“A STUDY OF ENERGY CONSUMPTION, ENERGY INTENSITIES AND INDUSTRIAL GROWTH IN INDIA.”

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1. INTRODUCTION

Energy as an input plays a vital role in every sector of an economy. Down the centuries the growth trend of energy consumption has proved quantitatively on physical indicators of economic growth. Availability of energy in any form confirmed its significance in the economic development. Although every production process realized the contribution of energy input, energy sector failed to realize that the natural resources are exhaustible, and energy is vital component until late sixties. During this time the Club of Rome Study[1] highlighted the depleting natural resources and non-availability of non-conventional energy resources. The study forecasted that global coal reserves are expected to last for about 100 years to 2300 years, and that of petroleum and Natural gas reserves to last about 20 and 50 years respectively. Against this background, it has been found that energy demand has been drastically increasing in India as overall economic activity such as industrialization, electrification, rapid growth of infrastructure and human development is taking shape. Although country is rich in coal and other renewable energy resources it is not able to meet the demand for energy. And India is forced to import over 25% of its energy. The Indian industries share 29% of the country's GDP and is one of the largest consumers of energy. When we examine the Micro, Small and Medium Enterprises (MSME) they account for 80% of industry (in terms units), among them a few large/heavy small-scale industries alone consume more than 60% of the energy. Therefore, it is imperative to improve the efficiency levels as cost of fueling and GHG (CO_2) increasing. Improving efficiency level depends on reducing energy intensity. Energy Intensity is the energy use per unit of Gross Domestic Product e.g. toe/USD 1000 of GDP or energy use per rupee GDP earned. Energy intensity is inversely related to efficiency; less the energy required to produce a unit of output or service, the greater is the efficiency level.

Energy intensity is an index to show how efficiently energy is used in the economy. The energy intensity of India is over twice that of the matured economies (OECD). India's energy intensity is also much higher than the emerging economies. However, since 1999,

[1] Donella H. Meadows et al, (1972)

India's energy intensity has been downward trending and is expected to decrease constantly (GOI, 2001). The indicator of energy–GDP (gross domestic product) elasticity which is the ratio of growth rate of energy to the growth rate GDP captures both the structure of the economy as well as the efficiency (Sarbapriya Ray, 2011). The increase in energy efficiency might be attributed to reduced energy inputs to given level of consumption level, superior services to given amount of energy inputs such as imports of superior technology or industry' ongoing R & D or Size and Age of the industries etc.

Since second five-year plan rapid industrialization policy caused great demand for energy use. The energy consumption of industries accounts around 43.6 per cent of energy availability as Indian industrial sector becoming more and more competent in the world economy (Energy balance Statistics 2012). This is partly due to constant increase in the investment in basic and energy-intensive industries, following the emphasis laid on achieving self-reliance in the past development plans.(TERI, 2015). Constant increase in Energy consumption was one of the major impacts on GHG, including CO_2. In India, heavy industries such as iron and steel, aluminum, cement, fertilizer, refining, and pulp and paper are more energy intensive (Bhattacharya and Copper 2010). The industries such as food processing, textiles, wood products, printing and publishing, and metal processing account for a lesser final energy consumption. The former and later mentioned industries make a contribution of 29% to the GDP at Current price. The energy use per rupee GDP earned said to have increased rapidly and this can be attributed to more energy intensive industries. At the same time there is a need to improve the efficiency to have much more reduced intensities. India made a commitment to reduce energy intensity of its GDP by 20-25 % from 2005 levels within 2020 (planning commission 2011). In this context it becomes more imperative to analyze the energy consumption trend in the industrial sector, its intensity on industrial output.

2. LITERATURE REVIEW

For a long time, the classical growth theories asserted that economic growth is dependent on labor and capital only but considering the oil embargo of 1973-74 and the continued rise in the energy prices challenged the thought and brought out a significant role of energy resources in the industrial production processes (Pindyck, 1979). Georgescu (1972) was one of the first to emphasize on energy as a critical input in manufacturing activities. According to him, optimum energy use improves efficiency and productivity. Since then, several studies were undertaken to analyze the nexus between energy input and economic output. Kraft and Kraft (1978) conducted one of the pioneering works on the causal relationship between energy input and economic growth using the time series data for the United States economy from the year 1947 to 1974. He used a bivariate causality test to determine the causality between energy input and economic growth. He identified a positive relationship between GNP growth and an increase in energy use. In another study, Yu and Erol (1987) studied the cause and effect relationship between energy consumption and real G.N.P. for developed countries like Canada, France, Germany, U.K, Italy, and Japan. By employing Granger and Sims test of causality methods, they found a bi-directional causality between two variables in Japanese economy and no causal relationship between the two variables for developed countries like the U.K and France. Whereas, in the study on Germany and Italy found that increased GNP led to increased energy consumption and this was vice-versa in the case of Canada.

Similarly, many other studies have been undertaken at global level to investigate the relationship between energy consumption and industrial output vis-à-vis economic growth. Some of these studies like Glasure (1998), Soytas and Sari (2003), Lee (2006), Zamani(2009) for various periods for economies such as South Korea, Singapore, Turkey, Argentina, United Nation, and Iran saw a bi-directional relationship among energy and output. These studies mostly used models such as the Engle-Granger Causality Test, Error Correction Model, and ARDL Bound Test. In contrast, other researchers like Hondroyiannis et al. (2002), Lee (2006), Jorbert & Karanfil (2007) used Engle-Granger, Granger Causality Test, Johnsen's Multivariate Co-integration Technique, Co-integration and Vector Error Correction Model (VECM), for economies such as United Kingdom, France, Sweden, Germany, U.S.A. and Turkey. They found no causality between energy consumption and output. Whereas, few other studies done by Bradley, and Ugur (2007) for economies such as Japan, Turkey, and United States for different research periods have shown uni-directional causality between energy and output.

