ABSTRACT

Energy serves as an input for all economic activity sectors. The need for energy has significantly increased as general economic activity including industrialization, electrification, rapid infrastructure construction, and human development. Despite having an abundance of coal and other renewable energy sources, the nation finds it hard to meet its energy needs fully. Therefore, it is still importing more than 25 percent. Indian industries are one of the top energy consumers in the world, contributing 29 percent of the nation's GDP. Since the second five-year plan, increased industrialization has resulted in high demand for energy, as India's industrial sector becomes increasingly competitive in the global economy, its energy consumption accounts for roughly 43.6 percent of total energy availability (Energy balance Statistics, 2020). This is largely due to a steady increase in investment in basic and energy-intensive industries, as a result of previous development plans' emphasis on achieving self-sufficiency, TERI (The Energy Research Institute, 2018). Heavy industries in India use more energy, such as iron and steel, aluminum, cement, fertiliser, refining, and pulp and paper (Bhattacharya and Copper 2010). Food processing, textiles, wood goods, printing and publishing, and metal processing are among the industries with the lowest final energy usage. At current prices, the first and second-mentioned industries contribute 29 percent of the GDP. Energy consumption per rupee of GDP earned is believed to have risen significantly, owing to more energy-intensive businesses. Simultaneously, there is a need to enhance efficiency to achieve much lower intensities. India pledged to cut its GDP's energy intensity by 20-25 percent by 2020, compared to 2005 levels (planning commission, 2011). In this environment, the situation warranted the detection of issues related to industry and energy use. It’s even more important to examine the industrial sector's energy consumption trends and the impact they have on industrial output. A couple of issues have been unlocked to anchor the research focus. Hence the following issues such as Quality coal production and supply stand key to fuel mix, Abundant low-quality coal and growing import for quality coal, Rapid urbanization, expanding middle class, rising income, improvement in the standard of living & high dependence on imports for its petroleum needs, increasing demand for gas, and geopolitical issues hampering gas supply, are identified.

As issues are many, and cannot contain all the issues under one study, only issues like industrial energy dependency, industrial energy sources, industrial energy intensities, and industrial value-added and their functional relationship has been unearthed with the suitable statistical investigation. The relationship has been studied for two decades i.e., from 2001-2021,

using data from the Annual survey of industries, Government of India. The study has targeted 23 different types of manufacturing industries 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 for 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.

The empirical investigation was expanded and discussed in seven different chapters. Chapter one is the introductory chapter which comprehends the understanding of the line of energy, intensity, and industrial gross value added and, their probable interlinked issues. Chapter two gathered thorough historical reviews on available literature both at national and international levels. The accounted reviews sufficed the study with the adequate idea bordering the research gap, determining the variables, and demarking the models pertaining to the objectives of the study. The third chapter mapped the energy scenario in India to supplement the present study, particularly with a focus on energy's economic implications on industry and, the economy as a whole. Moreover, the variables of investigative importance were tested for their statistical information for all the industries under the study. Chapter four has statistically explored the linkages between energy, labor, capital, and industrial value-added and their degree of elasticity through the applications of models such as fixed and random effect, trans-log production, and Allen elasticity of factor substitution. The fifth chapter went further to evaluate energy and output in a disaggregate manner through the modeling of Vector Error Correction. After having conceived the understanding of energy and industrial value-added in both aggregate and disaggregate manner the energy efficiency of these sectors was understood through the conduction of Malmquist Total Productivity analysis in the sixth chapter. The seventh chapter concludes the entire research in a summary form of chapterisation, main findings, suggestions, and, the contribution of the present study in the contemporary scenario and finally state the limitations of the present study.

