and economic growth. The results also diverge with regard to the time period of the study, the type of data and the methodology. To the best of our knowledge, no study has been conducted on the frequency domain causality, describing the causality at different time scales, which is more meaningful for a policy maker than for just examining the causality in the short run and long run only. Further, almost all the studies have been performed at the aggregate level, and the exceptions include Abbas and Choudhury (2013), who examined the relationship between only the agricultural electricity consumption and the economic growth nexus, and Ahmad et al. (2016), who analysed the relationship at the disaggregated level on the supply side of electricity and economic growth.

Table 1. Summary of the Indian Literature on Causality between Electricity Consumption and Economic Growth.

Period of Study	Data/Frequency	Results/Findings	Methodology	Author (Year)
1955–1990	Total energy consumption and GNP at constant price	Unidirectional causality energy to income	VECM-VAR	Masih and Masih (1996)
1973–1995	Commercial energy use and real GDP	Unidirectional causality (both short and long) EC => GDP	VECM-VAR	Asafu-Adjaye (2000)
1950–1951 to 1996–1997	Per-capita GDP and Electricity consumption/ Annual	No long-run relationship Granger Causality-GDP => ELEC	VECM-VAR	Ghosh (2002)
1950–1996	Energy consumption and Economic growth/Annual	Granger Causality-GDP< => EC	Engle-Granger Cointegration	Paul and Bhattacharya (2004)
1971–2003	Nominal energy consumption (Petroleum, gas, coal, electricity and total energy consumption) and real GDP/Annual	No Causality between EC and GDP	VECM and Toda and Yamamoto (1995)	Asghar (2008)
1970–1971 to 2005–2006	Electricity supply, employment and real GDP/Annual	Existence of long-run relationship Granger Causality (long and short) – GDP => EMP ELES=>EMP No causality between ELES and GDP	ARDL bound testing approach of cointegration	Ghosh (2009)
1972–2008	Per-capita and total GDP and Electricity consumption at aggregated and disaggregated level (Agricultural)/Annual	Granger Causality – AGRI ELEC<=>AGRI GDP (both short and long) GDP=> ELEC (both short and long) ##	VECM-VAR	Abbas and Choudhury (2013)
1960–2006	Total electricity consumption and real GDP	ELEC => Economic growth	Granger–Engle Causality Model	Gupta and Sahu (2009)

Table 1. *Cont.*

Period of Study	Data/Frequency	Results/Findings	Methodology	Author (Year)
1970–2005	Economic growth (Change in GDP), electricity consumption and coal consumption, Petroleum, Natural gas/Annual	Economic Growth => crude oil and electricity Coal consumption => Economic Growth	VAR Granger Causality,	Mallick (2009)
1971–2008	Per capita energy consumption (in Kg of oil), GDP and urban population as percentage of total population	Energy consumption => economic activity	ARDL, Toda and Yamamoto Granger causality	Ghosh and Kanjilal (2014)
1970–2008	Real GDP, Gross fixed capital formation, Energy consumption (kt of oil equivalent), CO_2 emission and trade openness/Annual	Energy consumption => economic growth and carbon emission Carbon emission <=> Economic growth	Out of sample granger causality test and Directed Acyclic Graph (DAG)	Yang and Zhao (2014)
1971–2011	Per capita CO_2 emission, credit to private sector to GDP ratio, Per capita energy consumption (kg. of oil equivalent)/Annual	Economic growth, energy consumption and financial development leads to environmental degradation	ARDL AND VECM	Sehrawat et al. (2015)
1971–2014	Carbon emissions, Per-capita consumption of coal, gas, oil and electricity and real GDP per capita	Energy consumption <=> economic growth #	ARDL and VECM	Ahmad et al. (2016)
1971–2012	Economic Growth, Energy consumption, Financial Development and urbanisation/Annual Data	Economic growth and urbanisation lead to energy demand and financial development is negatively related to energy demand	Bayer and Hanck (2013) Cointegration test	Shahbaz et al. (2016)
1960Q1–2015Q4	Real GDP, Energy use (KG of Oil), real domestic credit to private sector, real gross fixed capital formation, and labour force/Quarterly	Asymmetric cointegration between the variables. Asymmetric causality- Negative energy consumption shocks => economic growth	Non-linear ARDL	Shahbaz et al. (2017)

Note: AGRI is agricultural electricity consumption, ELEC is electricity consumption, ELES is electricity supply, and EC- is Energy consumption. # refers to the study at the disaggregated level from the supply side, while ## refers to the study at the sectoral consumption level, focusing only on the agricultural electricity consumption. => Unidirectional causality; <=> Bidirectional causality.

In the current study, we use demand-side disaggregated data for five electricity-consuming sectors of the economy as these sectors consume the majority of electricity (see Figure 1). The quarterly data are used, which suit the results better.

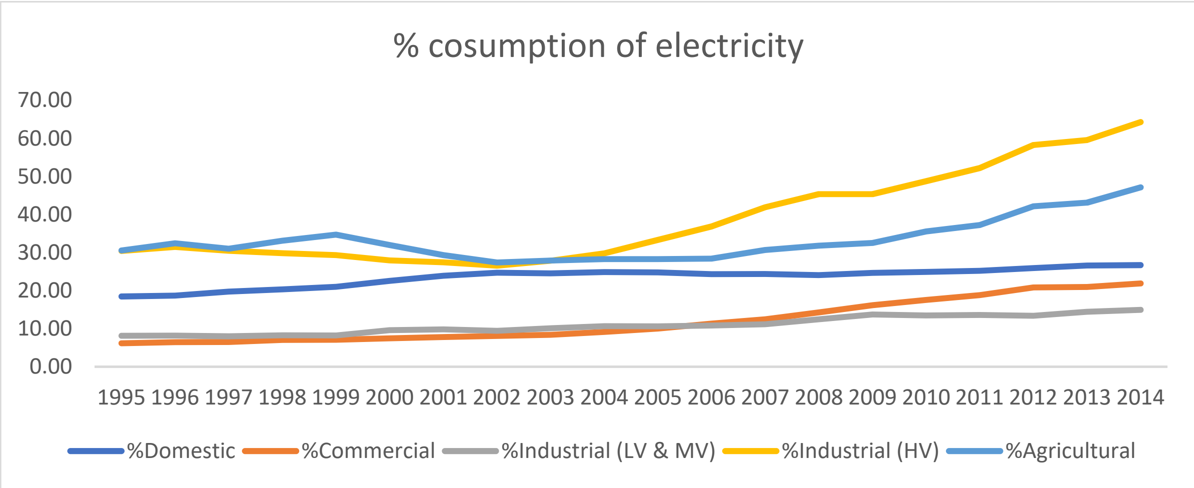

Figure 1. Electricity Consumption in Major Consuming Sectors.

3. Data and Estimation Strategy

3.1. Data Description

The data are annual and cover twenty years between 1995 and 2014 for per capita power consumption by only utility sectors (ln*PC*) and per capita GDP (*lnGDP*) in the constant prices of 2004–2005. They were sourced from the EPW (India's Economic and Political Weekly Foundation) database. The data for per capita sectoral electricity consumption are obtained for the domestic/household, commercial, industrial HV (High Voltage), industrial MV (Medium Voltage) and agriculture (AGRI) sectors. Electricity consumption is in kilowatts hours (KWh).

The annual data are converted into quarterly frequency by taking the averages following the Chow-Lin method[3], resulting in 80 quarterly data points for each variable[4]. The advantage of the conversion to quarterly data is that it increases the power of the statistical tests by using more observations, and also due to the insufficiency of annual data to enable us to achieve robust results (Zhou 2001). The quarterly interpolated data are widely accepted in empirical studies (Baxter and King 1999; Romero 2005; Mcdermott and McMenamin 2008; Tang and Chua 2012; Rashid and Jehan 2013). Investment (I) on completed projects is taken as a control variable in the study. Khan and Reinhart (1990) reported on the larger impact of private investment on economic growth. Milbourne et al. (2003) found a significant contribution of public investment to economic growth.

