Measuring Energy Efficiency: An Application of LMDI Analysis to Power Sector in Kerala

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Abstract

The traditional interest in energy efficiency has centred on a single energy input factor in terms of productivity that has become famous through the index method in terms of activity output per unit of energy use. The enquiry that has proceeded from the problems associated with this method has led to identifying the effect source of variation, in terms of decomposition analysis. A variant of factor decomposition analysis, index decomposition analysis takes energy as a single factor of production, and explores various effects on energy intensity changes, by decomposing these changes into pure intensity changes effect, structure changes effect and activity changes effect. The present paper seeks to measure energy efficiency in Kerala in terms of index decomposition analysis, using the Logarithmic Mean Divisia Index (LMDI) method. For the empirical exercise of decomposition, we consider two energy sectors of Kerala: power sector and petroleum sector. Since the petroleum consumption data is available only for the period from 2007-08 to 2016-17, we take this as our study period for the analysis. As the measure of activity, we have the usual real gross State domestic product (GSDP at 2011-12 prices). First we analyse the two sectors separately, and then the combined sector is analysed for decomposition. The petroleum consumption data relating only to the secondary and tertiary sub-sectors, the less-efficient petroleum sector is found to overweigh the combined energy sector of Kerala to such an extent that the energy-efficiency potential of these two sub-sectors gets clouded. A sufficiently high degree of energy efficiency in the petroleum sector can indeed reverse this anomaly.

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1. Introduction

Traditionally, there are two basically reciprocal energy efficiency Indicators: one, in terms of energy intensity, that is, energy use per unit of activity output, and the other, in terms of energy productivity, that is, activity output per unit of energy use. As a general concept, “energy efficiency refers to using less energy to produce the same amount of services or useful output. For example, in the industrial sector, energy efficiency can be measured by the amount of energy required to produce a tonne of product.” (Patterson, 1996: 377). Thus Patterson defines energy efficiency broadly by the simple ratio of the useful output of a process in terms of any good produced that is enumerated in market process, to energy input into that process (ibid.).

Energy efficiency research in general has opened up three avenues of enquiry, namely, the measurement of energy productivity, the identification of impact elements and the energy efficiency assessment. The traditional interest in energy efficiency has centred on a single energy input factor in terms of productivity that has become famous through the index method proposed by Patterson (1996). The enquiry that has proceeded from the problems associated with this method has led to identifying the effect source of variation, in terms of decomposition analysis.

As we know, energy intensity is obtained by dividing energy consumption by gross domestic product (GDP), which implies the quantum of energy consumption that must be input in order to increase one unit of GDP. Analyzed in terms of energy intensity changes, the index falls under two major decomposition methods, namely, Structural Decomposition Analysis (SDA) and Index Decomposition Analysis (IDA). SDA has both inputs and outputs as its theoretical foundation, and is hence also known as equilibrium analysis. There are two approaches here: input-output method and neo-classical production function method. The stringent assumptions associated with these approaches have made them practically unattractive for policy-orientated empirical exercises. Moreover, the prime significance of energy consumption reduction through energy use efficiency improvements following the 1973 oil crisis has essentially required complete evaluation of energy consumption patterns and identifying the driving factors of changes in energy consumption, creating a demand for effective tools to decompose aggregate indicators.

This need led to the development of the Index Decomposition Analysis (IDA) in the late 1970s in the United States (Myers and Nakamura 1978) and in the United Kingdom (Bossanyi 1979). These pioneering studies then spurred a number of different decomposition methods, most of which were derived from the index number theory, initially developed in economics to study the respective contributions of price and quantity effects to final aggregate consumption. A variant of factor decomposition analysis, IDA takes energy as a single factor of production, and explores various effects on energy intensity changes, by decomposing these changes into pure intensity changes effect and industrial structure changes effect. The first component (pure intensity changes effect) implies that when the industrial structure remains unchanged, the energy intensity change may be taken as the result of energy use efficiency changes in some sector, and the second implies that given the fixed energy efficiencies of various industries and their different energy intensity levels, the total energy intensity changes effect may be taken as the result of the dynamic changes of the yield of each industry.

IDA, as applied to time series data of a specific period, involves results which are very sensitive to the choice of the base period during the study period. In terms of the selection of base period, the approach usually considers Laspeyres Index of fixed weights and Divisia Index of variable weights.

Divisia index decomposition approach has become very popular these days in the context of analysis of energy intensity changes (see Ang and Zhang (2000), and Ang (2004) for a survey of index decomposition analysis in this field). There are two common Divisia index decomposition methods: Arithmetic mean (AMDI) and Logarithmic Mean Divisia index (LMDI). The AMDI method was first used by Gale Boyd, John McDonald, M. Ross and D. A. Hansont in 1987, for "separating the changing composition of the US manufacturing production from energy efficiency improvements" using Divisia index approach (as the title shows). This was followed by a number of studies, some attempts being directed towards modifying the index. These efforts were finally culminated in Ang and Choi (1997), who used logarithmic mean function as weights for aggregation with the attractive property that the decomposition leaves no residuals at all. Ang et al. (1998) called this model "Logarithmic Mean Divisia index (LMDI)".

The present paper seeks to measure energy productivity in Kerala in terms of index decomposition analysis, using the Logarithmic Mean Divisia Index (LMDI) method. The paper is structured in five sections; the next part details the method of decomposing the changes in energy consumption over time into three different effects of activity, structure and intensity in the framework of the LMDI approach. In section three, we present the results from the decomposition exercise; first we analyse the two sectors of power and petroleum separately, and then the combined sector is analysed for decomposition. Section four then turns to a simulation analysis for energy consumption in Kerala under different scenarios and the final section concludes the study.

2. Decomposition of Energy Consumption Change: Method

The changes in energy consumption over time (E) may be attributed to three different effects:

(i) an activity effect that refers to the overall level of activity (Q) in an economy; in general different units are used for different sectors of the economy to measure activity (for example, for the residential (or commercial) sector, we use either square footage of floor space or number of households (or commercial units), for the industrial sector, we use the money value of output produced, for the transport sector, we have passenger-miles, and so on);

(ii) a structural effect which refers to changes in the structure of activities in terms of their inter-sectoral or intra-sectoral shares (S_i); this reflects the impact on energy use emanating from the changes in the relative importance of sectors or sub-sectors with different absolute energy intensities; and

(iii) an intensity effect that represents the effect of changing energy intensity for sectors or sub-sectors (I_i).