Apart from the above cited studies at global levels, researchers have also endeavored to study and predict the relationship between energy consumption and industrial output with regards to India's GDP at the local levels. In one such study, Ghosh (2002) using time series data on variables such as electricity use and economic growth (per capita), observed that there is a long-run causality occurring from output to energy consumption. As opposed to this, Bhattacharya and Paul (2004) applied alternative econometric time series models such as: Engle-Granger, Granger Causality Test, and Johnsen's Multivariate Co-integration Technique. They found that bi-directional causality exists between energy consumption and economic growth. Tiwari (2011) for the sample period of 1970-2007 used time-series data and came out with the result that in the long-run that there is a causal relationship between GDP and energy consumption. Govindaraju and Tang (2013) for the sample period of 1965-2009 studied the linkages between coal consumption and real GDP per capita, where the results indicated no long-run relationship between energy and income. Still, there is a short-run relationship between income and energy.

Vidyarthi (2013) analyzed the period of 1971-2009 adopting the Johansen approach on time series data of energy consumption, real GDP and carbon emissions. The results indicated that there is a long-run linkage from energy to income, but a short-run linkage from income to energy. Abbas and Choudhary (2013) studied on the area for the period of 1972-2008 found that the aggregate level increase in GDP demanded more energy consumption both in the long-run and in the short run. Whereas, at the disaggregated level, they found bi-directional causality between income and energy consumption. Bildirici and Bakirtas (2014), between 1980 and 2011, used a combination of different energy sources such as coal, natural gas, and oil consumption with real GDP by applying the ARDL model. Their results indicated bi-directional relation running from energy to output for coal and oil. Nain, Ahmad, and Kamaiah (2015), on the other hand, used time-series data at aggregate and disaggregate levels on electricity consumption and real GDP by applying ARDL Bound Test. Their results indicated that there was no long-run relationship at the aggregate level, but a short-run relationship between energy and income.

A study conducted by the Economic Survey of India (2018-19) reveals that “India with a per-capita energy consumption of about one-third of the global average, will have to increase its per capita energy consumption at least 2.5 times to increase its real per capita GDP by USD 5,000 per capita, in 2010 prices, to enter the upper-middle income group”. Similarly, if India increases its per capita energy consumption four times the current consumption, it can achieve a higher Human Development Index.

A study conducted by Kamaljit Singh and Vashishta (2020) examines the relationships between per capita energy consumption and per capita GDP in India for the reference period from 1971 to 2015. The empirical analysis was conducted using the three-stage Johnson Co-integration, Vector Auto-regression and Granger Causality Test. The outcome of the study showed unidirectional causality occurring from per capita GDP per unit capita energy consumption and this was absent in the long-term equilibrium relationship between per capita energy consumption and per capita GDP in India.

A similar study by Aviral Kumar Tirwaria, Leena Mary Eapen and Sthanu R Nair (2021) examined the direction of the Granger-causal relationship between electricity consumption and economic growth at the State and Sectorial levels in India. In the investigation, the Panel Co-integration Tests with the structural break, the Heterogeneous Panel Causality Test, and the Panel VAR based impulse-response model have been used. The study evaluated agricultural and industrial sectors on its energy dependence and contribution to output for eighteen major Indian states for the reference period from 1961 to 2015. The results prove a long-term relationship between economic growth and electricity consumption only in the agriculture sector. Further, the results disclose presence of unidirectional Granger-causality running in the direction of overall economic growth to electricity consumption at the aggregate State level. However, focus on sectorial level depicts a unidirectional causal relationship flowing from electricity consumption to economic growth for the agriculture sector and economic growth to electricity consumption for the industrial sector.

All of the above studies are pertaining to different time periods yet in Indian context. These studies can be seen in three directions, one in the direction of analysis of the energy and economic growth nexus, another in the line of energy use in the industrial sectors and the third on energy intensity and industrial output. However, there are no recent studies examining inter relationship between industrial gross value added and energy consumption in the manufacturing sector on recent data. Moreover, methodology such as data envelopment model have not been employed to check the efficiency in manufacturing sector in the previous studies. At the same time Investigation of previous studies give an idea over the Subject, framing objectives, choice of variable, adjustment of the variable, length of time series, sample size, Data sources, various generation of methodologies followed. In the light of the above, this study titled "A study of Energy consumption, Energy Intensity and Industrial Growth in India" has been developed

3. OBJECTIVES OF THE STUDY

Based on the above review of related literature the following core objectives of the study are formulated:

1. To analyze the backdrop of industrial energy consumption scenario in Aggregate level
2. To understand the link between industrial output and energy efficiency in the context of technological development
3. To study the energy intensity of manufacturing industries (Such as Aluminum, cement, Iron- Steel, textiles, fertilizer, pulp and Paper, oil-Refineries, Sugar, Pharmaceuticals) in India
4. To analyze the impact of the use of energy and its intensity on industrial output

4. HYPOTHESIS

Based on the above objectives following are the Hypotheses formulated.

1. Greater energy consumption leads to higher industrial output.
2. Industries with less energy intensity produce higher efficiency in energy consumption.
3. Productivity and energy efficiency are related positively
4. Energy efficiency is dependent positively on technological development.

