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Estimation of energy efficiency in energy-intensive sectors: A cross-country analysis

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Abstract
Energy-intensive sectors (EISs) are responsible for a large share of global greenhouse gas emissions. Energy-intensive sectors included in this paper are Mining and Quarrying; Coke, Refined Petroleum, and Nuclear Fuel; Other Non-Metallic Minerals; Basic Metals and Fabricated Metal; Electricity, Gas, and Water Supply. The focus of the paper is on an econometric estimation of energy efficiency using some econometric approach. we seek to do cross-country comparisons, we include six industrialized and less environment-friendly nations (US, Japan, Russia, China, France, and India) in our paper. Our specification includes one desirable output, the gross output of industry, and one undesirable output, air emissions. Three major production factors included as inputs are: labor, capital, and energy use. Panel dataset of six countries over the period 1995 to 2009 is collected for our analysis. Our study has used Data Envelopment Analysis (DEA), a non-parametric approach (deterministic). Non-parametric Data Envelopment Analysis (DEA) is used to construct the efficient frontier and thereby compute total factor environment-adjusted energy efficiency instead of just a partial measure of efficiency. As per the expectations, it is found that output is positively related to emissions as emissions are also generated in the process of energy use in production.

Keywords: greenhouse gas emissions, data envelopment analysis, environmental pollution, energy efficiency

Introduction

Energy-intensive sectors (EISs) are responsible for a large share of global greenhouse gas emissions. Industries in these sectors convert natural resources into basic materials through processes that require high energy inputs. Energy-intensive sectors included in this paper are Mining and Quarrying; Coke, Refined Petroleum, and Nuclear Fuel; Other Non-Metallic Minerals; Basic Metals and Fabricated Metal; Electricity, Gas, and Water Supply. Globally, these sectors are majorly responsible for emissions that are harmful to an economy. Over the past decades, these sectors have made significant resource and energy efficiency improvements. However, with economic growth, increased production in these sectors is resulting in increased environmental pollution. And increased greenhouse emissions contribute to climate change, which can have serious consequences for humans and their environment. According to the U.S. Environmental Protection Agency, carbon emissions, in the form of carbon dioxide, make up more than 80 percent of the greenhouse gases emitted in the United States. The burning of fossil fuels releases carbon dioxide and other greenhouse gases. These carbon emissions raise global temperatures by trapping solar energy in the atmosphere. This alters water supplies and weather patterns, changes the growing season for food crops, and threatens coastal communities with increasing sea levels. Consequently, environmental accidents all over the country have also increased in recent years. Economic growth is the main factor deriving the energy demand, and environmental pollution not only comes from energy consumption but also from energy production, both of which can bring irrevocable negative impacts on nature. Therefore, the economy, energy, and environment form a complicated interdependent system.

Global energy-related CO_2 emissions grew by 1.4% in 2017, reaching a historic high of 32.5 gigatonnes (GT), a resumption of growth after three years of global emissions remaining flat. The increase in CO_2 emissions, however, was not universal. While most major economies saw a rise, others experienced a decline, including the United States, the United Kingdom, Mexico, and Japan. The biggest decline drop came from the United States, mainly because of the higher deployment of renewable. however, the economies that are highly contributing to environmental degradation include the major power of the world such as the US, Japan, Russia, China, France, and India. So, it becomes even more important for these nations to be responsible as well as aware of such problems and to use energy efficiently.

Several research has also indicated that these industries are responsible for a large share of global greenhouse gas emissions. To meet 2050 emission targets, an accelerated transition towards deep decarbonization is required in these industries. There were also some studies based on the analysis of energy efficiency and input trends in six energy-intensive sectors of the Indian economy, using growth accounting and econometric methods. Therefore, it is important to understand the econometric techniques or methods that can be used to compute energy efficiency. Some studies are also based on evaluating energy policy for energy-intensive manufacturing companies and its impact on energy efficiency improvements using a system dynamic approach. These studies indicated that energy management systems facilitate new energy metering and monitoring methods, which play a significant role to achieve energy savings. Therefore, to see the impact of energy policies it becomes significant to provide an evaluation of the policies that the nation has already implemented.

As we have mentioned above, the energy-intensive sector is majorly responsible for worldwide emissions of gases. In this regard, we seek to do cross-country comparisons, we include six industrialized and less environment-friendly nations (US, Japan, Russia, China, France, and India) in our paper.