The descriptive statistics of the log difference of the variables are presented in Table 2. As evident from the Jarque–Bera test, the log-returns of DOM (DlnDOM), INDUHV (DlnINDUHV), and INDUMV (DlnINDUMV) are non-normal, while the log-returns of COM (DlnCOM), AGRI (DlnAGRI), GDP (DlnGDP), PC (DlnPC), and I (DlnI) are normal. However, their relationship with the dependent variable, per capita GDP (lnPGDP), is non-linear as per the BDS test of Independence[5]. It denounces the applications of linear time series causality models. The evidence of non-linearity could be attributed to the complexity of the economic system, thus motivating the use of non-linear methods for studying the causal relationship.

Table 2. Descriptive Statistics of log Difference of the Variables.

	DLPGDP	DLPPC	DLINV	DLCOM	DLDOM	DLAGRI	DLINDUHV	DLNDUMV
Mean	0.027	0.011	0.022	0.016	0.015	0.006	0.010	0.008
Median	0.027	0.011	0.024	0.016	0.015	0.006	0.011	0.004
Maximum	0.043	0.038	0.219	0.037	0.046	0.048	0.039	0.061
Minimum	0.006	−0.013	−0.201	−0.011	0.001	−0.030	−0.017	−0.021
Std. Dev.	0.009	0.010	0.086	0.012	0.008	0.017	0.015	0.016
Skewness	−0.395	0.043	−0.133	−0.168	1.152	−0.162	0.002	0.747
Kurtosis	2.424	3.088	2.674	2.459	5.845	2.603	1.833	3.678
Jarque–Bera	3.151	0.050	0.582	1.336	44.126	0.862	4.486	8.867
Probability	0.207	0.975	0.747	0.513	0.000 ***	0.650	0.106 *	0.012 **
Observations	79	79	79	79	79	79	79	79

Note: ***, ** and * indicate the 1%, 5% and 10% levels of significance, respectively.

3.2. HEGY Seasonal Unit Root Tests

To capture the seasonality in the unit root process, several unit root tests have been proposed in the literature, such as by Hylleberg et al. (1990); Canova and Hansen (1995); Caner (1998); and Shin and So (2000) for quarterly and monthly data. As we have quarterly data, we follow a seasonal unit root test discussed by Franses (1990). This test is based on Hylleberg et al. (1990) (HEGY), which has the advantage that appropriate transformations follow directly from the procedure itself and do not have to be implemented a priori in order to remove possible (seasonal) unit roots. This test shows that testing for seasonal unit roots amounts to testing for the significance of the parameters of an auxiliary regression, which may also contain deterministic elements, such as constant, trend, and seasonal dummies. The results are presented in Table 3.

Table 3. HEGY Unit Root Analysis with Constant, Trend and Seasonal Dummies.

	lnGDP	lnPC	lnI	lnCOM	lnDOM	lnAGRI	lnINDUHV	lnINDUMV
Lag	7	7	8	8	7	7	7	7
Null	Simulated *p*-value							
Nonseasonal unit root (Zero frequency)	0.249	0.861	0.306	0.078 *	0.964	0.962	0.474	0.235
Seasonal unit root (2 quarters per cycle)	0.006 ***	0.006 ***	0.006 ***	0.006 ***	0.006	0.006 ***	0.006 ***	0.006 ***
Seasonal unit root (4 quarters per cycle)	0.000 ***	0.000 ***	0.000 ***	0.000 ***	0.000	0.000 ***	0.000 ***	0.000 ***

Note: Monte Carlo Simulations: 1000. *** and * indicate significance at the 1% and 10% levels, respectively.

The results show that the null of a seasonal unit is rejected at the 1% level. However, the non-seasonal unit at frequency zero cannot be rejected. This implies that all the variables are found stationary in the first difference, and we may conclude that the variables are integrated at the I(1). Our method of frequency domain causality is an appropriate way for the current dataset as the variables are stationary in the first difference.

3.3. The Frequency Domain Causality

The traditional approach to Granger causality tacitly ignores the possibility that the strength and/or direction of Granger causality (if any) can vary over different frequencies

(Lemmens et al. 2008). Following the suggestion of Granger (1969), we used the Breitung and Candelon (2006) approach to Granger causality in the frequency domain, which is based on a spectral-density approach. Specifically, Breitung and Candelon (2006) proposed an approach which is based on Granger's (1969) and Geweke's (1982) suggestion, and it decomposes the total spectral interdependence between the two series into a sum of 'instantaneous', 'feed-forward', and 'feedback' causality terms. The innovativeness of this measure of Granger causality is that one can know exactly for which periodicity one variable can Granger-cause the other, which the popular one-shot linear or non-linear Granger causality tests fail to measure. Following Breitung and Candelon (2006)[6], we can present this test by reformulating the relationship between x and y in the VAR(p) equation:

$$x_t = a_1 x_{t-1} + \cdots + a_p x_{t-p} + \beta_1 y_{t-1} + \cdots + \beta_p y_{t-p} + \varepsilon_{1t} \quad (1)$$

The null hypothesis tested by Geweke (1982), $H_0: \ M_{y \to x}(\omega) = 0$, corresponds to the null linear restriction:

$$R(\omega)\beta = 0, \quad (2)$$

where β is the vector of the coefficients of y and

$$R(\omega) = \begin{bmatrix} \cos(\omega) & \cos(2\omega) & \cdots & \cos(p\omega) \\ \sin(\omega) & \sin(2\omega) & \cdots & \sin(p\omega) \end{bmatrix}. \quad (3)$$

The ordinary F statistic for Equation (2) is approximately distributed as $F\ (2,\ T-2p)$ for $\omega \ \in \ (0,\ \pi)$. It is interesting to consider the frequency domain Granger causality test within a cointegrating framework. To this end, Breitung and Candelon (2006) suggest replacing x_t in the regression in Equation (2) by Δx_t, with the right-hand side of the equation remaining the same.[7]

4. Empirical Analysis

For comparison against a benchmark, we have estimated the causality in the time domain by using the Vector Error Correction[8] method for both the aggregate level of power consumption and the disaggregated level as well (i.e., at the sectoral level of power consumption). The results are presented in Table 4. No causality is evident from electricity consumption to economic growth (*DLPGDP*). However, a unidirectional causality is found running from economic growth to electricity consumption at the aggregate level and in the case of commercial (*DLCOM*) and industrial HV electricity (*DLNDUHV*) consumption. That means this average snapshot of the causality is assumed to be the same across the time scales. Again, the result being the outcome of a linear time series model ignores the existence of non-linearity between the dependent and independent variables. Therefore, in order to discern the causality at different time scales between power consumption and economic growth, we have applied the frequency domain causality test.

Table 4. VEC Causality Analysis.

Null Hypothesis	Chi-Square	*p*-Value	Null Hypothesis	Chi-Square	*p*-Value
DLPPC ≠> DLPGDP	2.758	0.251	DLPGDP ≠>DLPPC	7.798	0.0203 **
DLCOM ≠> DLPGDP	2.679	0.261	DLPGDP ≠> DLCOM	5.797	0.0551 *
DLDOM ≠> DLPGDP	1.112	0.573	DLPGDP ≠> DLDOM	0.058	0.9714
DLAGRI ≠> DLPGDP	2.586	0.274	DLPGDP ≠> DLAGRI	3.821	0.1479
DLNDUHV ≠> DLPGDP	2.721	0.256	DLPGDP ≠> DLINDUHV	5.825	0.0543 *
DLINDUMV ≠> DLPGDP	1.759	0.414	DLPGDP ≠> DLINDUMV	0.219	0.8959

Note: ** and *, respectively, denote significant at the 5%, and 10% levels. In the parenthesis, we report the *p*-values of each test. The symbol; "≠>" denotes "does not linearly Granger-cause.

Apart from considering the total electricity consumption at the aggregated level, to gain more insight into the nexus between power consumption and economic growth for robust policy making, the frequency domain causality is estimated for the different individual electricity-consuming sectors of the economy, that is, at the disaggregated level. The results of the frequency domain causality are presented in Figures 2–7.