5. SOURCES OF DATA AND RESEARCH METHODOLOGY

The main source of data for the study is from Annual Survey of Industries of India database for the period of 1999 to 2018. Data on manufacturing industry-wise consumption of energy input such as coal, natural gas, petroleum products and electricity in physical units and labour employed, fixed capital and gross value added in value term have been taken from various official data sources (e.g. petroleum and Natural gas statistics, published by ministry of petroleum and Natural Gas, Government of India, and Energy Statistics of various years, published by the Ministry of Statistics and Programme Implementation, Government of India). The various types of energy sources have been combined and presented in terms of million or thousand tons of oil equivalent.

The research has been carried out for 23 manufacturing industries of NIC 2008 -Two Digit for the period 1999 to 2018. List of the industries are namely Manufacturing of Basic Metal, Beverages, Chemical and Chemical Products, Coke and Refined Petroleum Products, Computer and Electronic Optical products, Electrical Equipment, Fabricated Metal Products except Machinery and Equipment, Manufacturing of Food Products, Manufacturing of furniture, Manufacturing of leather related products, Manufacturing of machinery and equipment, Other Non-Metallic Mineral products, Manufacturing of paper and paper products, Pharmaceutical medical, chemical & botanical products, Rubber plastic product, Manufacturing of textiles, Manufacturing of tobacco products, Manufacturing of wearing apparels, Manufacturing of wood and wood products, Other manufacturing, printing and reproduction of media, Publishing Activities, and Crop animal production and Hunting related.

Diversified methodological approach has been adopted in each chapter fulfilling the different objectives of the study at large.

6. THE CHAPTER SCHEME OF THE STUDY ARE:

Chapter One

Introduction

Chapter Two

Review of Literature

Chapter Three

The framework of aggregate Energy Consumption Output and Input: An Explorative and Descriptive Statistical Analysis

Chapter Four

An Analysis of Industrial Gross Value Added and Energy Consumption of Indian Manufacturing Industries: A Fixed and Random Effect Approach

Chapter Five

Energy Consumption and Gross Industrial Value Added Linkages: Evidence from Indian Manufacturing Sector

Chapter Six

Measuring the Efficiency of Energy Consumption of Major Indian Manufacturing Sector: A DEA-Based Malmquist Productivity Analysis

Chapter Seven

Summary and conclusion

7. CHAPTER-WISE DESCRIPTION

To leaf out one by one, the first chapter deals with introduction on the area of study, specifically on energy scenario in relation to industry, India's energy profile, different energy units, choice of energy units and energy conversion ratio.

The second chapter highlighted the detailed review of literature in three blocks, the block one presents the energy studies in the context of world economics, the block two lists energy related studies in India and the third block presents reviews of studies on energy intensity and energy efficiency studies in India. Various literatures gave an idea over the Subject, framing objectives, choice of variable, adjustment of the variable, length of time series, sample size, Data sources, various generation of methodologies followed.

The third chapter presents an explorative and descriptive statistical analysis for various industries under study. On conducting this, profile of each industry about energy consumption, labor employed, fixed capital, number of factories, profit, fuel price index and industrial gross valued added are brought to light. Chapter also examines the trends in the amount of energy use and energy intensity of various manufacturing sector and relative percentage fuel consumption across various industries. The preliminary results are presented below: (for example)

		Total Fuel Consumed					
		BM	*CH*	*Non M*	*PP*	*TEX*	*All Ind*
1998-03	Mean	4819.06	106586.5	76262.16	24370.78	77628.18	573454.4
	S.Deviation	988.7208	19327.67	9883.684	3195.627	10502.97	74331.65
	Sample Variance	977568.8	3.74E+08	97687216	10212034	1.1E+08	5.53E+09
	Kurtosis	-1.5694	1.523405	2.072622	2.19361	2.051655	1.181455
	Skewness	-0.81861	-1.39092	-1.39975	-0.98088	-1.37952	-0.57641
	Range	2299.4	48064.1	25564.8	8783.2	25925.7	203163
	Minimum	3422.2	75268.2	60090.9	19307.5	60441.2	462595.2
	Maximum	5721.6	123332.3	85655.7	28090.7	86366.9	665758.2
2003-08	Mean	8771.16	149084.2	132754.1	31828.62	115885.4	1048189
	S.Deviation	2114.056	20043.87	32783.89	4996.962	23126.87	189488.2
	Sample Variance	4469232	4.02E+08	1.07E+09	24969626	5.35E+08	3.59E+10
	Kurtosis	-0.39081	-2.04241	-0.13604	2.653107	-2.70643	-2.28075
	Skewness	0.872712	0.073921	0.747424	1.530689	0.149641	0.563867
	Range	5197.6	48073.6	84024.6	12909.1	50524.1	437078.6
	Minimum	6713.2	125186.8	97024.6	27248.5	89625.3	858538.4
	Maximum	11910.8	173260.4	181049.2	40157.6	140149.4	1295617
2008-13	Mean	18945.38	248572.1	291664.9	62706.84	197268.9	2038339
	S. Deviation	5440.678	62571.95	72877.89	13706.75	42865.61	501842.9
	Sample Variance	29600977	3.92E+09	5.31E+09	1.88E+08	1.84E+09	2.52E+11
	Kurtosis	-2.20192	-0.85523	-2.72751	-2.09227	-1.21318	-2.28217
	Skewness	0.555301	0.76673	0.258122	-0.11943	0.346905	0.337104
	Range	12352.4	154680.2	156940.9	32723.7	105740.8	1153832
	Minimum	13773	184132.1	221714.2	46403.9	149986.3	1521620
	Maximum	26125.4	338812.3	378655.1	79127.6	255727.1	2675452
2013-18	Mean	30672.72	375963	424828.7	90686.18	301466.2	3092749
	S.Deviation	4692.941	25433.28	31230.83	6433.663	11592.38	234045
	Sample Variance	22023692	6.47E+08	9.75E+08	41392014	1.34E+08	5.48E+10
	Kurtosis	1.331908	3.812244	-0.86317	-2.63373	-0.12334	3.777043