The focus of the paper is on an econometric estimation of energy efficiency using some econometric approach. Based on this understanding, trends in energy efficiency and emissions (from the energy use in production) are analyzed over the period 1995 to 2009. In the later stage, cross-country differences in trends are examined in light of the comprehensive review of environmental policies. The next step involves setting up of regression framework to see the impact of emissions (from energy use) and air quality.

Literature Review

Most of the literature related to the measurement of energy efficiency has based its analysis either on parametric or non-parametric frontier methods. The choice of estimation method has been an issue of debate, with some researchers preferring the parametric and others the non-parametric approach. Luis R. Murillo-Zamorano (2004) attempted to provide a critical and detailed review of both core frontier methods. This paper and also in the various empirical studies seem to confirm that no approach is strictly preferable to any other, each of them has its advantages and disadvantages. Similarly, Massimo Filippini and Lester C. Hunt (2011) [4] estimated a panel "frontier" whole economy aggregate energy demand function for 29 countries over the period 1978 to 2006 using parametric stochastic frontier analysis (SFA). The framework adopted there isolated the "underlying energy efficiency" for each country after controlling for income, price, climate effects, technical progress, and other exogenous factors, as well as effects due to the difference in area size and the structure of the economy.

Various research has been done to compare energy productivity performance over time and across countries. In this regard, Enrica De Cian, M. Schymura, E. Verdolini, and S.Voigt (2013) analyzed energy intensity trends and drivers in 40 major economies using the WIOD database for the period 1995-2007. They attributed efficiency changes to either change in technology or changes in the structure of the economy and highlighted sectoral and regional differences. It was found that heterogeneity within each sector across countries is high. These general trends within the sectors are dominated by large economies. Regarding changes in energy intensity at the country level, improvements are largely attributable to technological change while structural change is less important in most countries.

An effective measure of energy efficiency should include interactions with environmental quality because a large number of emissions are generated as a result of production activity. Keeping this in mind, Nela V. Lenz, A. Segota, and D. Maradin (2018) measured total-factor energy efficiency in the EU which includes desirable (GDP) and undesirable outputs (greenhouse gas emissions).

Analysis of the relationship between economic development, energy consumption, and emissions is considered to be important for environmental planning on a national and international level. Several studies have focused on this issue and generally, the results obtained showed the existence of a positive relationship between these variables. Similar results were founded by Nanos S. and others, which tested the hypothesis that there is any statistical correlation between development (GDP) and energy consumption and also between development and carbon emissions (from the electricity and transportation sector). Unsurprisingly, the results validate the hypothesis, and these variables were found to be related positively. This result emphasized the fact that energy should be used judiciously to have sustainable growth. Similar findings were reported by J.L. Sullivan and others in which they presented a model (VMA) that calculates the environmental burden concerning the vehicles. They showed the alarming signals of vehicle emissions as they contribute immensely to the pollutants.

Howard Geller (2005) presented his experience with energy efficiency policies and programs in IEA countries. He viewed greater energy efficiency as a strategy for reducing carbon dioxide emissions and helping countries meet their Kyoto Protocol targets and analyzed the success and failure of various efficiency policies. The Paris agreement is considered to be a milestone that is being led by the 195 nations that gathered in Paris and discussed a new global agreement on Climate change aimed at reducing greenhouse gas emissions. A Paper published in the Journal for European Environmental and Planning law named "The Paris Agreement- A beginning" takes into account the global engagement of the nations that laid down various steps to be followed and policies to be implemented for the betterment of not just the present generation but also for the generation to be coming. There was also an overall Climate goal set up to channel the resources effectively.

Data Description

Our paper aims to assess energy efficiency in energy-intensive industries of major countries and compare these results with environmentally adjusted energy efficiency. Our specification includes one desirable output, the gross output of industry, and one undesirable output, air emissions. Three major production factors included as inputs are: labor, capital, and energy use. Panel dataset of six countries over the period 1995 to 2009 is collected for our analysis. Our measure combines three production factors as inputs and measures single-factor efficiency in a total-factor environment. This total-factor efficiency model is more realistic because it includes substitution effects between energy and other production factors.