Thus the decomposition identity may be written as

$$E = \sum_i E_i = \sum_i Q \frac{Q_i}{Q}\frac{E_i}{Q_i} = \sum_i Q\, S_i I_i$$

where E is the total energy consumption, Q (= $\sum_i Q_i$) is the activity level, S_i (= Q_i/Q) is the *i*th sector's activity share and I_i (= E_i/Q_i) is that sector's energy intensity.

Assuming from period 0 to T, the aggregate (E) changes from E^0 to E^T, our objective is to find out the contributions of the components to the change in the aggregate. Thus, the change in energy use in multiplicative decomposition model is given by

$$D_{total} \equiv E^T/E^0 = D_{activity}\, D_{structure}\, D_{intensity}$$

And in the additive decomposition model by

$$\Delta E_{total} \equiv E^T - E^0 = \Delta E_{activity} + \Delta E_{structure} + \Delta E_{intensity}$$

These equations simply indicate that change in total energy consumption is due to changes in activity level, Q (activity effect), sectoral shares, S_i (structural effect) and sectoral energy intensities, I_i (energy intensity effect).

These effects evaluated for the multiplicative model of the LMDI-I are:

$$D_{activity} = \exp\left(\sum_i \widetilde{w_i}\, \ln\left(\frac{Q^T}{Q^0}\right)\right)$$

$$D_{structure} = \exp\left(\sum_i \widetilde{w_i}\, \ln\left(\frac{S_i^T}{S_i^0}\right)\right)$$

$$D_{intensity} = \exp\left(\sum_i \widetilde{w_i}\, \ln\left(\frac{I_i^T}{I_i^0}\right)\right)$$

$$\text{where } \widetilde{w_i} = \frac{(E_i^T - E_i^0)/(\ln E_i^T - \ln E_i^0)}{(E^T - E^0)/(\ln E^T - \ln E^0)}$$

The effects evaluated for the additive model of the LMDI-I are:

$$\Delta E_{activity} = \sum_i w_i \ \ln\left(\frac{Q^T}{Q^0}\right)$$

$$\Delta E_{structure} = \sum_i w_i \ \ln\left(\frac{S_i^T}{S_i^0}\right)$$

$$\Delta E_{intensity} = \sum_i w_i \ \ln\left(\frac{I_i^T}{I_i^0}\right)$$

where $w_i = (E_i^T - E_i^0)/(\ln E_i^T - \ln E_i^0)$

3. Decomposition of Energy Consumption Change: Empirical Analysis

For the empirical exercise of decomposition, we consider two energy sectors of Kerala: power sector and petroleum sector. Since the petroleum consumption data is available only for the period from 2007-08 to 2016-17, we take this as our study period for the analysis. As the measure of activity, we have the usual real gross State domestic product (GSDP at 2011-12 prices), available in the *Economic Review* of the Government of Kerala. First we analyse the two sectors separately, and then the combined sector is analysed for decomposition. Corresponding to the three broad sectors of primary, secondary and tertiary of the GSDP, we consider the sub-sectors of agriculture, industry and others of the power sector, data on which are available from the Kerala State Electricity Board's publications (*Power System Statistics*, *System Operations*), and unpublished records. The petroleum data are from *Monthly Petroleum Products Sale data*, compiled by SLC, Kerala; and *Monthly data of Petroleum*, Planning and Analysis Cell, Ministry of Petroleum and Natural gas. For the LMDI exercise, we have utilized the "LMDI Program for Stata module" by Kerry Du (2017).

For our analysis, first we consider the power sector of Kerala. Table 1 presents electricity consumption and real GSDP in Kerala (sector-wise and total) for the study period (from 2007-08 to 2016-17).

Table 1: Electricity Consumption and Real GSDP in Kerala

	Electricity Consumption MU				Real GSDP, Rs Lakh			
	Agriculture	Industry	Others	Total	Primary	Secondary	Tertiary	Total
2007-08	230.55	4123.68	9042.38	13396.61	4341828	4571935	12819755	21733518
2008-09	225.22	4002.37	8650.06	12877.65	4643108	4576364	13841297	23060769
2009-10	257	4481.09	9286.9	14024.99	4504923	4854334	15522423	24881679
2010-11	231.56	4616.59	9829.99	14678.14	4131565	5576848	16503211	26211624
2011-12	286.18	4926.43	10969.02	16181.63	4266424	8369967	17390244	30026635
2012-13	306.08	5007.11	11526.02	16839.21	4104417	8580866	19042425	31727708
2013-14	310.25	5132.05	13426.35	18868.65	4052624	8865392	20439675	33357691
2014-15	298.28	5236.64	13249.43	18784.35	4263300	9033930	21507602	34804832
2015-16	279.48	5209.23	13889.87	19378.58	3636758	9825120	22933704	36395582
2016-17	321.98	5260.116	14505.44	20087.54	3794551	10164829	24640455	38599835

From this basic data, we estimate the sectoral energy intensity of electricity (unit (or kWh) of electricity used per Rupee of real GSDP) and the sectoral shares of GSDP, which are given in Table 2. These are then input into the LMDI decomposition exercise, and the results thereof are given in Table 3.

The results show that the electrical energy consumption increased in all but two years: 2008-09 and 2014-15 over the respective previous years. It is significant to note that energy efficiency improvement contributed to energy intensity reduction in all but one year: 2013-14 over 2012-13. Energy efficiency improvement reduced energy use by