Skewness	1.322649	1.934969	0.945937	0.310615	0.07743	1.895962
Range	11780.8	60507.9	72940.7	14554	30746.6	585628.2
Minimum	26429.9	359614	397909.2	83482.5	286180.3	2912349
Maximum	38210.7	420121.9	470849.9	98036.5	316926.9	3497977

The investigation from chapter four on eleven groups of manufacturing industries reveals that there is a positive relation between fuel consumption and gross industrial value- added. The results have been obtained by conducting various models. Among the fixed and random models, the fixed effect model fits the data better and result outcomes are significant and effective to the economic theories. The slope coefficient of the fuel consumed under fixed effect model indicates that per unit increase in fuel consumption leads to increasing in Industrial gross value-added by 0.58814 at 1% level of significance with the R^2 of 0.9802. The slope coefficient of fixed capital drives the industrial gross value-added to change by 0.29315 for every one unit change in fixed capital. Similarly, the coefficient of the labor influences the industrial gross value-added by 0.52091 for every unit change in labor. The statistical representation of the slope coefficient of fuel consumption is large enough to impact on the industrial gross value-added. Hence, there has been a substantial influence of energy on industrial gross value added. (For example)

The pooled OLS is a pooled linear regression without fixed or random effects. It assumes there is no difference in intercept and slopes across all the group and time period.

$$y_{it} = \alpha + X_{it}\beta + \varepsilon_{it}\ (u_i = 0)$$

$$Gross\ Industrial\ Value\ Added_i = \beta_0 + \beta_1 fuelconsumed_i + \beta_2 fixed\ capital_i + \beta_3 labour_i + \varepsilon_i$$

$$\beta_0\ is\ the\ intercept$$

$$\beta_1 = is\ the\ slope\ (coefficient\ or\ parameter\ estimate) of\ fuelconsumed$$

$$\beta_2 = is\ the\ slope\ of\ fixed\ capital$$

$$\beta_3 = is\ the\ slope\ of\ labour\ used$$

$$\varepsilon_i = is\ the\ error\ term$$

Comparison of Pooled OLS, Fixed Effect and Random Effect Models Results

	OLS	Fixed Effect	Random Effect
Fuel consumed	-.47287** (.0526)	.58814** (.0680)	.3575** (.0728)
Fixed capital	1.2553** (.5090)	.29315** (.0740)	.6386** (.0675)
Labour	.22338** (.0316)	.52091** (.1348)	.0515** (.0731)
over all intercept	-.73070** (.1386)	-2.6169** (.6415)	-.2482** (.2909)
F, Wald, LR test	996.35	784.84	2483.83
SEE	5.1784	1.5206	.0859
$\hat{\sigma}_\mu$	-	-	.0883
θ	-	-	.7874
R2	0.9326	0.9802	0.9321
Adjusted R2	0.9317	0.9790	-

Standard errors in parenthesis; Statistical significance: * <.05, **<.01

Source: Author’s Calculation

The chapter five examines the inter linkages between energy inputs and industrial value-added for Indian industries for the sample period of 1999-2018. It explores the relationship both at the aggregate and dis-aggregate levels upon finding the presence of integrated series at the level through the panel unit root test. The Johansen Maximum Likelihood approach indicated strong co-integration of the variables. The cointegration results record that the GIVA and energy input in industry both at aggregate and disaggregate levels are co-integrated, and the combination of the following series such as I.V.A. and T.F.C.; I.V.A. and I.C.C.; I.V.A. and I.E.C.; I.V.A. and IOFC; I.V.A. and I.P.P.; tending together in the long run. Hence, posits that the pairs of investigated variable series are in a long-run relationship. Later, to find out the direction of the Granger causality between variables, VECM has been undertaken. In long-run, the results of VECM showed that InGIVA, InCC, and InIEC have cause and effect relationships among the variable in the long-run. At the disaggregated level, an increase in gross industrial value-added has a positive impact on the demand for coal usage and electricity consumption at a 5% significance level. These findings are similar to Akhmat and Zaman (2013) and Bildirci (2014) for coal usage and economic growth. But at the same time, the results contradict the finding of Nain, Ahmed, and Kamaiah

(2015). As their conclusion for the industrial sector at disaggregates level revealed no long run relationship between Energy and Income.

Moreover, the short-run VECM results show short-run causality running from GIVA to industrial fuel consumption, electricity consumption, and petroleum consumption, which means expanding industrial production demands for more energy inputs in the short-run. Moreover, the Granger Causality test reveals the direction of causality running from GIVA to TIFCV, GIVA to I.E.C., GIVA to IPPC, and I.C.C. to GIVA.