The six countries included in our analysis are India, the US, Russia, China, France, and Japan. As we are majorly concerned with energy-intensive sectors, so we have considered the following five sectors: Mining and Quarrying; Coke, Refined Petroleum, and Nuclear Fuel; Other Non-Metallic Mineral; Basic Metals and Fabricated Metal; Electricity, Gas, and Water Supply. World Input-Output Database (WIOD) is used in our paper. In this multi-output model, the good output is 'gross output by industry at current basic prices (in national currency)'. Real fixed capital stock at 1995 prices is used as a proxy for capital input and the number of persons engaged in the industry as a labor input. Energy use in production consists of five main components: coal and lignite, petroleum, electricity (power), natural gas, and LPG. Each of them is measured in terajoules. Major pollutants into the air as a result of production activity include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), carbon monoxide (CO), and sulfur oxide (SO_x). Units of these emissions are tons except for CO_2 which is in kilotons. These five emissions are then combined into an appropriate index for 'air emissions' which is a measure of bad (or undesirable) output in our study.
Our research provides a comparison of energy efficiency estimates that do and do not incorporate environmental emissions. In this regard, non-parametric Data Envelopment Analysis (DEA) is used to construct the efficient frontier and thereby compute total factor environment-adjusted energy efficiency instead of just a partial measure of efficiency.
The mean values of industry output and energy use are reported in Figures 1 and 2 for different industries across the nations. The basic Metals and Fabricated Metal Industry, on average, witnessed the highest production relative to other reported industries. Almost in all industries, the average production in India is the highest among all six nations.

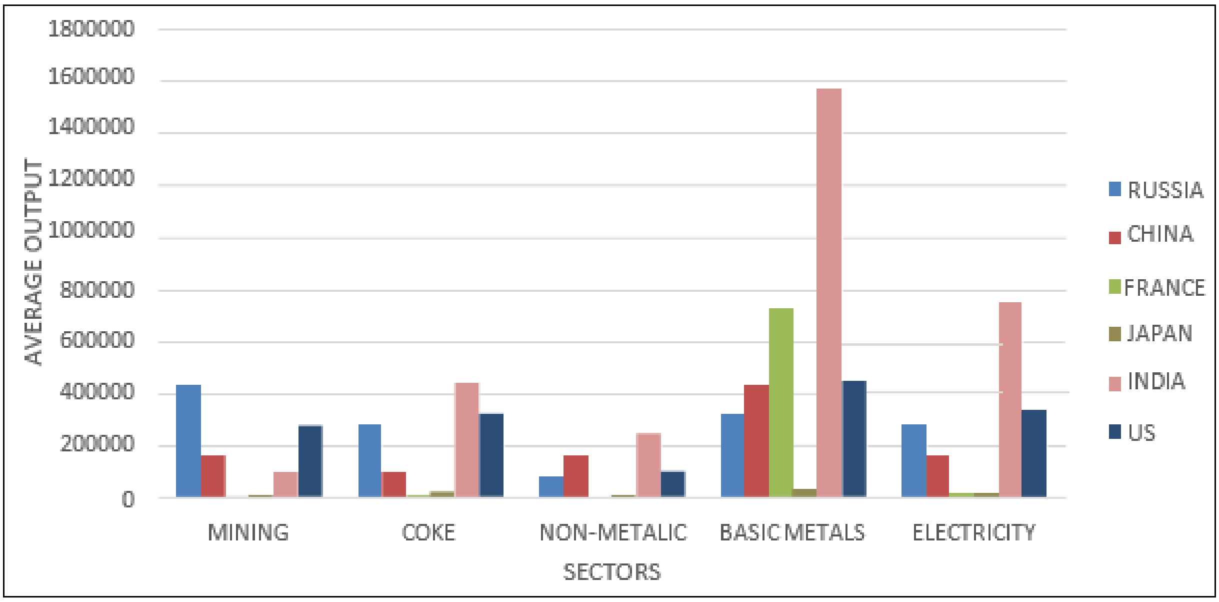

Fig 1: Average industry output across nations

Similarly, average energy use values are reported in Figure 2. We found that, relative to other industries, energy use is higher in the 'Coke, Refined Petroleum and Nuclear Fuel Industry' and 'Electricity, Gas and Water Supply Industry' while the 'Mining and Quarrying industry' witnessed the lowest energy use.