Table 2: Sectoral Energy Intensity and Sectoral Share of GSDP

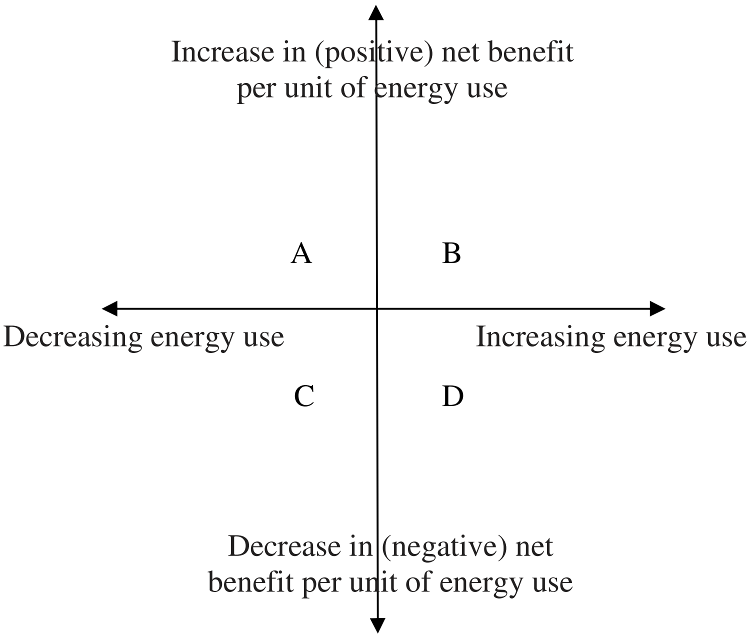
	Sectoral Intensity, Electricity, kWh/Re			Sectoral Share of GSDP		
	Primary	Secondary	Tertiary	Primary	Secondary	Tertiary
2007-08	0.00053	0.00902	0.00705	0.2	0.21	0.59
2008-09	0.00049	0.00875	0.00625	0.201	0.198	0.6
2009-10	0.00057	0.00923	0.00598	0.181	0.195	0.624
2010-11	0.00056	0.00828	0.00596	0.158	0.213	0.63
2011-12	0.00067	0.00589	0.00631	0.142	0.279	0.579
2012-13	0.00075	0.00584	0.00605	0.129	0.27	0.6
2013-14	0.00077	0.00579	0.00657	0.121	0.266	0.613
2014-15	0.0007	0.0058	0.00616	0.122	0.26	0.618
2015-16	0.00077	0.0053	0.00606	0.1	0.27	0.63
2016-17	0.00085	0.00517	0.00589	0.098	0.263	0.638

Table 3: LMDI Decomposition Result

From	Energy Consumption Change	Intensity Effect	Structure Effect	Activity Effect
2007-08 to 2008-09	0.961	0.912	0.994	1.061
2008-09 to 2009-10	1.089	0.991	1.019	1.079
2009-10 to 2010-11	1.047	0.963	1.032	1.053
2010-11 to 2011-12	1.102	0.938	1.026	1.146
2011-12 to 2012-13	1.041	0.972	1.014	1.057
2012-13 to 2013-14	1.121	1.057	1.008	1.051
2013-14 to 2014-15	0.996	0.955	1	1.043
2014-15 to 2015-16	1.032	0.966	1.022	1.046
2015-16 to 2016-17	1.037	0.975	1.003	1.061

about 9% in 2008-09 over 2007-08 and nearly 5% in 2013-14 over the previous year; no energy efficiency improvement means that consumption would have increased. This may be explained in the light of Fig. 1 given below:

Figure 1: The energy efficiency and conservation quadrants



Source: Adapted from Lermit and Jollands (2001, p. 7).

In Figure 1, the quadrants A and B represent energy efficiency, defined in terms of net benefits per unit of input. They also capture the idea of energy efficiency improvement, "defined [by Energy Efficiency and Conservation Authority, 1997] as any change in energy use that results in increased net benefits per unit of energy, whether or not total energy use increases or decreases" (Lermit and Jollands (2001, p. 7). Thus, quadrant B represents energy efficiency improvement, by increasing net benefits per unit of energy use through increasing energy use and quadrant A, on the other hand, represents energy efficiency improvement, by increasing net benefits per unit of energy use through decreasing energy use (for example, by installing double-glazing windows that can reduce heating energy bill costs during winter).

Cases like quadrant B simply show that energy efficiency improvement need not imply energy savings and render monitoring energy efficiency difficult. “If energy efficiency were the same as energy savings, then all that would be required would be to estimate the amount of energy saved compared to some base year and add up energy savings across sectors. However, this does not necessarily equate to energy efficiency.” (Lermit and Jollands (2001, p. 8).

Energy conservation, as an important complement to energy efficiency, is defined in terms of reduction in total energy use, and is thus represented by quadrants A and C. Thus, this can happen in two ways: quadrant A represents efficiency-improving energy conservation, where energy savings lead to an increase in net benefits per unit of energy use; and quadrant C represents efficiency-reducing energy conservation, where energy savings lead to a decrease in net benefits per unit of energy use, “as is the case with the proverbial “cold bath in the dark”” (ibid.).

In this light, it can be found that those two years (2008-09 over 2007-08 and 2013-14 over the previous year) that we have examined above correspond to quadrant A in Fig. 1 on energy efficiency and conservation quadrants.

On the other hand, the activity structure change led to increase in energy use in all but one year (2008-09 over 2007-08) and the activity effect was always greater than unity.

The latter is so expected, as unity minus activity effect represents the growth rate of the economic activity (here the real GSDP), and higher the growth rate, greater the social benefit. Hence, we have to take the activity effect as given. Note that according to the LMDI decomposition, energy consumption change is the product of these three effects, intensity, structure and activity effects; for example, for 2008-09 over 2007-08, energy consumption change = 0.961 = 0.912 x 0.994 x 1.061. Thus, given the activity effect, the combined effect of structure and intensity must more than compensate the activity effect in order for an effective energy conservation. That is, the combined effect of structure and intensity must be sufficiently smaller.

Energy conservation means that the energy consumption change is less than unity; this in turn requires the combined effect of activity (ΔA), structure (ΔS) and intensity (ΔI) be less than unity ($\Delta A \times \Delta S \times \Delta I < 1$); that is, the given activity effect be less than the reciprocal of the combined effect of the other two ($\Delta \mathrm{A} < \frac{1}{\Delta \mathrm{S} \Delta \mathrm{I}}$); for example, for 2008-09 over 2007-08, an energy consumption change of 0.961 implies $\Delta \mathrm{A} = 1.061 < \frac{1}{\Delta \mathrm{S} \Delta \mathrm{I}} = \frac{1}{(0.994)(0.912)} = 1.1031$. Note that this also means that the combined effect of structure and intensity must be sufficiently smaller, as already stated ($\Delta \mathrm{S} \Delta \mathrm{I} < \frac{1}{\Delta \mathrm{A}}$).