Based on the above empirical results, we know that the Gross industrial value-added is delivered primarily through energy consumption. The industrial sector's energy intake remains as high as 50% of the total available commercial energy. Among which coal & electricity is used as a critical component in industrial production both in the short-run and long-run. Energy-intensive manufacturing such as food, pulp & paper, basic chemicals, refining, iron & steel, nonferrous metals & nonmetallic mineral seems to be energy dependent for decades ahead. Hence the policymakers must fulfill two objectives. First, balance the demand for and supply of energy and safeguard the environment from negative externalities of excessive energy consumption. This requires a focus on industrial energy efficiency and scope for saving energy by adopting energy-efficient technology (EETs), substitution for conventional sources of energy, renewable energy Technology (RETs), and best operating practices (B.O.P.s).

Moreover, the current Indian economic thought being "a self-reliant India" (Atmanirbhar Bharat) will double energy consumption in the near future and widen the energy deficit. Hence in time to come, India needs to design robust energy policies such as reducing dependency on fossil fuels, particularly petroleum and coal, and moving towards renewable energy sources, including hydrogen. This will make India a manufacturing hub, creating global competitiveness, and Atmanirbhar Bharat achievable. (For example)

The Error Correction Models for Y_t and X_t are as follows:

$$\Delta giva_t = \alpha + \sum_{i-1}^{k-1} \beta_i \Delta Ingiva_{t-i} + \sum_{j=1}^{K-1} \emptyset_j \Delta Intifc_{t-j} + \sum_{k=1}^{k-1} \varphi_k \Delta Inicc_{t-k} + \sum_{l=1}^{k-1} \sigma_l \Delta Iniepv_{t-l} + \sum_{m-1}^{k-1} \vartheta_m \Delta Iniofc_{t-m} + \sum_{n-1}^{k-1} \theta_n \Delta Inipp_{t-n} + \gamma_1 ECT_{t-1} + u_{1t} \dots\dots\dots\dots (4)$$

$$\Delta Intifc_t = a + \sum_{i=1}^{k-1} \beta_i \Delta Ingiva_{t-i} + \sum_{j=1}^{k-1} \emptyset_j \Delta Intifc_{t-j} + \sum_{k=1}^{k-1} \varphi_k \Delta Inicc_{t-k} + \sum_{l=1}^{k-1} \sigma_l \Delta Iniepv_{t-l} + \sum_{m=1}^{k-1} \vartheta_m \Delta Iniofc_{t-m} + \sum_{n-1}^{k-1} \theta_n \Delta Inipp_{t-n} + \gamma_2 ECT_{t-1} + u_{2t} \dots\dots\dots\dots(5)$$

$$\Delta Inicc_t = b + \sum_{i=1}^{k-1} \beta_i \Delta Ingiva_{t-i} + \sum_{j=1}^{k-1} \emptyset_j \Delta Intifc_{t-j} + \sum_{k=1}^{k-1} \varphi_k \Delta Inicc_{t-k} + \sum_{l=1}^{k-1} \sigma_l \Delta Iniepv_{t-l} + \sum_{m=1}^{k-1} \vartheta_m \Delta Iniofc_{t-m} + \sum_{n-1}^{k-1} \theta_n \Delta Inipp_{t-n} + \gamma_3 ECT_{t-1} + u_{3t} \dots\dots\dots\dots\dots(6)$$

$$\Delta Iniepv_t = c + \sum_{i-1}^{k-1} \beta_i \Delta Ingiva_{t-i} + \sum_{j-1}^{k-1} \emptyset_j \Delta Intifc_{t-j} + \sum_{k-1}^{k-1} \varphi_k \Delta Inicc_{t-k} + \sum_{l-1}^{k-1} \sigma_l \Delta Iniepv_{t-l} + \sum_{m-1}^{k-1} \vartheta_m \Delta Iniofc_{t-m} + \sum_{n-1}^{k-1} \theta_n \Delta Inipp_{t-n} + \gamma_4 ECT_{t-1} + u_{4t} \dots\dots\dots\dots\dots\dots(7)$$

$$\Delta Iniofc_t = d + \sum_{i-1}^{k-1} \beta_i \Delta Ingiva_{t-i} + \sum_{j-1}^{k-1} \emptyset_j \Delta Intifc_{t-j} + \sum_{k-1}^{k-1} \varphi_k \Delta Inicc_{t-k} + \sum_{l-1}^{k-1} \sigma_l \Delta Iniepv_{t-l} + \sum_{m-1}^{k-1} \vartheta_m \Delta Iniofc_{t-m} + \sum_{n-1}^{k-1} \theta_n \Delta Inipp_{t-n} + \gamma_5 ECT_{t-1} + u_{5t} \dots\dots\dots\dots\dots\dots\dots(8)$$

$$\Delta Inipp_t = e + \sum_{i-1}^{k-1} \beta_i \Delta Ingiva_{t-i} + \sum_{j-1}^{k-1} \emptyset_j \Delta Intifc_{t-j} + \sum_{k-1}^{k-1} \varphi_k \Delta Inicc_{t-k} + \sum_{l-1}^{k-1} \sigma_l \Delta Iniepv_{t-l} + \sum_{m-1}^{k-1} \vartheta_m \Delta Iniofc_{t-m} + \sum_{n-1}^{k-1} \theta_n \Delta Inipp_{t-n} + \gamma_6 ECT_{t-1} + u_{6t} \dots\dots\dots\dots\dots(9)$$

k-1= the optimal lag length is reduced by 1

$\beta_1, \emptyset_j, \varphi_k, \vartheta_m, \theta_n =$ Short run dynamic coefficient of the model's adjustment long run equilibrium

γ_i= the velocity of adjustment parameter with a negative sign.

ECT_{t-1}= the error correction term is the lagged value of the residuals derived from the co-integrating regression of the dependent variable on the regressors. It incorporates long run inference obtained from a long run co-integration association.

u_{it}= Residuals in the equation.