The study on the Indian energy profile gave a vivid understanding of energy and related variables. It was found that energy had a nature of derived demand over the years. The driving elements were population growth, rapid industrialization, expansion of urbanization, positive

change in per-capita income, good standard of living, and habit of mass consumption. The Indian energy demand mostly came from three major fuels coal, oil, and solid biomass. Among them, coal had a lion's share in the energy mix. Coal demand nearly tripled between 2001 and 2021, responsible for 50 percent of primary energy demand growth. Since 2000 Indian energy demand accounts for about 10 percent of the world's energy demand. It is bound to increase energy demand further. About 74 percent of the required coal is produced in India, for the rest about 26.48 percent of its dependency was found on the external economy. Crude oil dependency is about 87 percent. Natural gas dependency is about 56 percent.

The observation revealed the co-existence of scarcity and abundance in the Indian energy system, notably i) India has the world's largest coal reserves yet it is the largest coal importer. ii) India has grown into the world hub for refineries yet it is the world's largest crude oil importer. iii) India's per capita energy consumption is below international standards yet it is the world's third largest CO_2 emitter. iv) Increasing coal-fueled economic growth yet reducing environmental quality. The absolute numbers on energy consumption seem to have increased although per-capita energy consumption is below the world average, due to the exponential growth of the population.

It was also found that not much change in sectoral dependency on a particular fuel. The industrial sector largely depended on coal, the transportation sector largely depended on oil, the building sector largely depended on electricity whereas agriculture heavily depended on the electricity sector. The final energy consumption in the industrial sector is the second largest, amounting to 36 to 40 percent.

Indian energy policy framework has been attempting to reduce the dependency on fossil fuels and moving towards non-fossil fuels like gas, biofuels, and renewable fuels. As a result, in the last one-decade, solar power installation expanded tremendously.

In the year of the low fuel price index, the usage of fuel increased drastically. This had a subsequent effect on the Industrial gross value added. The presence of such linkages validated the existence of the economic theory of the law of demand. Late in some years, it has been observed that with a lower or constant fuel price index the improvement in the gross value added was minimal. This warrants low capital expansion in that referred period.

The investigations revealed that by and large industries depended on electricity for their production. However, there are few coal-dependent industries such as non-metallic minerals (cement, chemical, etc.) and paper and paper products. The non-metallic mineral industry on average depends on 60 percent coal-based fueling whereas the paper and paper industry depended

on an average of 50 percent on coal energy. The Tobacco industry over recent years replaced oil with electricity. The textile industry for a few years avoided the usage of gas and oil, and instead increased the usage of electricity. The Rubber producing industries over the recent years reduced the consumption of oil and gas and instead increased the usage of electricity. Thus, it is noticeable that industries over the decades transformed their infrastructure to be compatible with electricity rather than other sources of energy input.

Based on the above scenario the statistical investigation of the industry and energy relation was conducted in two compartments, with two sets of variables using techniques such as fixed and random effect models, Trans-log production function, and Allen elasticity of factor substitution.

The investigation of eleven groups of manufacturing industries revealed that there is a positive relation between fuel consumption and gross industrial value- added and an inverse relationship between real energy price and fuel demanded. The results have been obtained by conducting various models. Such as the fixed & random models and Allen Partial Elasticity of Substitution, 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 the fixed effect model indicates that per unit increase in fuel consumption leads to increasing in Industrial gross value-added by 0.58814 at a 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 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 the industrial gross value-added. Hence, there has been a substantial influence of energy on industrial gross value added.

On the other hand, the energy demand model estimates reveal that the price elasticity of energy demand for manufacturing is about (-) 0.4. which means a one percent change in energy price will lead to a 0.4 percent decline in fuel demand in the manufacturing sector. However, that of the estimated trans-log production functions of the price elasticity of energy demand is found to be (-) 1.4. Similarly, here a one percent increase in the energy price will lead to a 1.4 percent reduction in fuel consumption over all for the reported eleven industries.

Based on the above empirical results, a vivid functional relationship between inputs and outputs of interest is understood clearly. It is identified that energy consumption and industrial gross value added are positively connected, a fall in the real price of energy leads to more energy demand, and energy plays an important role in the industrial output as an input.