The upper panel of each figure presents the unconditional frequency domain causality between the power consumption variables and the per capita GDP at different frequencies, starting from 0.00 (the lowest frequency) and through to 3.2 (the highest frequency)[9]. The lower panel shows the conditional (conditional on investment) frequency domain causality, as in this study, the value of an investment is taken as a conditioning variable that impacts the GDP apart from power consumption. Furthermore, the figures on the left of each panel present the causality from power consumption to per capita GDP and vice-versa through the figures on the right of each panel.

Figure 2 presents the frequency domain causality between aggregate power consumption (*DLPPC*) and economic growth (*DLPGDP*). In Figure 2, both the results of conditional and unconditional frequency domain causality are similar, defying the role of investment in the causal dynamics between total power consumption (*DLPPC*) and economic growth (*DLPGDP*). Our null hypothesis states that there is no business cycle causality existing between power consumption and economic growth. Our results are interesting and contrasting in comparison to the causality estimated using the VEC method and are presented in Table 4. The VEC causality shows there is unidirectional causality from economic growth (*DLPGDP*) to power consumption (*DLPPC*). However, in contrast, the frequency domain results show that a unidirectional causality exists and runs from power consumption to economic growth only for the frequencies level (omega) between 0.60 and 3.32, which correspond to the cycle length of 10.47[10] and three quarters, respectively. That means power consumption does Granger-cause economic development after two quarters and up to 10.47 quarters and not beyond that. The null hypothesis of the business cycle causality from economic growth to power consumption cannot be rejected at the 5% level of significance. Thus, power consumption is an important indicator of economic development. Our findings are consistent with studies by Ghosh and Kanjilal (2014) and Gupta and Sahu (2009), where energy consumption was found to cause economic growth. However, in the India-based studies by Paul and Bhattacharya (2004), they found a bi-directional causality between energy consumption and economic growth. Further, our findings support the growth hypothesis, which states a unidirectional causality running from electricity consumption to economic growth, as examined in Pradhan (2010) and Ahamad and Islam (2011).

Figure 3 through Figure 7 present frequency domain causality between sectoral power consumption, i.e., commercial power (*DLCOM*), domestic (household) (*DLDOM*), industrial high voltage (*DLINDUHV*), industrial medium voltage (*DLINDUMV*), agricultural (*DLAGRI*), and economic growth (*DLPGDP*), respectively.

Long-run (i.e., 15–62 quarters at the frequency level of 0.10–0.40) bidirectional causality between power consumption in the commercial sector (*DLCOM*) and economic growth (*DLPGDP*) is evidenced in Figure 3. Similar long run (i.e., 7.85–20.94 quarters at the frequency level of 0.30–0.80), bidirectional causality is also observed between domestic sector consumption of electricity and economic growth, as shown in Figure 4. In addition to this, a short-run unidirectional causality runs from domestic sector consumption of electricity and economic growth. Our results are contradictory to the findings of Thoma (2004), who found no causality between residential electricity usage and economic growth.

As far as industrial power consumption (*DLINDUHV*) is concerned, Figure 5 shows unidirectional causality runs from industrial power consumption to GDP growth both in the short-and long-run ranging between the 2nd to the 12th quarter at the frequencies of 0.05–3.2. Thus, the policy makers should pursue a promotional instead of adopting a conservation policy for the industrial sector. However, this is in contrast to the findings of Thoma (2004) in the context of the US, where causality is reported from industrial production (a proxy for economic growth) to total commercial and industrial electricity consumption. Zamani (2007) finds bidirectional causality between industrial electricity consumption and economic growth, which is in contrast to our findings. However, our study is consistent with Soytas and Sari (2007), who reported a unidirectional causality running from industrial electricity consumption and manufacturing value added in Turkey. Nevertheless, in the context of industrial power consumption (*DLINDUMV*), unidirectional causality runs from economic growth (*DLPGDP*) to power consumption in the medium term, i.e., between 3–5 quarters (between 1.3–1.7 omega) as evidenced from Figure 6. Therefore, in contrast to *DLINDUHV*, the policy should be reversed for this industrial sector consumption (*DLINDUMV*).

It is apparent from Figure 7 that there is a unidirectional causality running from agricultural electricity consumption to economic growth both in the short- and the long-run, starting from the 3rd quarter and throughout the time period (i.e., at all frequencies). This supports the findings of Zamani (2007), who reports a unidirectional causality running from agricultural electricity consumption to economic growth. There is also a bidirectional causality in the very short period up to the second quarter at the frequencies between 2.80–3.2. Similar to the industrial (HV) sector, the policy makers should bring about a promotional policy of power consumption for the agricultural sector.

On the whole, the impact of using investment as a control variable is not apparent. As far as policy implications of our findings are concerned, one single policy is not the right solution for economic growth because the sectoral impact of power consumption on GDP growth is heteroscedastic. Thus, policy makers should bring about sector-specific policy initiatives which could contribute better to the economic development of the country.

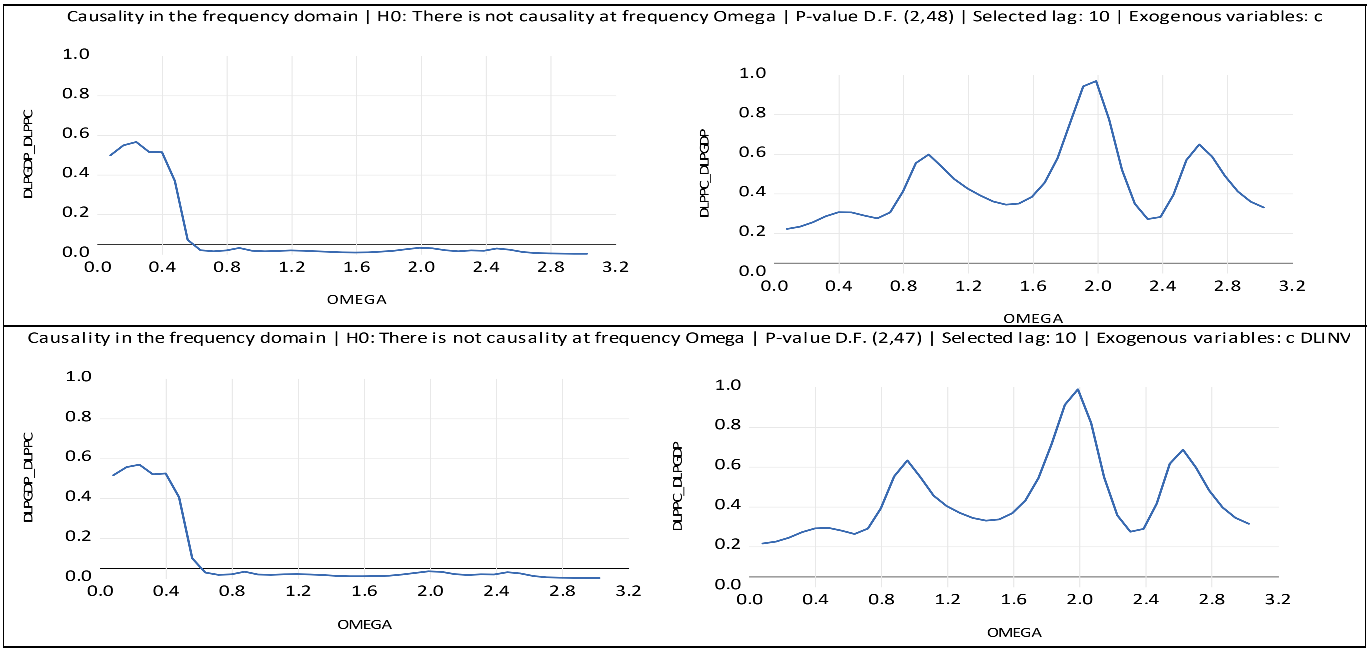

Figure 2. The unconditional and conditional on investment i.e., DLINV frequency domain causalities are reported in the upper and lower panel, respectively. Frequency is represented by omega (ω) on the horizontal axis, while the corresponding *p*-values are on the vertical axis. The label of the graph to the left of the vertical axis is in the form of ($var_i - var_j$) where var_i is the dependent variable and var_j is the independent variable. The figures on the left (right) illustrate the causality from *DLPPC to DLPGDP* (*DLPGDP to DLPPC*). The null hypothesis is H0: There is no causality at the frequency Omega. The black horizontal line represents 5% level of significance.