Note that an energy consumption change of 0.961 for 2008-09 over 2007-08 implies a 3.9% fall in energy use in that year. An approximate decomposition of this energy saving as obtained from the three effects is as follows:

Energy saved in efficiency improvement = 1 – 0.912 = 0.088

Energy saved in structural change = 1 – 0.994 = 0.006

Total energy saved = 0.088 + 0.006 = 0.094.

Surplus energy used for activity change = 1 – 1.061 = (–) 0.061

Therefore, Net energy saved = 0.094 – 0.061 = 0.033

Energy saved in consumption = 1- 0.961 = 0.039

Next we turn to the petroleum sector of Kerala; Table 4 presents the sector-wise a product-wise petroleum consumption in Kerala for the study period (from 2007-08 to 2016-17) and the next Table (5) provides the combined data for two sectors, industry (secondary) and others (tertiary) to correspond to the National Income Accounts classification that we followed in the last part (for the power sector). The activity measure that we use is the same, real GSDP (2011-12 prices) for the same period, from 2007-08 to 2016-17.

As earlier, from this basic data, we estimate the sectoral energy intensity of petroleum (MT/lakh Rupees of real GSDP) and the sectoral shares of GSDP, which are given in Table 6. The corresponding LMDI decomposition results are given in Table 7.

The results show that the petroleum energy consumption increased in all the years over the respective previous years, without any exception. At the same time, it is significant to note that energy efficiency improvement contributed to energy intensity reduction in all but two years: 2008-09 over 2007-08 and 2016-17 over 2015-16. In 2011-12, energy efficiency improvement reduced energy intensity by about 10% over 2010-11. However, the structure effect was less than unity only for three years (2010-11, 2011-12 and 2015-16 over the respective previous years) and the activity effect was always greater than unity. That no year witnessed energy conservation effort in this sector implies that the combined effect of intensity and structure was not sufficient to cover the growth in the economic activity. Note that the activity effect is temporally different

Table 4: Consumption of Petroleum Products in Kerala, TMT

Product	LPG	Naphtha	Auto LPG	MS	HSD - For Automobiles	HSD-Industrial	HSD-Commercial DG Sets etc	SKO*-PDS	SKO-Fishing	LDO	FO/LSHS	Bitumen	Lubes	ATF	Natural Gas	All Products
2007-08	517.53	397.92	0	555.95	1403	84.8	169.4	134.47	89.65	0.55	297.7	111.72	41.19	202.9	0	4006.73
2008-09	514.5	609.31	10.79	619.12	1496.4	87.86	164.18	131.87	87.92	1.96	380.1	143.26	37.75	228.7	0	4513.73
2009-10	559.49	646.67	15.24	705.81	1575.3	96.54	179.3	135.65	90.43	1.36	408	148.52	44.72	271	0	4877.98
2010-11	627.4	487.8	12.6	757.7	1726.5	101.4	188.3	110.7	73.8	0.5	347.5	178.7	42.6	297.8	0	4953.1
2011-12	647.9	272.7	11.7	800.4	1887.2	110.9	205.9	93.4	62.3	0.1	322.8	222.5	42.5	302	0	4982.3
2012-13	662.5	403.3	11	846	2111.1	110.6	205.4	59.4	39.6	0.1	338.7	170.9	40.6	314.9	0	5314
2013-14	662.6	269.3	8.9	917.2	2331.9	72.8	135.2	56.9	38	0.1	264.3	221.5	42	337.9	0.1	5358.6
2014-15	715.6	181.1	8.5	1024	2325.8	86	159.7	56.9	37.9	0.1	263.7	178.4	42.1	358.1	0.1	5437.9
2015-16	769.2	23.5	6.5	1129.8	2317.6	111.2	206.5	58.8	39.2	0.1	322.6	193.4	43.7	382.1	0.2	5604.4
2016-17	848.1	0	5.5	1259.6	2329.5	109.6	203.5	48.5	32.3	0.3	314.9	173.3	42.8	428.1	287.7	6083.8
2017-18	933.3	4	5.7	1404	2372.2	114.2	212.2	37.3	30	0.8	243.7	234	41	473.7	291	6397.1
Sector	Domestic	Industrial	Transport	Transport	Transport	Industrial	Commercial	Domestic	Transport	Industrial	Industrial	Infrastructure	Transport	Transport	Industrial	

Source: (i) Monthly Petroleum Products Sale data, compiled by SLC, Kerala; (ii) Monthly data of Petroleum Planning and Analysis Cell, Ministry of Petroleum and Natural gas.

Table 5: Sectoral Consumption of Petroleum Products and Real GSDP in Kerala

	Petroleum, TMT			Real GSDP, Rs Lakh		
	Industrial	Others	Total	Secondary	Tertiary	Total
2007-08	780.96	3225.77	4006.733	4571935	12819755	17391690
2008-09	1079.2	3434.51	4513.729	4576364	13841297	18417661
2009-10	1152.6	3725.39	4877.977	4854334	15522423	20376756
2010-11	937.17	4015.98	4953.144	5576848	16503211	22080059
2011-12	706.47	4275.79	4982.261	8369967	17390244	25760211
2012-13	852.6	4461.35	5313.95	8580866	19042425	27623291
2013-14	606.56	4752.06	5358.619	8865392	20439675	29305067
2014-15	530.98	4906.96	5437.9371	9033930	21507602	30541532
2015-16	457.52	5146.86	5604.3813	9825120	22933704	32758824
2016-17	712.51	5371.27	6083.779	10164829	24640455	34805284

Table 6: Sectoral Energy Intensity and Sectoral Share of GSDP

	Sectoral Intensity, Petroleum, MT/lakh Rs		Sectoral Shares of GSDP	
	Secondary	Tertiary	Secondary	Tertiary
2007-08	0.171	0.252	0.263	0.737
2008-09	0.236	0.248	0.248	0.752
2009-10	0.237	0.24	0.238	0.762
2010-11	0.168	0.243	0.253	0.747
2011-12	0.084	0.246	0.325	0.675
2012-13	0.099	0.234	0.311	0.689
2013-14	0.068	0.232	0.303	0.697
2014-15	0.059	0.228	0.296	0.704
2015-16	0.047	0.224	0.3	0.7
2016-17	0.07	0.218	0.292	0.708