$\Delta Y_t = \sum_{i=1}^{n} \alpha_i \, \Delta Y_{t-i} + \sum_{j=1}^{n} \beta_j \, \Delta X_{t-j} + u_{1t}$…………… (10)

$\Delta X_t = \sum_{i=1}^{n} \alpha_i \, \Delta X_{t-i} + \sum_{j=1}^{n} \delta_j \, \Delta Y_{t-j} + u_{2t}$…………… (11)

Short Run Causal Effect Revealed by the t-statistics of Error Correction Term,

			Coefficient	Std. Error	t-Statistic	Prob.
InGIVA	1	C(4)	0.118894	0.086133	1.380346	0.1676
		C(6)	0.498032	0.164476	3.027996	0.0025
		C(8)	0.024984	0.073283	0.340926	0.7332
		C(10)	-0.015811	0.0226	-0.69959	0.4843
		C(12)	-0.076841	0.050152	-1.53214	0.1256
InPCTIFCV	2	C(16)	0.18817	0.054543	3.449911	0.0006
InPCCVV	3	C(30)	0.030355	0.018355	1.653741	0.0983
InPCIEPV	4	C(44)	0.127027	0.048756	2.605331	0.0092
InPCIOFCV	5	C(58)	0.271607	0.126714	2.14347	0.0322
InPCIPPV	6	C(72)	0.271243	0.068515	3.958861	0.0001

Long Run Causal Effect Revealed by the t-statistics of E.C.T.,

Model		Coefficient	Std. Error	t-Statistic	Prob.
InGIVA	C(1)	-0.191877	0.053712	-3.57235	0.0004
InTIFCV	C(15)	0.003308	0.002168	1.526045	0.1271
InCCV	C(29)	0.003162	0.000729	4.335113	0.000
InIEPV	C(43)	-0.004866	0.001938	-2.51135	0.0121
InIOFCV	C(57)	0.013077	0.005036	2.596854	0.0095
InIPPV	C(71)	0.00928	0.002723	3.408126	0.0007

The chapter six on input-oriented data envelopment model has been employed to measure the energy consumption productivity change over the reported period of 1999-2018 for 23 manufacturing sectors in India. Here Malmquist productivity index is used and presented in decomposed form: TEC & EPFS. TEC is employed to measure the technical change, and EPFS shows the shift in the efficient production frontier. Both TEC and EPF show the value of MPI. Hence the change of productivity is determined by change in technical efficiency and the shift of the EPF.

This chapter aims at measuring energy efficiency, estimates energy use efficiency in the Indian manufacturing industry. Energy efficiency is understood to mean using energy most cost-effectively to carry out the manufacturing process or provide a service, whereby wastage of energy is minimized. For the same, methods like Malmquist productivity index used, which is part of a Data Envelopment Model based on a Non-Parametric, Linear Programming Method of distance functions that are often employed to estimate the total factor productivity changes. Choosing the data envelopment model is that it does not require any prior assumption to perform. The MPI decomposes changes in technical efficiency and efficient production frontier shifts. Thus the DEA-based MPI is best suitable for measuring the productivity of energy consumption in the Indian manufacturing sector.

Suppose x and y are the input and output vectors, respectively. S^t (y) is the efficient production frontier. $\theta$is the ratio of input reduction for moving to the EPF. Hence the distance function can be defined as below:

$$D^t(x^t, y^t) = \max\{\theta \left| \frac{x^t}{\theta} \in S^t(y)\right.\} \qquad (1)$$

The MPIs in time period *t* can be defined as

$$\text{MPI}=\frac{D^t(x^{t+1},y^{t+1})}{D^t(x^t,y^t)} \qquad (2)$$

Where $D^t(x^t, y^t)$ is the distance function for measuring the distance from the position in the input and output space of the time period t to the EPF at time t. .$D^t(x^{t+1}, y^{t+1})$ is the distance function for measuring the distance from the position at time period t+1 to the EPF at time t.

The MPIs in time period *t+1* can be defined as:

$$\text{MPI}=\frac{D^{t+1}(x^{t+1},y^{t+1})}{D^{t+1}(x^{t},y^{t})} \quad (3)$$

Where $D^{t+1}(x^{t+1},y^{t+1})$ is the distance function for calculating the distance from the position in the input and output space at time period t+1 to the EPF at time t+1. $D^{t+1}(x^{t},y^{t})$ is the distance function for estimating the distance from the position at time period t to the EPF at time t+1.

Farrell(1989) denoted the Malmquist productivity index as

$$MPI_0=\left[\frac{D_0^t(x_0^t,y_0^t)}{D_0^t(x_0^{t+1},y_0^{t+1})}\frac{D_0^{t+1}(x_0^{t+1},y_0^t)}{D_0^{t+1}(x_0^{t+1},y_0^{t+1})}\right]1/2 \quad (4)$$

In this paper, the MPI can be used to estimate the change of energy consumption of different manufacturing units in India for the time period between t and t+1. If $\text{MPI}_0>1$, progress in efficiency ; If $\text{MPI}_0=1$, then efficiency remains constant, and efficiency decreases if $\text{MPI}_0<1$.