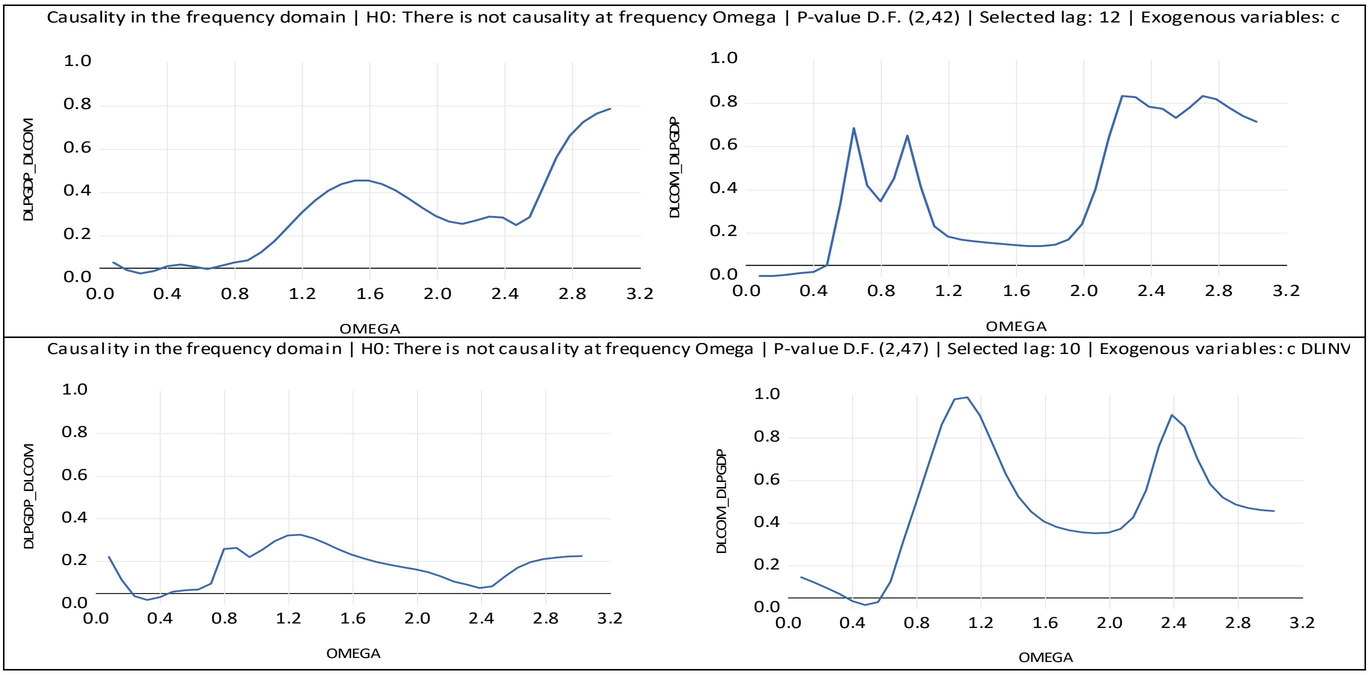

Figure 3. Causality from DLCOM → DLPGDP in the left and from DLPGDP → DLCOM in the right.

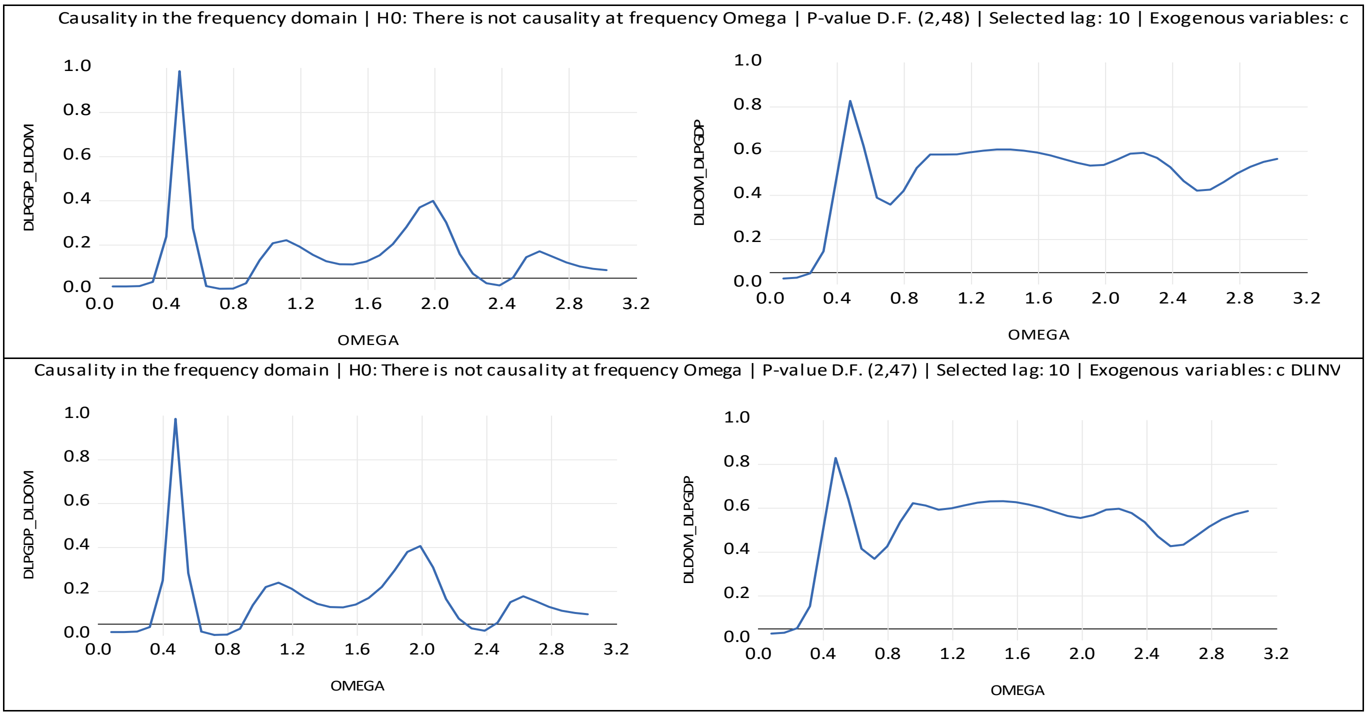

Figure 4. Causality from DLDOM → DLPGDP in the left and from DLPGDP → DLDOM in the right.