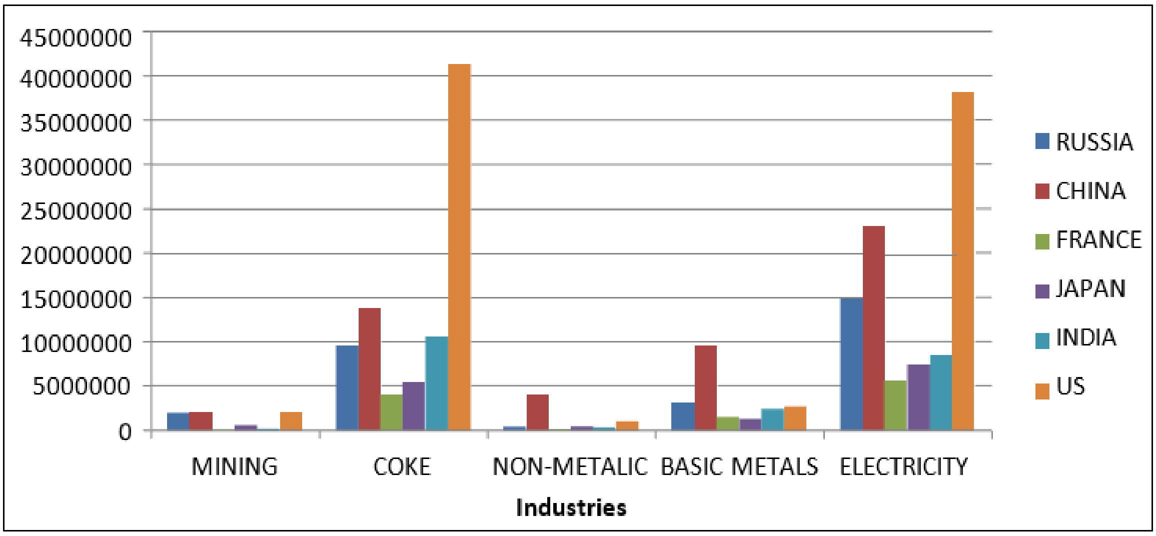

Fig 2

As we can see from Figure 3, air emissions in the 'Non-Metallic Mineral Industry' are the lowest of all the energy-intensive industries. This finding is consistent with the fact that energy use is much lower in this industry. It is shown that air emissions either increased or remained stagnant over the period of study.

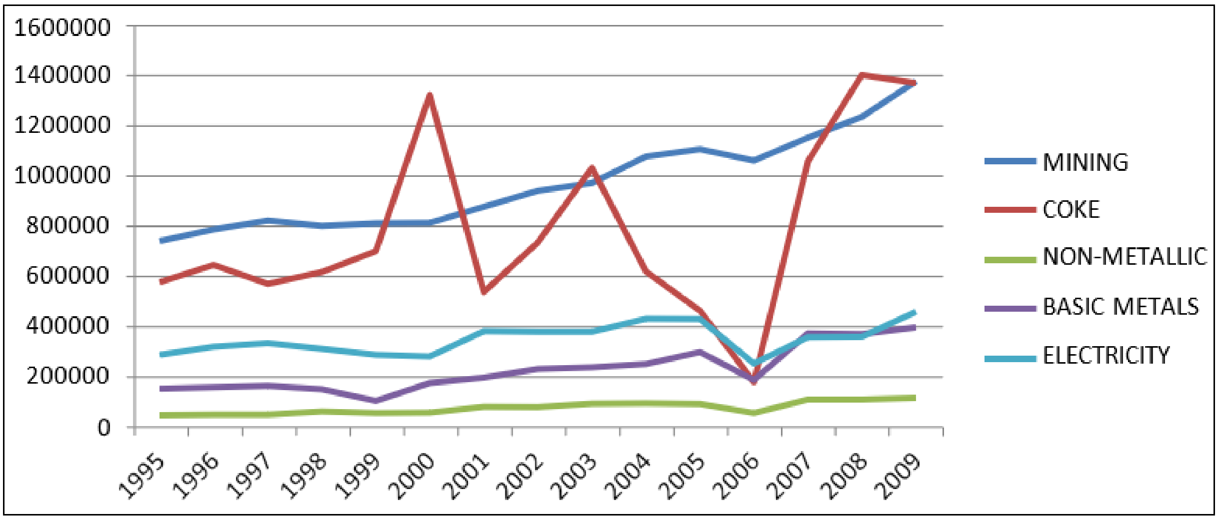

Fig 3: Air emissions in Indian energy-intensive industries over time

Methodology

Consider a production process involving n DMUs, j = 1... N, consuming m inputs x_{ij}, i = 1… m to produce s desirable outputs yrs, r = 1... S and k undesirable outputs bp, p = 1,..., k