In order to find out reasons for MPI change, we follow Fare et al[2] and disaggregate the MPI into two components. Along with that we use the similar method to check efficiency change and technical change, namely;

$$\text{MPI}_0=\frac{D_0^t(x_0^t,y_0^t)}{D_0^{t+1}(x_0^{t+1},y_0^{t+1})}\left[\frac{D_0^{t+1}(x_0^{t+1},y_0^{t+1})}{D_0^t(x_0^{t+1},y_0^{t+1})}\frac{D_0^{t+1}(x_0^t,y_0^t)}{D_0^{t+1}(x_0^t,y_0^t)}\right]1/2 \quad (5)$$

Among the two components the first component calculates the degree of technical efficiency change (TEC) from the time period t and t+1, namely:

$$\text{TEC}_0=\frac{D_0^t(x_0^t,y_0^t)}{D_0^{t+1}(x_0^{t+1},y_0^{t+1})} \quad (6)$$

TEC estimates the catch-up effect, which indicates the energy consumption performance in the indicated period. Whereas the second component measures the efficiency production frontier shift (EPF) between the time period t and t+1 namely,

$$\text{EPFS}_0=\left[\frac{D_0^{t+1}(x_0^{t+1},y_0^{t+1})}{D_0^t(x_0^{t+1},y_0^{t+1})}\frac{D_0^{t+1}(x_0^t,y_0^t)}{D_0^{t+1}(x_0^t,y_0^t)}\right]1/2 \quad (7)$$

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[2]R. F¨are, S. Grosskopf, B. Lindgren, and P. Roos, "Productivitychanges in Swedish pharamacies 1980–1989: a non-parametric Malmquist approach," *Journal of Productivity Analysis*, vol. 3, no. 1-2, pp. 85–101, 1992.

EPFS calculates the frontier-shift effect, which shows the shift in the production technology of an industry. If $EPFS_0>1$, then it means a positive shift of EPF or technical progress. $EPFS_0<1$ indicates a negative shift of EPF or technical regression. If $EPFS_0= 1$, then the EPF is constant. As per the above theoretical background, MPI can be constructed as follows:

$MPI_0= TEC_0.EPFS_0$

The results suggest that there are ten manufacturing sectors, namely manufacturing of basic metal, beverages, manufacturing of furniture, leather related products, machinery and equipments, other non metallic mineral products, wearing apparels, wood and wood products, other manufacturing and printing and reproducing that experienced moderate effective energy consumption. It also suggests that these units lie very close to the efficiency frontier of energy consumption as benchmarks. About thirteen sectors out of twenty years of time period, for about ten to eleven different period of time experienced bottom performance, namely, chemical and chemical products, coke and refined petroleum products, computer and electronic optical products, Electrical equipments, fabricated Metal products except machinery and equipments, and manufacturing of food products. On one hand the value of changes of Malmquist Productivity Index in the negative side indicates that these above mentioned thirteen industries face a situation of increased energy consumption productivity throughout most of the reported time periods. On the other hand the positive value of changes in Malmquist Productivity Index shows that the ten most efficient DMUs face a situation of declining energy consumption of productivity for most of the reported years.

To conclude, ten decision making units, such as manufacturing of basic metal, beverages, manufacturing of furniture, leather related products, machinery and equipments, other non metallic mineral products, wearing apparels, wood and wood products, other manufacturing and printing and reproducing sectors have by and large increased productivity in most of the time periods, very specifically basic metal sector improved productivity 1999 to2001, 2002-2004, 2006-07, 2008-09, 2011-12, 2013-15 & 2017-18, beverages sector enhanced energy efficient productivity for the reference period 1999 to 2001, 2002-2004, 2006-07, 2008-09,2009-10 & 2011 to 2015, furniture sector saw positive productivity in the following time period 2000-01,2002 to 2005,2006-07, 2008 to 2012, 2013 to 2015 & 2017-18, leather related products in 2000-01,2002 to 2005,2006-07, 2008-09,2010-12, 2013-15 & 2017-18, machinery and equipments realized productivityin the time period of 2000-01,2002 to 2005, 2006-07, 2008-09, 2010 to 2012, 2013 to 2015 & 2017-18, that of non-metallic mineral products saw positive change in the productivity in the time period of 2002 to 2005, 2006-07,2008-09, a consistency of productivity improvement from 2010 to 2015, later in 2017-18, whereas manufacturing of wearing apparels maintained productivity in the following years 2001-02, a consistency of productivity improvement from 2003 to 2008, 2009 to 2012, 2013-14 & 2017-18, that of wood and wood products experienced productivity in the following years 2000 to 2002, 2004 to 2005, 2006 to 2008, 2013 to 2016 & 2017 to 2018, similarly other-manufacturing sector contained productivity improvement in these reported time periods 1999-2000, a constant energy enabled productivity growth from 2001 to 2005, 2007-08,2010 to 2012, 2013-14, 2015-16, & 2017-18, & finally the manufacturing of printing and reproduction witnessed maintaining productivity growth in the years such as 1999-2000, a consistent improvement from 2001 to 2005, 2007-08, 2010 to 2012, 2013-14. Further, the increase in the productivity of these ten sectors was caused by either positive in both EPF&TEC, or positive change in either of them. Hence to enhance and promote the improvement in the productivity of energy consumption of major industry sectors in India, it is necessary for the Indian government to make policies to strengthen industrial energy management, distinctively in those manufacturing sectors which consumes huge amount of energy inputs with low level of output and generation of gross industrial value added.

The seventh and final chapter draws the conclusion on the results of the above empirical investigation and proclaims policy recommendations in terms of energy use on Indian manufacturing sector as well as importance of energy on economic indicator of the country.