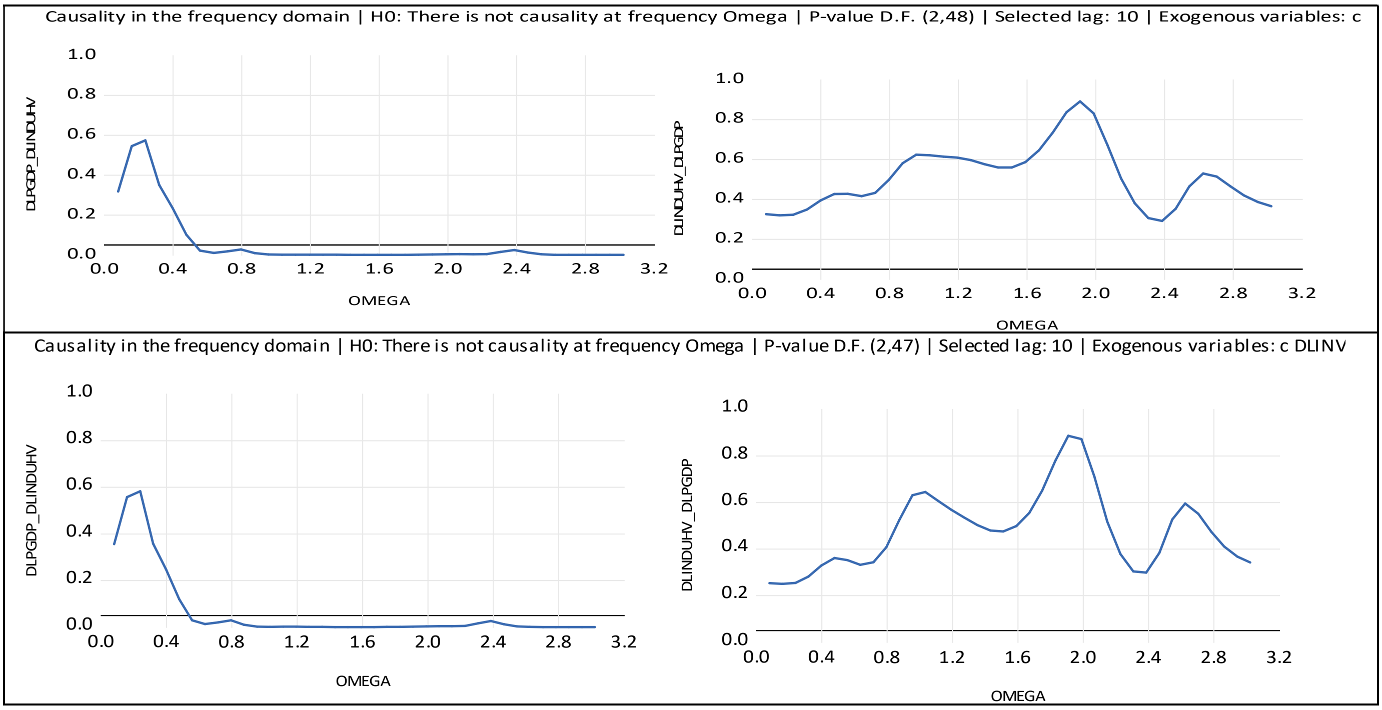

Figure 5. Causality from DLINDUHV → DLPGDP in the left and from DLPGDP → DLINDUHV in the right.

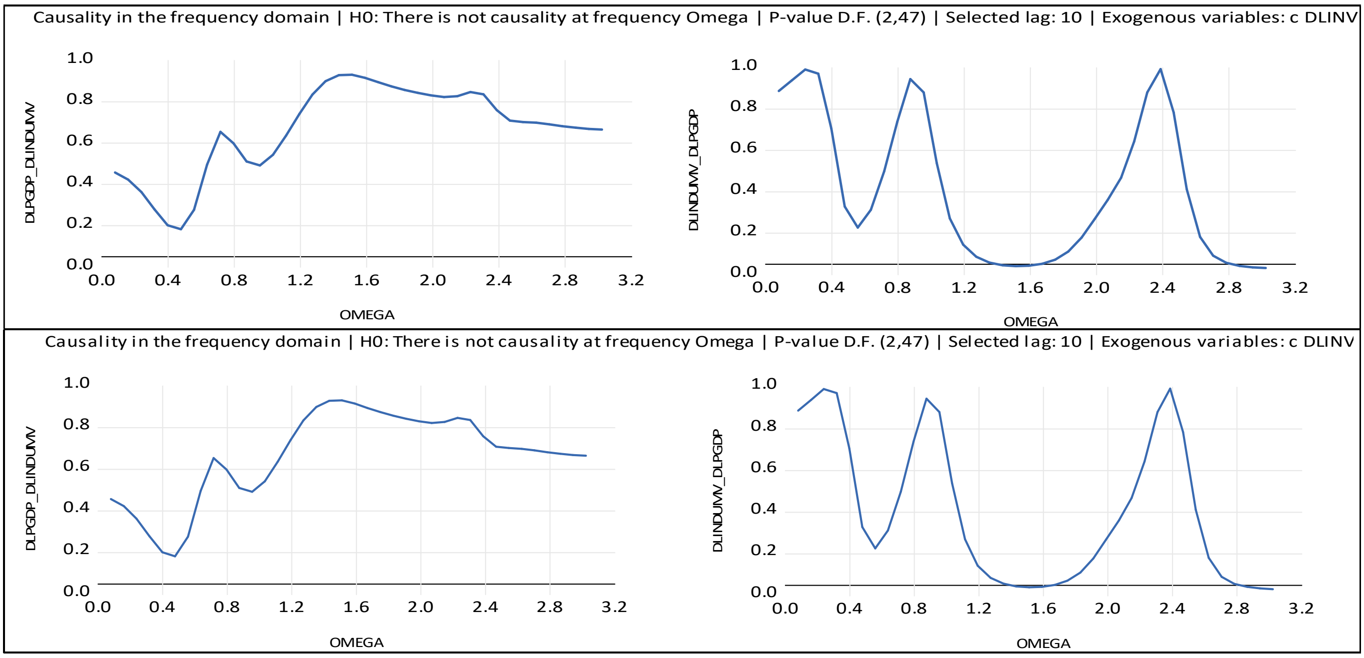

Figure 6. Causality from DLINDUMV → DLPGDP in the left and from DLPGDP → DLINDUMV in the right.

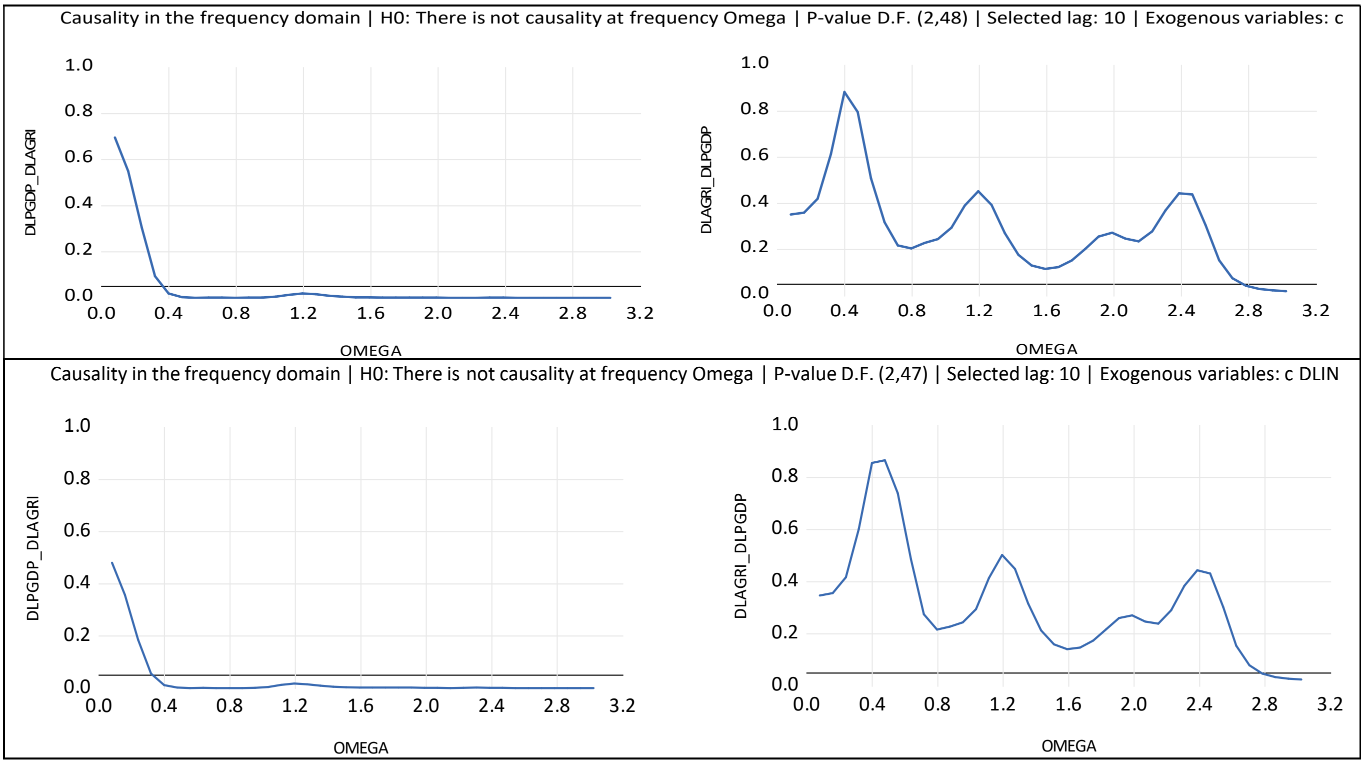

Figure 7. Causality from DLAGRI → DLPGDP in the left and from DLPGDP → DLAGRI in the right.