Table 7: LMDI Decomposition Result

From	Energy Consumption Change	Intensity Effect	Structure Effect	Activity Effect
2007-08 to 2008-09	1.127	1.061	1.003	1.059
2008-09 to 2009-10	1.081	0.976	1	1.106
2009-10 to 2010-11	1.015	0.94	0.997	1.083
2010-11 to 2011-12	1.006	0.901	0.957	1.166
2011-12 to 2012-13	1.067	0.984	1.011	1.072
2012-13 to 2013-14	1.008	0.944	1.007	1.061
2013-14 to 2014-15	1.015	0.968	1.006	1.042
2014-15 to 2015-16	1.031	0.965	0.996	1.073
2015-16 to 2016-17	1.086	1.014	1.007	1.062

Table 8: Sectoral Consumption of Petroleum Products in Kerala

Petroleum Mu			
	Industrial	Others	Total
2007-08	9082.58	37515.7	46598.3
2008-09	12551.36	39943.3	52494.67
2009-10	13404.63	43326.2	56730.87
2010-11	10899.23	46705.8	57605.06
2011-12	8216.23	49727.5	57943.7
2012-13	9915.77	51885.5	61801.24
2013-14	7054.3	55266.4	62320.74
2014-15	6175.3	57067.9	63243.21
2015-16	5321.01	59858	65178.95
2016-17	8286.52	62467.8	70754.35
2017-18	7603.29	66795.3	74398.56

in this sector compared with the earlier model, because here we considered only two sectors, secondary and tertiary.

Finally we turn to the decomposition analysis for the combined energy sector of Kerala (electricity and petroleum sectors taken together); as conversion factor for petroleum, we take one metric ton oil equivalent = 11630 kwh and thus one thousand metric ton (TMT) oil equivalent = 11.63 MU. The converted petroleum data in MU is given in Table 8. For the combined energy sector, we consider the three usual economic activity sectors: agriculture (primary), industry (secondary) and others (tertiary), and real GSDP (at 2011-12 prices) for activity measure for the period from 2007-08 to 2016-17; the corresponding data are reported in Table 9. The information required for decomposition analysis (that is, the sectoral intensities and shares) is given in Table 10. The decomposition results are presented in the next Table (11).

Table 9: Sectoral Energy Consumption (Electricity and Petroleum) and Real GSDP in Kerala

	Energy Consumption, MU					Real GSDP, Rs Lakh		
	Agriculture	Industry	Others	Total	Primary	Secondary	Tertiary	Total
2007-08	230.55	13206.26	46558.11	59994.91	4341828	4571935	12819755	21733518
2008-09	225.22	16553.73	48593.36	65372.32	4643108	4576364	13841297	23060769
2009-10	257	17885.72	52613.14	70755.86	4504923	4854334	15522423	24881679
2010-11	231.56	15515.82	56535.82	72283.2	4131565	5576848	16503211	26211624
2011-12	286.18	13142.66	60696.49	74125.33	4266424	8369967	17390244	30026635
2012-13	306.08	14922.88	63411.49	78640.45	4104417	8580866	19042425	31727708
2013-14	310.25	12186.35	68692.79	81189.39	4052624	8865392	20439675	33357691
2014-15	298.28	11411.94	70317.34	82027.56	4263300	9033930	21507602	34804832
2015-16	279.48	10530.24	73747.82	84557.53	3636758	9825120	22933704	36395582
2016-17	321.98	13546.63	76973.28	90841.89	3794551	10164829	24640455	38599835

Table 10: Sectoral Energy Intensity and Sectoral Share of GSDP

	Sectoral Intensity , units/Rs			Sectoral Share		
	Primary	Secondary	Tertiary	Primary	Secondary	Tertiary
2007-08	0.00053	0.029	0.036	0.2	0.21	0.59
2008-09	0.00049	0.036	0.035	0.201	0.198	0.6
2009-10	0.00057	0.037	0.034	0.181	0.195	0.624
2010-11	0.00056	0.028	0.034	0.158	0.213	0.63
2011-12	0.00067	0.016	0.035	0.142	0.279	0.579
2012-13	0.00075	0.017	0.033	0.129	0.27	0.6
2013-14	0.00077	0.014	0.034	0.121	0.266	0.613
2014-15	0.0007	0.013	0.033	0.122	0.26	0.618
2015-16	0.00077	0.011	0.032	0.1	0.27	0.63
2016-17	0.00085	0.013	0.031	0.098	0.263	0.638

Table 11: LMDI Decomposition Result

From	Energy Consumption Change	Intensity Effect	Structure Effect	Activity Effect
2007-08 to 2008-09	1.09	1.028	0.999	1.061
2008-09 to 2009-10	1.082	0.979	1.024	1.079
2009-10 to 2010-11	1.022	0.944	1.027	1.053
2010-11 to 2011-12	1.025	0.908	0.986	1.145
2011-12 to 2012-13	1.061	0.981	1.023	1.057
2012-13 to 2013-14	1.032	0.968	1.014	1.051
2013-14 to 2014-15	1.01	0.965	1.004	1.043
2014-15 to 2015-16	1.031	0.965	1.022	1.046
2015-16 to 2016-17	1.074	1.005	1.008	1.061

We have the same results as for the petroleum sector: increase in total energy consumption for all the years compared with the respective previous years; contribution of energy efficiency improvement to energy intensity reduction in all but two years: 2008-09 and 2016-17 over the respective previous years. In 2011-12, energy efficiency improvement reduced energy intensity by about 10% over 2010-11 as in the petroleum sector case. However, the structure effect was less than unity only for two years (2008-09 and 2011-12 over the respective previous years) and the activity effect was always greater than unity. The net result of all these is that the energy consumption did increase in all the years under consideration. It is significant to note that the energy efficiency achieved in the power sector, though in a limited way, got melted away in the combined sector under the flames from the petroleum sector performance.

4. Simulation for Energy Consumption Under Different Scenarios

We have already seen that the decomposition identity may be written as

$$E = \sum_i E_i = \sum_i \frac{E_i}{Q_i}\frac{Q_i}{Q}\mathrm{Q}$$

where E is the total energy consumption, Q (= $\sum_i Q_i$) is the activity level (in our case, real GSDP), Q_i /Q is the ith sector's activity share (S_i) and E_i /Q_i is that sector's energy intensity (I_i). We can make use of this identity to simulate energy consumption under different scenarios.