Input-oriented CRS efficiency of sectors from 1999-2018 $D_0^t(x_0^t, y_0^t)$																				
DMU	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
1	0.721	0.602	0.137	1	0.656	0.934	1	1	0.525	0.673	0.916	0.343	1.000	0.357	0.883	1.000	0.193	0.888	0.942	1.000
2	0.696	0.521	0.146	1.000	0.614	0.912	1	0.727	0.579	0.710	1.000	0.202	1.000	0.195	0.922	1.000	0.253	0.853	0.942	1.000
3	0.429	0.690	0.148	1.000	0.683	1.000	1	0.663	0.496	0.776	0.741	0.371	1.000	0.150	0.882	0.778	0.226	1.000	0.441	1.000
4	0.472	0.476	0.150	0.966	0.802	0.986	0.597	0.413	0.637	1.000	0.749	0.463	0.995	0.109	0.837	1.000	0.287	0.934	0.705	0.387
5	0.655	0.614	0.149	0.247	0.720	1.000	0.538	0.579	0.653	1.000	0.833	0.467	0.416	0.129	0.889	1.000	0.187	0.885	0.592	0.178
6	0.681	1.000	0.172	0.540	1.000	0.486	0.564	0.512	0.612	0.903	0.749	0.346	0.595	0.117	0.825	0.950	0.348	1.000	1.000	0.198
7	0.796	1.000	0.154	0.474	1.000	0.473	0.507	0.478	0.744	0.852	0.893	0.483	0.588	0.109	0.785	0.776	0.382	1.000	1.000	0.231
8	0.513	0.851	0.175	0.804	1.000	0.442	0.474	0.903	1.000	1.000	0.888	1.000	0.966	0.114	0.788	0.850	0.400	1.000	1.000	0.147
9	0.554	0.658	0.120	1.000	0.432	0.421	0.426	0.617	0.701	0.880	1.000	1.000	0.516	0.132	1.000	1.000	0.445	1.000	0.793	0.217
10	0.727	0.725	0.135	0.723	0.408	0.414	0.451	0.736	0.804	0.866	0.966	0.773	0.608	0.149	0.494	0.901	0.473	1.000	0.543	0.355
11	0.585	0.962	0.186	0.567	0.400	0.510	0.497	1.000	1.000	0.982	0.830	1.000	0.604	0.156	0.856	0.955	0.443	0.596	0.752	0.279
12	0.523	0.965	0.338	1.000	0.372	0.538	0.553	0.802	0.901	1.000	0.689	0.857	0.369	0.145	0.836	0.944	0.466	0.535	0.720	0.110
13	0.537	0.839	0.348	1.000	0.377	0.685	0.487	0.476	0.985	1.000	1.000	0.893	0.434	0.168	0.811	1.000	0.872	0.376	0.829	0.443
14	0.625	0.564	0.233	0.771	0.446	0.743	0.527	0.846	0.890	0.110	0.824	0.858	0.586	0.186	0.725	0.972	1.000	0.618	0.848	0.270
15	0.428	1.000	0.184	0.969	0.456	0.759	0.536	0.655	1.000	0.102	0.855	0.885	0.770	0.164	0.799	1.000	0.754	0.627	1.000	1.000
16	0.610	1.000	0.231	0.878	0.624	0.763	0.541	0.881	1.000	0.111	0.878	0.928	0.520	0.182	1.000	0.403	0.990	0.620	0.756	0.905
17	0.595	1.000	0.341	0.842	0.222	0.950	0.547	1.000	1.000	0.110	0.841	0.987	0.649	0.194	0.865	0.401	0.885	0.686	0.684	0.404
18	0.519	0.652	0.491	0.631	0.697	0.860	0.479	1.000	1.000	0.100	0.952	1.000	0.488	0.219	1.000	0.322	0.862	0.683	1.000	0.602
19	0.563	0.500	1.000	0.826	0.570	0.766	0.441	0.866	0.887	0.099	1.000	0.960	0.475	0.260	1.000	0.252	1.000	0.611	0.999	0.618
20	0.616	0.302	1.000	0.889	0.378	0.712	0.425	0.901	0.999	0.136	1.000	1.000	0.533	0.272	0.877	0.318	0.870	0.592	1.000	0.735
21	1.000	0.398	0.804	1.000	0.458	0.544	0.453	0.623	0.871	0.135	1.000	1.000	0.571	0.261	0.739	0.276	0.947	0.971	0.997	0.672
22	1.000	0.397	1.000	1.000	0.493	0.607	0.547	0.441	0.911	0.174	0.810	0.922	0.767	0.784	0.602	0.203	1.000	1.000	1.000	0.438
23	0.606	0.401	1.000	0.761	0.448	0.549	1.000	0.392	0.982	0.222	0.982	1.000	0.966	1.000	1.000	0.350	0.720	0.984	1.000	0.502

1. Manufacturing of Basic Metal, 2. Beverages, 3.Chemical and Chemical Products, 4.Coke and Refined Petroleum Products, 5.Computer and Electronic Optical products, 6.Electrical Equipments, 7.Fabricated Metal Products except Machinery and Equipments, 8. Manufacturing of Food Products, 9. Manufacturing of furniture, 10.Manufacturing of leather related products, 11. Manufacturing of machinery and equipments, 12. Other Non Metallic Mineral products, 13. Manufacturing of paper and paper products, 14.Phamachitical medical, chemical & botanical products, 15. Rubber plastic product, 16. Manufacturing of textiles, 17. Manufacturing of tobacco products, 18. Manufacturing of wearing apparels, 19. Manufacturing of wood and wood products, 20. Other manufacturing, 21.printing and reproduction of media, 22.Publishing Activities, 23.Crop animal production and Hunting related.

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