The technology or production possibility set (P(x)), can be specified as:

$$P(x) = \{(y_{rj}, b_{pj}) \text{ where } x_{ij} \text{ can produce jointly } (y_{rj}, b_{pj})\}$$

There are two methods for the estimation of a frontier: a parametric and a nonparametric approach. These methods differ in the way the frontier is specified and estimated. Our study has used Data Envelopment Analysis (DEA), a non-parametric approach (deterministic). The Data Envelopment Analysis (DEA) technique measures the efficiency of a homogeneous set of DMUs in their use of multiple inputs to produce multiple outputs. The efficiency is estimated by comparison to other observed DMUs, and thus it is a relative measure. DEA uses a linear programming measure of efficiency for each DMU is then estimated relative to the frontier constructed.

The DEA method is based on the axiomatic approach. The standard DEA models rely on the main assumptions that inputs are minimized, and outputs are maximized along with some basic axioms that should be met.

The focus of the paper is to compare the energy efficiency of DMUs when emissions are not considered as one of the outcomes of the production process with the level of energy efficiency that we obtain after considering undesirable output.

We consider the production possibility set (PPS) characterized by inputs and undesirable outputs that are strongly disposable. As we have mentioned earlier, some various gases and particles contribute to air emissions. To take into account different emissions into the environment, we use an index of the total emissions. For the formation of the index, we regressed the total level of emissions to air on five major pollutants (i.e. CO_2, CH_4, N_2O, SO_X, CO) from which we can see the relative contribution of individual gas to the total emissions. After normalizing coefficients, depending on their magnitudes we assigned weights to the above-mentioned pollutants in the total emission index. This index is mentioned as 'air emissions' throughout the paper.

Analysis of Result

India

Direct energy efficiency that does not incorporate environmental pollution is overestimated in Mining and Quarrying Industry over the period of study. The contrasting results are obtained for the other two energy-intensive sectors; Coke, Refined Petroleum and Nuclear Fuel Industry and Electricity, Gas, and Water Supply Industry, where direct energy efficiency is lower than the environment-adjusted efficiency estimate. The striking feature in all the included sectors is that energy efficiency is declining over the years.

Japan

In the case of Japan, the results obtained are significantly different from other countries in consideration. In all the sectors, except electricity, the energy efficiency with environmental emissions is higher relative to without emissions. Also, the efficiency estimates have remained stagnant over the years.

United States
In the case of the US, there are significant differences between direct energy efficiency and environment-adjusted efficiency. In all the sectors, analogous to our expectations, energy efficiency that does not incorporate air emissions is relatively higher.

Russia
Analogous to our expectations, in all the sectors, except Coke, Refined Petroleum, and Nuclear Fuel Industry, energy efficiency without accounting for emissions is relatively higher than the efficiency estimate that accounts for emissions.

China
Energy efficiency that doesn't adjust for environmental emissions is overestimated in all the reported energy-intensive sectors of China. Both the efficiency estimates are almost equal in the initial years and thereafter they are significantly different from each other.

France
Direct energy efficiency is significantly higher than environment-corrected efficiency in all five sectors into consideration. The Mining and Quarrying Industry and Electricity Industry experienced an increase in efficiency over time, while other energy-intensive sectors witnessed a decline in efficiency. This result can be attributed to the catching-up effect and adoption of new technologies in these two sectors.

Conclusion
Non-parametric Data Envelopment Analysis (DEA) is used to construct the efficient frontier and thereby compute total factor environment-adjusted energy efficiency instead of just a partial measure of efficiency. As per the expectations, it is found that output is positively related to emissions as emissions are also generated in the process of energy use in production.
Our results confirm that most of the countries have higher efficiency scores when the model does not include air emissions. In all the countries, except Japan and India (in two sectors), direct energy efficiency is relatively higher in all the included sectors than it ought to be. Measurement of energy efficiency can be overestimated and misleading when it doesn't incorporate environmental (bad) impacts. A striking feature that is common to all the countries is that energy efficiency is declining over the period of study. Moreover, various policies are adopted by different nations in the direction of environmental protection and energy management. Varying degrees of implementation could explain the observed trend.
The obtained results have consequences in implementing measures for improving energy efficiency in light of the ongoing desire to reduce greenhouse gas emissions.

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