The following Table reports the annual growth rate of real GSDP of Kerala for the last few years:

Real GSDP Annual Growth Rate (%)								
2008-09	2009-10	2010-11	2011-12	2012-13	2013-14	2014-15	2015-16	2016-17
6.11	7.9	5.35	14.55	5.67	5.14	4.34	4.57	6.06

Based on this, for simulation purposes, we assume an annual growth rate of real GSDP of 6%; thus, given the real GSDP of Rs 38599835 lakh of 2016-17 and 6% annual growth rate, the first year of simulation will have a real GSDP of Rs. 40915825 lakh. We also assume that the energy efficiency improvement leads to annual 10% fall in energy intensity in all sectors and also the real GSDP sectoral shares remain the same. Given this information, we estimate the total energy for the next four years after 2016-17; we find that the annual energy conservation in this scenario amounts to 4.6%. Also note that these assumptions imply an activity effect of 1.06, structure effect of unity, and intensity effect of 0.9; and yield an annual change in energy consumption of 0.954 (= 1.06 x 1 x 0.9), with an energy conservation of 4.6% (Table 12).

Table 12: Simulation for Energy Consumption under Scenario 1

	Intensity, kWh/Re			Sectoral shares			Real GSDP Rs Lakh	Energy consumption	
Year	Primary	Secondary	Tertiary	Primary	Secondary	Tertiary		MU	Fall %
2016-17	0.00085	0.013	0.031	0.098	0.263	0.638	38599835	90841.89	
Year 1	0.00076	0.012	0.028	0.098	0.263	0.638	40915825	86663.16	-4.6
Year 2	0.00069	0.011	0.025	0.098	0.263	0.638	43370775	82676.66	-4.6
Year 3	0.00062	0.01	0.023	0.098	0.263	0.638	45973021	78873.53	-4.6
Year 4	0.00056	0.009	0.02	0.098	0.263	0.638	48731402	75245.35	-4.6

Assumptions: (i) Annual growth rate of real GSDP = 6%; (ii) Energy efficiency improvement leads to annual 10% fall in energy intensity in all sectors; and (iii) Real GSDP sectoral shares remain the same.

The following Tables represent different scenarios of simulation.

Table 13 assumes (i) 5% annual growth rate of real GSDP; (ii) annual 10% fall in energy intensity in all sectors thanks to energy efficiency improvement; and (iii) real

GSDP sectoral shares remain the same. This scenario involves an annual energy conservation of 5.5%.

Table 14 assumes (i) annual growth rate of real GSDP of 5%; (ii) annual 5% fall in energy intensity in all sectors owing to energy efficiency improvement; and (iii) real GSDP sectoral shares remain the same. This results in 0.25% energy saving per annum.

Table 15 assumes (i) 6% annual growth rate of real GSDP; (ii) annual 10% fall in energy intensity in all sectors energy following efficiency improvement; and (iii) an increase in the real GSDP shares of secondary and tertiary sectors by 1% per annum and a corresponding decrease in the primary sector share. This yields 3.68% energy saving per year.

Table 16 assumes (i) 6% annual growth rate of real GSDP; (ii) annual 10% fall in energy intensity in all sectors from energy efficiency improvement; and (iii) a decrease in the real GSDP shares of secondary and tertiary sectors by 2% per annum with a corresponding increase in the primary sector share. Strangely this leads to greater energy conservation; this evidently can be due to the predominance of energy-inefficient petroleum sector through the secondary and tertiary sectors. The real contributions of these two sectors (secondary and tertiary) can come out of this mask only when this sector becomes energy-efficient.

Table 13: Simulation for Energy Consumption under Scenario 2

	Intensity, kWh/Re			Sectoral shares			Real GSDP Rs Lakh	Energy consumption	
Year	Primary	Secondary	Tertiary	Primary	Secondary	Tertiary		MU	Fall %
2016-17	0.00085	0.013	0.031	0.098	0.263	0.638	38599835	90841.89	
Year 1	0.00076	0.012	0.028	0.098	0.263	0.638	40529827	85845.59	-5.5
Year 2	0.00069	0.011	0.025	0.098	0.263	0.638	42556318	81124.08	-5.5
Year 3	0.00062	0.01	0.023	0.098	0.263	0.638	44684134	76662.25	-5.5
Year 4	0.00056	0.009	0.02	0.098	0.263	0.638	46918341	72445.83	-5.5

Assumptions: (i) Annual growth rate of real GSDP = 5%; (ii) Energy efficiency improvement leads to annual 10% fall in energy intensity in all sectors; (iii) Real GSDP sectoral shares remain the same.

Table 14: Simulation for Energy Consumption under Scenario 3

	Intensity, kWh/Re			Sectoral shares			Real GSDP Rs Lakh	Energy consumption	
Year	Primary	Secondary	Tertiary	Primary	Secondary	Tertiary		MU	Fall %
2016-17	0.00085	0.013	0.031	0.098	0.263	0.638	38599835	90841.89	
Year 1	0.00081	0.013	0.03	0.098	0.263	0.638	40529827	90614.79	-0.25
Year 2	0.00077	0.012	0.028	0.098	0.263	0.638	42556318	90388.25	-0.25
Year 3	0.00073	0.011	0.027	0.098	0.263	0.638	44684134	90162.28	-0.25
Year 4	0.00069	0.011	0.025	0.098	0.263	0.638	46918341	89936.87	-0.25

Assumptions: (i) Annual growth rate of real GSDP = 5%; (ii) Energy efficiency improvement leads to annual 5% fall in energy intensity in all sectors; (iii) Real GSDP sectoral shares remain the same.

Table 15: Simulation for Energy Consumption under Scenario 4

	Intensity, kWh/Re			Sectoral shares			Real GSDP Rs Lakh	Energy consumption	
Year	Primary	Secondary	Tertiary	Primary	Secondary	Tertiary		MU	Fall %
2016-17	0.00085	0.01333	0.03124	0.0983	0.2633	0.6384	38599835	90841.89	
Year 1	0.00076	0.01199	0.02811	0.0893	0.2660	0.6447	40915825	87498.55	-3.68
Year 2	0.00069	0.01079	0.02530	0.0802	0.2686	0.6512	43370775	84278.54	-3.68
Year 3	0.00062	0.00972	0.02277	0.0710	0.2713	0.6577	45973021	81177.31	-3.68
Year 4	0.00056	0.00874	0.02050	0.0617	0.2740	0.6643	48731402	78190.45	-3.68

Assumptions: (i) Annual growth rate of real GSDP = 6%; (ii) Energy efficiency improvement leads to annual 10% fall in energy intensity in all sectors; (iii) Real GSDP shares of secondary and tertiary sectors increase by 1% per annum and the primary sector share correspondingly decreases.