5. Conclusions and Policy Implications

India is the sixth largest and the fastest-growing large economy in the world. Further, the country being an energy-led-growth economy with a chronic deficit of power, it needs efficient allocations of resources and utilisation of power to achieve better economic growth. Furthermore, the inconclusive empirical results in the literature fail to help policy makers to come up with an appropriate energy policy for the economy in this regard. With this background, we have investigated the causality between power consumption and economic growth both at the aggregate and sectoral level using the frequency domain causality method.

The results show that total consumption of power Granger causes economic growth but not vice versa, starting from the second quarter through to the seventh quarter. It is projected that India's energy consumption will grow the fastest among all the major economies by 2035. Therefore, having more detailed insights on the sectoral level consumption causalities with GDP growth would induce more efficient policy making. No frequency domain causality is observed between the industrial medium voltage (MV) power consumption and GDP growth, thereby allowing the adoption of an energy conservation policy for the industrial sector. It is possible that this sector uses new productivity-enhancing technologies, which curb the causality. For the commercial consumption sector, since a bidirectional causality exists after the 15th quarter, then a short-term energy conservation policy could be initiated in this sector, but in the long run causality kicks in in this sector which may suggest that it uses more energy-intensive processes.

As far as domestic power consumption is concerned, the impact on economic growth is observed in the long run only. Therefore, short-term (long-term) household power policy measures may be initiated to make it productive (sustainable) in terms of economic growth. For the high voltage (HV) industrial sector, the presence of unidirectional causality running from industrial power consumption to economic growth throughout the period incentivises policy makers to have promotional initiatives in both the long run and the short run that spur more industrial power consumption for better economic development. The manufacturing sector generates 17% of GDP and 15% of the total employment in India and supports a diverse spectrum of industries which may account for the unidirectional causality. Therefore, India understands the importance of manufacturing in the country's growth strategy.

Similar to the industrial sector, policy makers should also bring about promotional policies of power consumption in the agricultural sector as a causality exists from agricultural electricity consumption to economic development in the short run and long run, but vice versa holds only in the very short period. Power consumption in the agricultural sector has increased by more than six-fold during the period 1980–2007. Thus, the government should be cautious with the implementation of its Ag DSM programme, which holds a promise for improved energy efficiency in groundwater irrigation in order not to hurt the agricultural sector.

In the context of the Indian economy, formulation of policies may be sought at both the aggregate and sectoral level for different periods in relation to significant cycles found in the frequency domain analysis to enhance the efficient utilisation of electricity for economic development. The government could bring out immediate policy measures to help the industrial sector and the domestic/household and commercial sectors in the short run to make those sectors more energy efficient. Energy in these sectors could be transferred to more productive sectors.

Further, for the industrial sector, an uninterrupted power supply should be ensured through the use of more appropriate policy measures. As far as the agricultural sector is concerned, a perpetual power supply will encourage farmers to opt for mechanisation and automation, which would increase the contribution of this sector to the GDP. Moreover, India is an agricultural economy, and the slow growth in this sector has been a cause of concern for the government.

Additionally, for these three sectors, policy initiatives could be pursued to control environmental pollution by incentivising those sectors to use more renewable energy sources. Overall, our findings should help policy makers in dealing with energy consumption across different sectors to promote better economic development.

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Notes

1. Power Sector January 2017, Central Electricity Authority, Ministry of Power, Government of India, New Delhi.
2. India is the third largest consumer of energy, following China and the U.S. See the Global Energy Statistical Year Book, 2015.
3. Transformation has been performed by following the Chow-Lin methodology in Eviews 10. It's a regression -based interpolation technique that finds the value of a series x by relating one or more highest frequency indicator series Z to lower frequency benchmark series through the equation $x(t) = Z(t)\beta + \alpha(t)$. We have also performed transformation by following the method of Littreman and Denton also available in Eviews 10. However, there is so no change in the result. The results are available upon request. Eviews 10 is used to covert the annual data of Y, PC and I into quarterly data. These methods are also suggestive for conversion of low to high frequency data as per the Eviews 10 user's guide on frequency conversion.
4. We have followed Bozoklu and Yilanci (2013) where they have studied the frequency domain causality applying Breitung and Candelon (2006) methodology on annual data ranging from 40–45 years. Further, although in their work, Breitung and Candelon (2006) have not mentioned about the sample size, although they talk about increase in power of the test with the increase in sample size.

5 The results are available upon request. The BDS test (Broock et al. 1996) of non-linearity is applied on the residual of the regression estimate of the DlnGDP with a constant, own lag and the lag of each electricity consumption variable. The null hypothesis of i.i.d. residuals prevails at various embedding dimensions (i.e., m for each electricity consumption variable). Since the null hypothesis is strongly rejected at even the 1% level of significance, it's an evidence of non-linearity relationship between economic growth and electric consumption both at aggregate and sectoral level.

6 Details of this test is presented in appendix.

7 For a more detailed discussion on this and also on the case when one variable is $I(1)$ and the other is $I(0)$, see Breitung and Candelon (2006).

8 VECM Granger causality is estimated by following Granger (1988) methodology because of the presence of cointegration relationship between electricity consumption and GDP growth as evidenced from Johansen (1992) test. Serial correlation LM test is applied for the residual diagnostics. Based on the p-value for Chi-Square test the null of hypothesis of no serial correlation in the residual cannot be rejected. The results of the Johansen cointegration test are available upon request.

9 Frequency (omega) = $2\pi/$cycle length (T). High frequencies are associated with short periods, while low frequencies coincide with the long run. Through the figures in Panel A and Panel B the short-run business cycle causality is presented in the right-hand side of the figure and vice versa.

10 Cycle length (T) = $2\pi/$Frequency (ω).

References

Abbas, Faisal, and Nirmalya Choudhury. 2013. Electricity consumption-economic growth Nexus: An aggregated and disaggregated causality analysis in India and Pakistan. *Journal of Policy Modeling* 35: 538–53. [CrossRef]

Acaravcı, Ali, Sinan Erdogan, and Guray Akalın. 2015. The electricity consumption, real income, trade openness and FDI: The empirical evidence from Turkey. *International Journal of Energy Economics and Policy* 5: 1050–57.

Ahamad, Mazbahul Golam, and AKM Nazrul Islam. 2011. Electricity consumption and economic growth nexus in Bangladesh: Revisited evidences. *Energy Policy* 39: 6145–50. [CrossRef]

Ahmad, Ashfaq, Yuhuan Zhao, Muhammad Shahbaz, Sadia Bano, Zhonghua Zhang, Song Wang, and Ya Liu. 2016. Carbon emissions, energy consumption and economic growth: An aggregate and disaggregate analysis of the Indian economy. *Energy Policy* 96: 131–43. [CrossRef]

Aqeel, Anjum, and Mohammad Sabihuddin Butt. 2001. The relationship between energy consumption and economic growth in Pakistan. *Asia-Pacific Development Journal* 8: 101–10.

Asghar, Zahid. 2008. Energy-GDP relationship: A causal analysis for the five countries of South Asia. *Applied Econometrics and International Development* 8: 14.