Proceeding forward the inter linkages between energy inputs and industrial value-added for Indian industries at the aggregate and dis-aggregate levels conducted. The combination of the following series as Industrial Value Added and Total Fuel Consumption; Industrial Value Added and Industrial Coal Consumption; Industrial Value Added and Industrial Energy Consumption; Industrial Value Added and Industrial Other Fuel Consumption; Industrial Value Added and Industrial Petroleum Products; showed their long-run association. In long-run, the results of the Vector Error Correction Model showed that Industrial gross value added, Industrial Coal Consumption, and Industrial energy Consumption have cause-and-effect relationships among the variables 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.

Moreover, the short-run results of the Vector Error Correction Model showed short-run causality running from Gross Industrial Value Added to industrial fuel consumption, electricity consumption, and petroleum consumption, which meant expanding industrial production, and increasing the demand for energy inputs in the short-run. Moreover, the Granger Causality test reveals the direction of causality running from Gross Industrial Value Added to Total Industrial Fuel Consumption, Gross Industrial Value Added to Industrial Energy Consumption, Gross Industrial Value Added to Industrial Petroleum Products and Industrial Coal Consumption to Gross Industrial Value Added.

Hence the inference revealed that the Gross industrial value-added was delivered primarily through energy consumption. The industrial sector's energy intake remained as high as 50 percent of the total available commercial energy. Coal & electricity was used as critical component in industrial production both in the short run and long run. Energy-intensive manufacturing such as pulp & paper, basic chemicals, refining, iron & steel, nonferrous metals & nonmetallic mineral seems to be energy dependent for decades ahead.

Further energy efficiency measures through an input-oriented data envelopment model have been employed to measure the energy consumption productivity change over the reported period of 2001-2021 for 23 manufacturing sectors in India. Here the analysis based on the Malmquist productivity index was used and presented in the decomposed form: Technical Efficiency Change & Efficient Production Frontier Shift. Total Efficiency Change was employed to measure the technical change, and Efficient Production Frontier Shift was utilized to identify the shift in the efficient production frontier. Both Technical Efficiency Change and Efficient Production Frontier showed the value of Malmquist Productivity Index. Hence the change in

productivity was determined by the change in technical efficiency and the shift of the Efficient Production Frontier.

The findings indicated that eight manufacturing industries, including the production of basic metals, beverages, chemicals, and chemical products, as well as furniture, clothing, wood products, rubber and plastic, and printing and reproducing media, consumed energy effectively for at least more than six of the two decadal periods. Additionally, it implied that these units are quite close to the benchmarks for energy consumption's efficiency frontier. Coke and refined petroleum products, computer and electronic optical products, electrical equipment, fabricated metal items, and food product manufacturing all showed moderate energy efficiency.

Based on the empirical analysis and their results in different chapters, the following are the suggestions.

One of the observations revealed that increased energy consumption has been due to mass material consumption, leading to increased industrial production and, ultimately the energy demand. Therefore, to maintain an adequate amount of industrial output, a stable energy supply should be enhanced.

The research also indicated that the major source of energy is from coal and oil, hence industries both in the short run and long run should practice optimization of energy use, avoiding energy loss and storing energy. India also 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 a judicious energy conservation approach by the stakeholders involved.

The bi-directional causation between energy consumption and industrial gross value-added warrants that the Indian manufacturing sector should use energy efficiently and secure energy as it has a vital role in the production for the stabilization of industrial production.

The price elasticity of demand for energy reveals that a 1 percent rise in energy prices leading to a 1.4 percent fall in the demand for energy affects 0.58 percent of industrial gross value-added which mandates fuel price stabilization and, support throughout the production process to maintain sufficient manufacturing output. Moreover, the government should invest in the power sector or invite more competition into the power sector.

As, many industries are energy inefficient, using energy intensively, gaining energy efficiency should be imperative to account for a reduction in energy use. To optimize energy use as it is demanded more, industries should be encouraged to reuse or recycle material if it causes efficient use of energy. And apply the energy-saving technology in heavy industries such as Iron-steel and, light industries such as textiles, manufacturing, and food processing. Since Iron-steel accounts for major energy consumption, there must be substitutes for these products, for example, steel-use optimization in vehicles, buildings, and material efficiency.

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