Table 16: Simulation for Energy Consumption under Scenario 5

	Intensity, kWh/Re			Sectoral shares			Real GSDP Rs Lakh	Energy consumption	
Year	Primary	Secondary	Tertiary	Primary	Secondary	Tertiary		MU	Fall %
2016-17	0.00085	0.0133	0.0312	0.0983	0.2633	0.6384	38599835	90841.89	
Year 1	0.00076	0.0120	0.0281	0.1163	0.2581	0.6256	40915825	84992.39	-6.44
Year 2	0.00069	0.0108	0.0253	0.1340	0.2529	0.6131	43370775	79520.71	-6.44
Year 3	0.00062	0.0097	0.0228	0.1513	0.2479	0.6008	45973021	74402.37	-6.44
Year 4	0.00056	0.0087	0.0205	0.1683	0.2429	0.5888	48731402	69614.53	-6.44

Assumptions: (i) Annual growth rate of real GSDP = 6%; (ii) Energy efficiency improvement leads to annual 10% fall in energy intensity in all sectors; (iii) Real GSDP shares of secondary and tertiary sectors decrease by 2% per annum and the primary sector share correspondingly increases.

Fig. 2: Energy Consumption Change

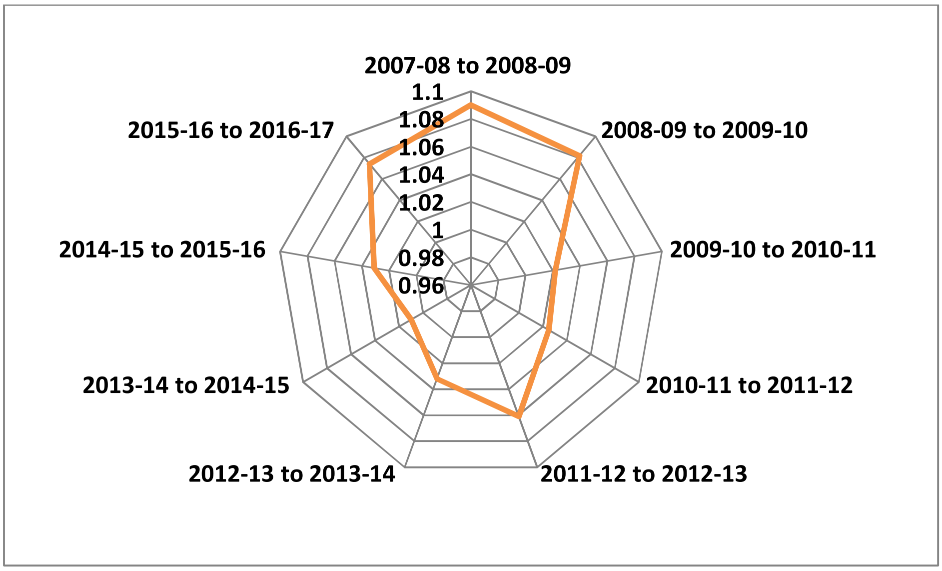


Fig. 3: Structure Effect

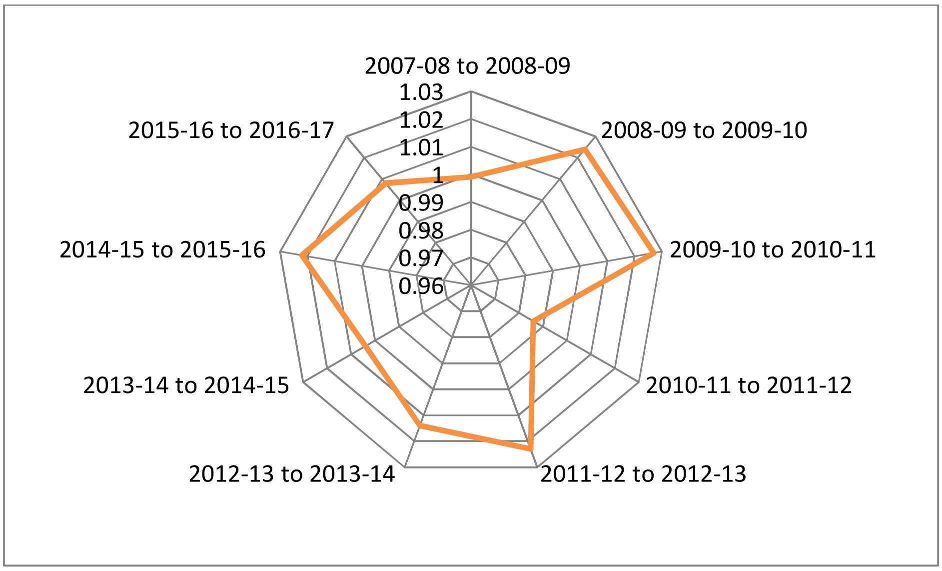


Fig. 4: Activity Effect

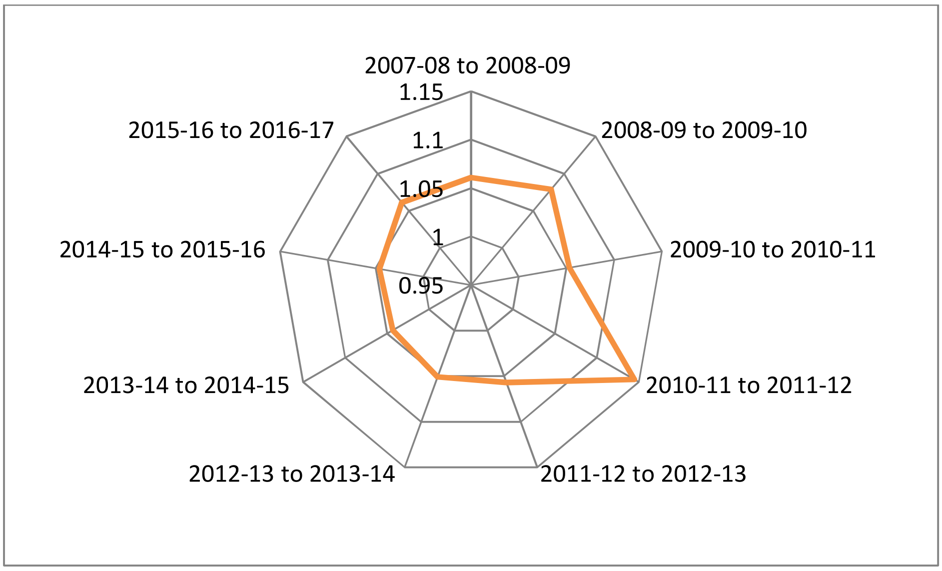
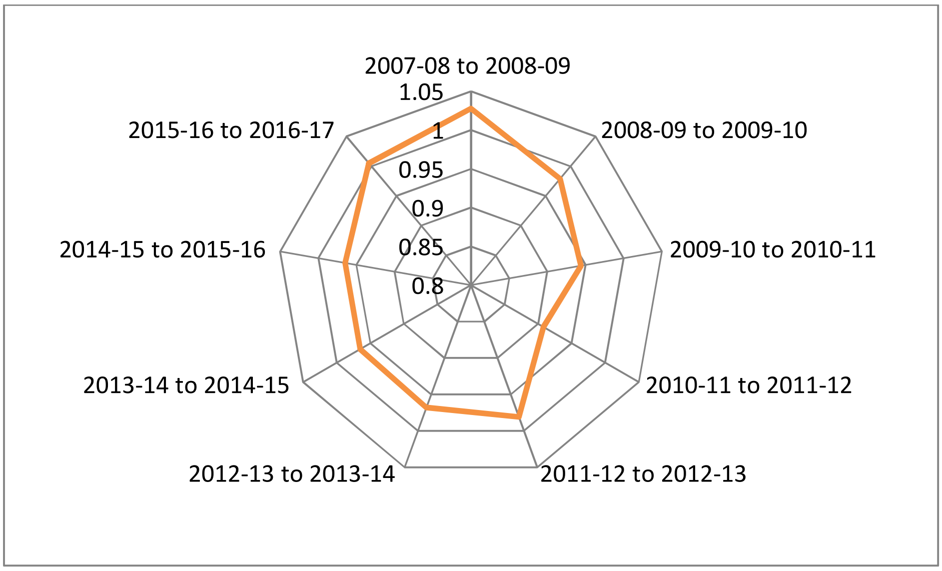


Fig. 5: Intensity effect



5. Conclusion

In this paper, we have applied the index decomposition analysis to measure energy productivity in Kerala in terms of the Logarithmic Mean Divisia Index (LMDI) method. This method helps us to decompose the changes in energy consumption over time into three different effects of activity, structure and intensity. As already indicated, non-availability of suitable time-series data for Kerala has forced us to limit our ambition down to an empirical decomposition exercise for Kerala in terms of only two sectors, power and petroleum, that too, for a limited period (from 2007-08 to 2016-17); first we have analysed the two sectors of power and petroleum separately, and then the combined sector has been analysed for decomposition.

Note that energy conservation means the energy consumption change be less than unity; this in turn requires the combined effect of activity, structure and intensity be less than unity. The activity effect is expected to be greater than unity; since unity minus activity effect represents the growth rate of the economic activity (here the real GSDP), and higher the growth rate, greater the social benefit. Hence, we have to take the activity effect as given. This in turn requires that given the activity effect, the combined effect of structure and intensity must more than compensate the activity effect in order for an effective energy conservation. That is, the combined effect of structure and intensity must be sufficiently smaller. The empirical exercise for Kerala power sector shows that this was possible only for two years during the study period (from 2007-08 to 2016-17). Energy consumption reduced by about 9% in 2008-09 over 2007-08 and nearly 5% in 2013-14 over the previous year.