Asafu-Adjaye, John. 2000. The relationship between energy consumption, energy prices and economic growth: Time series evidence from Asian developing countries. *Energy Economics* 22: 615–25. [CrossRef]

Baxter, Marianne, and Robert G. King. 1999. Measuring business cycles: Approximate band-pass filters for economic time series. *The Review of Economics and Statistics* 81: 575–93. [CrossRef]

Bayer, Christian, and Christoph Hanck. 2013. Combining non-cointegration tests. *Journal of Time Series Analysis* 34: 83–95. [CrossRef]

Bélaïd, Fateh, and Fares Abderrahmani. 2013. Electricity consumption and economic growth in Algeria: A multivariate causality analysis in the presence of structural change. *Energy Policy* 55: 286–95. [CrossRef]

Bozoklu, Seref, and Veli Yilanci. 2013. Energy consumption and economic growth for selected OECD countries: Further evidence from the Granger causality test in the frequency domain. *Energy Policy* 63: 877–81. [CrossRef]

Breitung, Jörg, and Bertrand Candelon. 2006. Testing for short-and long-run causality: A frequency-domain approach. *Journal of Econometrics* 132: 363–78. [CrossRef]

Broock, William A., José Alexandre Scheinkman, W. Davis Dechert, and Blake LeBaron. 1996. A test for independence based on the correlation dimension. *Econometric Reviews* 15: 197–235.

Caner, Mehmet. 1998. A local optimal seasonal unit root. *Journal of Business and Economics Statistics* 16: 349–59.

Canova, Fabio, and Bruce E. Hansen. 1995. Are seasonal patterns constant over time: A test for seasonal stability. *Journal of Business and Economics Statistics* 13: 237–52.

Chandran, V. G. R., Susan Sharma, and Karunagaran. 2010. Electricity consumption–growth nexus: The case of Malaysia. *Energy Policy* 38: 606–12. [CrossRef]

Chang, Tsangyao, Wenshwo Fang, and Li-Fang Wen. 2001. Energy consumption, employment, output, and temporal causality: Evidence from Taiwan based on cointegration and error-correction modelling techniques. *Applied Economics* 33: 1045–56. [CrossRef]

Cheng, Benjamin S., and Tin Wei Lai. 1997. An investigation of co-integration and causality between energy consumption and economic activity in Taiwan. *Energy economics* 19: 435–44. [CrossRef]

Chontanawat, Jaruwan, Lester C. Hunt, and Richard Pierse. 2008. Does energy consumption cause economic growth? Evidence from a systematic study of over 100 countries. *Journal of Policy Modeling* 30: 209–20. [CrossRef]

Costantini, Valeria, and Chiara Martini. 2010. The causality between energy consumption and economic growth: A multi-sectoral analysis using non-stationary cointegrated panel data. *Energy Economics* 32: 591–603. [CrossRef]

Das, Anupam, Murshed Chowdhury, and Syeed Khan. 2012. The dynamics of electricity consumption and growth nexus: Empirical evidence from three developing regions. *Margin: The Journal of Applied Economic Research* 6: 445–66. [CrossRef]

Dogan, Eyup. 2014. Energy consumption and economic growth: Evidence from low-income countries in Sub-Saharan Africa. *International Journal of Energy Economics and Policy* 4: 154.

Fang, Zheng, and Youngho Chang. 2016. Energy, human capital and economic growth in Asia Pacific countries—Evidence from a panel cointegration and causality analysis. *Energy Economics* 56: 177–84. [CrossRef]

Franses, Philip Hans. 1990. Testing for seasonal unit roots in monthly data. In *Econometric Institute Report 9032A*. Rotterdam: Erasmus University Rotterdam.

Geweke, John. 1982. Measurement of linear dependence and feedback between multiple time series. *Journal of the American Statistical Association* 77: 304–13. [CrossRef]

Ghosh, Sajal. 2002. Electricity consumption and economic growth in India. *Energy Policy* 30: 125–29. [CrossRef]

Ghosh, Sajal. 2009. Electricity supply, employment and real GDP in India: Evidence from cointegration and Granger-causality tests. *Energy Policy* 37: 2926–29. [CrossRef]

Ghosh, Sajal, and Kakali Kanjilal. 2014. Long-term equilibrium relationship between urbanization, energy consumption and economic activity: Empirical evidence from India. *Energy* 66: 324–31. [CrossRef]

Granger, Clive W. J. 1988. Some recent development in a concept of causality. *Journal of Econometrics* 39: 199–211. [CrossRef]

Granger, Clive W. J. 1969. Investigating causal relations by econometric models and cross-spectral methods. *Econometrica: Journal of the Econometric Society* 31: 424–38. [CrossRef]

Gupta, Geetu, and Naresh Chandra Sahu. 2009. Causality between Electricity Consumption & Economic Growth: Empirical Evidence from India. MPRA Paper No 22942. Available online: https://mpra.ub.uni-muenchen.de/22942/ (accessed on 29 March 2022).

He, Yiming, Thomas M. Fullerton Jr., and Adam G. Walke. 2017. Electricity consumption and metropolitan economic performance in Guangzhou: 1950–2013. *Energy Economics* 63: 154–60. [CrossRef]

Ho, Chun-Yu, and Kam Wing Siu. 2007. A dynamic equilibrium of electricity consumption and GDP in Hong Kong: An empirical investigation. *Energy Policy* 35: 2507–13. [CrossRef]

Hu, Jin-Li, and Cheng-Hsun Lin. 2008. Disaggregated energy consumption and GDP in Taiwan: A threshold co-integration analysis. *Energy Economics* 30: 2342–58. [CrossRef]

Huang, Bwo-Nung, Ming Jeng Hwang, and Chin Wei Yang. 2008. Causal relationship between energy consumption and GDP growth revisited: A dynamic panel data approach. *Ecological Economics* 67: 41–54. [CrossRef]

Hylleberg, Svend, Robert F. Engle, Clive WJ Granger, and Byung Sam Yoo. 1990. Seasonal integration and cointegration. *Journal of Econometrics* 44: 215–38. [CrossRef]

Iyke, Bernard Njindan. 2015. Electricity consumption and economic growth in Nigeria: A revisit of the energy-growth debate. *Energy Economics* 51: 166–76. [CrossRef]

Jafari, Yaghoob, Jamal Othman, and Abu Hassan Shaari Mohd Nor. 2012. Energy consumption, economic growth and environmental pollutants in Indonesia. *Journal of Policy Modeling* 34: 879–89. [CrossRef]

Johansen, Soren. 1992. Determination of cointegration rank in the presence of a linear trend. *Oxford Bulletin of Economics and Statistics* 54: 383–97. [CrossRef]

Kasman, Adnan, and Yavuz Selman Duman. 2015. CO_2 emissions, economic growth, energy consumption, trade and urbanization in new EU member and candidate countries: A panel data analysis. *Economic Modelling* 44: 97–103. [CrossRef]

Khan, Mohsin S., and Carmen M. Reinhart. 1990. Private investment and economic growth in developing countries. *World Development* 18: 19–27. [CrossRef]

Khan, Muhammad Arshad, Abdul Qayyum, and Eatzaz Ahmad. 2007. Dynamic Modelling of Energy and Growth in South Asia [with Comments]. *The Pakistan Development Review* 46: 481–98. [CrossRef]

Lemmens, Aurélie, Christophe Croux, and Marnik G. Dekimpe. 2008. Measuring and testing Granger causality over the spectrum: An application to European production expectation surveys. *International Journal of Forecasting* 24: 414–31. [CrossRef]

Mahmoodi, Majid, and Elahe Mahmoodi. 2011. Renewable energy consumption and economic growth: The case of 7 Asian developing countries. *American Journal of Scientific Research* 35: 146–52.