It is significant to note that energy intensity in the power sector reduced in all but one year: 2013-14 over 2012-13, thanks to energy efficiency improvements; and this lies behind the energy use reduction in the two years of 2008-09 and 2013-14; no energy efficiency improvement means that consumption would have increased. Thus in these two years, social benefit increased along with positive energy conservation. That this occurred only for two years is explained by the performance of the other component, structure effect, that was greater than unity in all but one year (2008-09 over 2007-08). In short, despite energy intensity reduction thanks to energy efficiency improvement in the power sector of Kerala for a number of recent years, energy conservation along with increased social benefit (real GSDP) could not be achieved because of the anomaly in the real GSDP structure (composition of sectoral shares). If the current state of nature dictates this activity structure as given, then the only recourse for energy conservation is through higher levels of energy efficiency improvement for greater reduction in intensity.

The results for the petroleum sector (with only two sectors, secondary and tertiary), however, show that no year witnessed energy conservation effort in this sector. This is despite energy intensity reduction (thanks to energy efficiency improvement) in all but two years: 2008-09 over 2007-08 and 2016-17 over 2015-16. The structure effect was less than unity only for three years (2010-11, 2011-12 and 2015-16 over the respective previous years). Their combined effect was incapable of containing the activity effects of the secondary and tertiary sectors for occasioning any energy conservation. Such performance of the petroleum sector has overshadowed that of the power sector, and the combined sector of energy in Kerala has shown almost similar results as the petroleum sector, with the net result that the energy consumption increased in all the years under consideration.

Following this, we have then turned to a simulation analysis for energy consumption in Kerala under different scenarios that offer energy savings. This exercise shows some strange results, emanating from the peculiar characteristics of the petroleum sector in Kerala. As already remarked earlier, the petroleum consumption data relating only to the secondary and tertiary sub-sectors, the less-efficient petroleum sector overweighs the combined energy sector of Kerala to such an extent that the energy-efficiency potential of these two sub-sectors gets clouded. In this situation, the simulation with an assumption of a small reduction in the real GSDP shares of secondary and tertiary sectors yields greater energy conservation. A sufficiently high degree of energy efficiency in the petroleum sector can indeed reverse this anomaly.

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