Mallick, Hrushikesh. 2009. Examining the linkage between energy consumption and economic growth in India. *The Journal of Developing Areas* 43: 249–80. [CrossRef]

Masih, Abul M. M., and Rumi Masih. 1996. Energy consumption, real income and temporal causality: Results from a multi-country study based on cointegration and error-correction modelling techniques. *Energy Economics* 18: 165–83. [CrossRef]

Mcdermott, John F. M., and Peter McMenamin. 2008. Assessing Inflation Targeting in Latin America with a DSGE Model. Central Bank of Chile Working Papers 469. Available online: https://si2.bcentral.cl/public/pdf/documentos-trabajo/pdf/dtbc469.pdf (accessed on 29 March 2022).

Milbourne, Ross, Glenn Otto, and Graham Voss. 2003. Public investment and economic growth. *Applied Economics* 35: 527–40. [CrossRef]

Murry, Donald A., and Gehuang D. Nan. 1994. A definition of the gross domestic product-electrification interrelationship. *The Journal of Energy and Development* 19: 275–83.

Mutascu, Mihai. 2016. A bootstrap panel Granger causality analysis of energy consumption. *Renewable and Sustainable Energy Reviews* 63: 166–71. [CrossRef]

Narayan, Paresh Kumar, and Arti Prasad. 2008. Electricity consumption–real GDP causality nexus: Evidence from a bootstrapped causality test for 30 OECD countries. *Energy Policy* 36: 910–18. [CrossRef]

Narayan, Paresh Kumar, and Baljeet Singh. 2007. The electricity consumption and GDP nexus for the Fiji Islands. *Energy Economics* 29: 1141–50. [CrossRef]

Narayan, Paresh Kumar, Seema Narayan, and Stephan Popp. 2010. Does electricity consumption panel Granger cause GDP? A new global evidence. *Applied Energy* 87: 3294–98. [CrossRef]

Nasreen, Samia, and Sofia Anwar. 2014. Causal relationship between trade openness, economic growth and energy consumption: A panel data analysis of Asian countries. *Energy Policy* 69: 82–91. [CrossRef]

Ozturk, Ilhan. 2010. A literature survey on energy–growth nexus. *Energy Policy* 38: 340–49. [CrossRef]

Ozturk, Ilhan, and Ali Acaravci. 2011. Electricity consumption and real GDP causality nexus: Evidence from ARDL bounds testing approach for 11 MENA countries. *Applied Energy* 88: 2885–92. [CrossRef]

Paul, Shyamal, and Rabindra N. Bhattacharya. 2004. Causality between energy consumption and economic growth in India: A note on conflicting results. *Energy Economics* 26: 977–83. [CrossRef]

Payne, James E. 2010. A survey of the electricity consumption-growth literature. *Applied Energy* 87: 723–31. [CrossRef]

Polemis, Michael L., and Athanasios S. Dagoumas. 2013. The electricity consumption and economic growth nexus: Evidence from Greece. *Energy Policy* 62: 798–808. [CrossRef]

Pradhan, Rudra Prakash. 2010. Energy consumption-growth nexus in SAARC countries: Using Cointegration and error correction model. *Modern Applied Science* 4: 74. [CrossRef]

Rashid, Abdul, and Zanaib Jehan. 2013. Derivation of Quarterly GDP, Investment Spending, and Government Expenditure Figures from Annual Data: The Case of Pakistan. MPRA Paper No 46937. Available online: https://mpra.ub.uni-muenchen.de/id/eprint/46937 (accessed on 29 March 2022).

Romero, Ana. Maria. 2005. *Comparative study: Factors That Affect Foreign Currency Reserves in China and India*. Honors Projects 33. Bloomington: Economics Department, Illinois Wesleyan University. Available online: https://digitalcommons.iwu.edu/econ_honproj/33 (accessed on 29 March 2022).

Sarwar, Suleman, Wei Chen, and Rida Waheed. 2017. Electricity consumption, oil price and economic growth: Global perspective. *Renewable and Sustainable Energy Reviews* 76: 9–18. [CrossRef]

Sehrawat, Madhu, A. K. Giri, and Geetilaxmi Mohapatra. 2015. The impact of financial development, economic growth and energy consumption on environmental degradation: Evidence from India. *Management of Environmental Quality: An International Journal* 26: 666–82. [CrossRef]

Shahbaz, Muhammad, Hrushikesh Mallick, Mantu Kumar Mahalik, and Perry Sadorsky. 2016. The role of globalization on the recent evolution of energy demand in India: Implications for sustainable development. *Energy Economics* 55: 52–68. [CrossRef]

Shahbaz, Muhammad, Thi Hong Van Hoang, Mantu Kumar Mahalik, and David Roubaud. 2017. Energy consumption, financial development and economic growth in India: New evidence from a nonlinear and asymmetric analysis. *Energy Economics* 63: 199–212. [CrossRef]

Shin, Dong Wan, and Beong Soo So. 2000. Gaussian tests for seasonal unit roots based on Cauchy estimation and recursive mean adjustments. *Journal of Econometrics* 99: 107–37. [CrossRef]

Śmiech, Sławomir, and Monika Papież. 2014. Energy consumption and economic growth in the light of meeting the targets of energy policy in the EU: The bootstrap panel Granger causality approach. *Energy Policy* 71: 118–29. [CrossRef]

Soytas, Ugur, and Ramazan Sari. 2007. The relationship between energy and production: Evidence from Turkish manufacturing industry. *Energy Economics* 29: 1151–65. [CrossRef]

Soytas, Ugur, and Ramazan Sari. 2009. Energy consumption, economic growth, and carbon emissions: Challenges faced by an EU candidate member. *Ecological Economics* 68: 1667–75. [CrossRef]

Stern, David I. 2000. A multivariate cointegration analysis of the role of energy in the US macroeconomy. *Energy Economics* 22: 267–83. [CrossRef]

Tang, Chor Foon, and Soo Y. Chua. 2012. The savings-growth nexus for the Malaysian economy: A view through rolling sub-samples. *Applied Economics* 44: 4173–85. [CrossRef]

Tang, Chor Foon, and Muhammad Shahbaz. 2013. Sectoral analysis of the causal relationship between electricity consumption and real output in Pakistan. *Energy Policy* 60: 885–91. [CrossRef]

Tang, Chor Foon, Muhammad Shahbaz, and Mohamed Arouri. 2013. Re-investigating the electricity consumption and economic growth nexus in Portugal. *Energy Policy* 62: 1515–24. [CrossRef]

Thoma, Mark. 2004. Electrical energy usage over the business cycle. *Energy Economics* 26: 463–85. [CrossRef]

Tiba, Sofien, and Anis Omri. 2017. Literature survey on the relationships between energy, environment and economic growth. *Renewable and Sustainable Energy Reviews* 69: 1129–46. [CrossRef]

Toda, Hiro Y., and Taku Yamamoto. 1995. Statistical inference in vector autoregressions with possibly integrated processes. *Journal of Econometrics* 66: 225–50. [CrossRef]

Wolde-Rufael, Yemane. 2006. Electricity consumption and economic growth: A time series experience for 17 African countries. *Energy Policy* 34: 1106–14. [CrossRef]

Wolde-Rufael, Yemane. 2009. Energy consumption and economic growth: The experience of African countries revisited. *Energy Economics* 31: 217–24. [CrossRef]

Wolde-Rufael, Yemane. 2014. Electricity consumption and economic growth in transition countries: A revisit using bootstrap panel Granger causality analysis. *Energy Economics* 44: 325–30. [CrossRef]

Yang, Zihui, and Yongliang Zhao. 2014. Energy consumption, carbon emissions, and economic growth in India: Evidence from directed acyclic graphs. *Economic Modelling* 38: 533–40. [CrossRef]

Yoo, Seung-Hoon, and So-Yoon Kwak. 2010. Electricity consumption and economic growth in seven South American countries. *Energy Policy* 38: 181–88. [CrossRef]

Zamani, Mehrzad. 2007. Energy consumption and economic activities in Iran. *Energy Economics* 29: 1135–40. [CrossRef]

Zhou, Su. 2001. The power of cointegration tests versus data frequency and time spans. *Southern Economic Journal* 67: 906–21.