Energy Efficiency Analysis of Indian Iron and Steel Industry: An Economic Perspective

Thesis submitted during 2021 to the University of Hyderabad in partial fulfilment for the award of

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In

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by

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CERTIFICATE

This is to certify that the thesis entitled **"Energy Efficiency Analysis of Indian Iron and Steel Industry: An Economic Perspective"** submitted by **Salman Haider** bearing registration number 16SEPH23 in partial fulfilment of the requirements for the award of Doctor of Philosophy in the School of Economics is a bonafide work carried out by him under my supervision and guidance.

The thesis is free from plagiarism and has not been submitted previously in part or full to this or any other university or institution for award of any degree or diploma.

Further, the student has the following publications before submission of the thesis.

A) Published in

i) Benchmarking: An International Journal, Vol. 26, Issue: 04, 2019 ISSN: 1463-5771 (Chapter two of the Thesis).

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Further, the student has passed the following courses towards fulfilment of coursework requirement for Ph.D.

S. No.	Course Code	Course Title	Credits	Results
01	EC701	Advanced Economic Theory	4	Pass
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03	EC703	Research Methodology	4	Pass

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Signature of the Supervisor

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Dean, School of Economics

DECLARATION

I, **Salman Haider**, hereby declare that this thesis entitled, "**Energy Efficiency Analysis of Indian Iron and Steel Industry: An Economic Perspective**", submitted by me under the guidance and supervision of **Dr. Prajna Paramita Mishra** is a bonafide research work. I also declare that it has not been submitted previously in part or in full to this University or any other University or Institution for the award of any degree or diploma.

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Abbreviations

ASI	Annual Survey of Industries
BAT	Best Available Technology
BEE	Bureau of Energy Efficiency
BF	Blast Furnace
BOF	Basic Oxygen Furnace
BSFA	Bayesian Stochastic Frontier Analysis
CMC	Coal Moisture Control
CAC	Command and Control
CDM	Clean Development Mechanism
CDQ	Coke Dry Quenching
CER	Corporate Environmental Responsibility
CPCB	Central Pollution Control Board
CRS	Constant Return to Scale
COP	Conference of the Parties
CO_2	Carbon dioxide
CMIE	Centre for Monitoring Indian Economy
CSR	Corporate Social Responsibility
DEA	Data Envelopment Analysis
DMA	Disclosure on Management Approach
DMU	Decision Making Unit
DRI	Direct Reduced Iron
DCs	Designated Consumers
EAF	Electric Arc Furnace
EETs	Energy Efficient Technologies
EMS	Environmental Management System
EIA	Energy Information Administration
EIM	Energy-intensive manufacturing
ESCO	Energy Service Companies
GRI	Global Reporting Initiative
GBP	Global Best Practice
Gcal/t	Giga calories per Tonne
Gcal/tcs	Giga calories per Tonne of Crude Steel
GHG	Green-House Gas
GJ/tcs	Giga-joule per Tonne of Crude Steel
GMI	Group Managerial Inefficiency

GOI	Government Of India
GT	Gig Tonne
IDA	Index Decomposition Analysis
IEA	International Energy Agency
IED	Industrial Energy Demand
IF	Induction Furnace
ISO	International Organization for Standardization
ISP	Integrated Steel Plants
LSIP	Large-Scale Integrated Plant
m3	Cubic Meter
MEE	Meta-frontier Energy Efficiency
MOS	Ministry of Steel
MT	Million Tonnes
MSMEs	Micro, Small and Medium-sized Enterprises
MTOE	Million Tonne of Oil Equivalent
NOx	Oxide of Nitrogen
NAPCC	National Action Plan on Climate Change
NMEEE	National Mission for Enhanced Energy Efficiency
NCAP	National Clean Air Programme
NSP	National Steel Policy
PAT	Perform, Trade, and Achieve
PM	Particulate of Matter
PCI	Pulverized Coal Injection
R&D	Research & Development
RE	Renewable Energy
SAIL	Steel Authority of Indian Limited
SBM	Slack-Based Measure
SDG	Sustainable Development Goal
SEC	Specific Energy Consumption
SFA	Stochastic Frontier Analysis
SME	Small and Medium Enterprises
SOx	Oxide of Sulphur
SPM	Suspended Particulate Matter
TCS	Tonnes of Crude Steel
TERI	The Energy Research Institute
TFP	Total Factor Productivity

TGI	Technology Gap Inefficiency
TGR	Technological Gap Ratio
TRTG	Top Recovery Turbine Generator
tCO2 /tcs	Tonne of CO_2 per Tonnes of Crude Steel
UNFCC	United Nations Framework Convention on Climate Change
USD/GJ	U.S. Dollar per Giga Joule
VEP	Voluntary Environment Program
VRS	Variable Returns to Scale
WEO	World Economic Outlook
WDI	World Development Indicators
WHR	Waste Heat Recovery
ZLD	Zero Liquid Discharge

Chapter 1
Introduction

1.1: Global energy use, efficiency and achievement: An overview

Energy consumption is an essential element for enhancing the standard of living. It is strongly correlated with socio-economic indicators. Per capita energy use across countries show considerable differences that reflect the state of development and lifestyle. A higher standard of living demand more energy driven facilities. Lack of energy access indicates energy poverty and energy services deprivation. In the 21st century, energy for lighting and clean cooking fuel become inevitable for stepping up the living standard. It has become an inclusive agenda of goal 7 of sustainable development goals (SDGs) to provide universal access to electricity and clean cooking energy to alleviate energy poverty. Further, energy provides essential support to the industrial development of a country. The current use of exhaustive energy sources seems to reach an unprecedented level with its direct and indirect negative impact on the environment and society.

Energy consumption becomes inevitable for economic growth. Clean energy use occupies a vital position in the business and society because share of fossil-fuel cause massive greenhouse gas (GHG) emissions. Global energy-related carbon dioxide (CO_2) emissions increased to 33.1 giga tonne (GT), of which 30 per cent of emissions are contributed by the thermal power plant (Internation Energy Agency (IEA), 2018a). Hence, the energy transition from fossil-fuel to clean energy source is crucial for sustainable development. It will reduce the dependence on fossil-fuel and fulfil growing energy demand. Along with this, energy efficiency improvement is necessary to limit the growing energy demand. Therefore, government initiatives for the development and diffusion of clean technology are required[1]. There is relatively faster adoption of clean energy because of significant cost reduction and technological advancement in developed countries. Contrary to developed countries, developing countries lack in the race of clean energy and technology and remain as primary user of conventional energy (IPCC, 2018).

[1] Clean technology refers to a set of technological advancement that minimises negative environmental impacts through pollution control, energy efficiency improvements and sustainable use of resources.

Energy demand across the world grew by 2.3 per cent in 2018, natural gas registering the highest growth (World Energy Outlook (WEO), 2018). A significant share of growing energy demand is fulfiled from fossil-fuel sources. Renewable energy generation crossed double-digit growth but still inadequate to fulfil the overall additional electricity demand world wide. China, the United States and India are the primary sources of growth in energy demand. The energy mix in the global primary energy remained fairly constant. Coal, followed by oil and gas, has a significant energy source (WEO, 2018). Meagre changes in the energy mix have been seen towards natural gas and RE.

The recent increase in energy demand also contributed to climate change. European and other Asian countries are experiencing extreme weather conditions, leading to higher energy demand in the building sector (commercial or residential). Some recovery from economic slowdown during 2017 also boosted energy demand. Three major factors that drive energy demand are: activity effects indicated by economic growth, structural effects indicated by changes in the energy mix, technological advancement, structure of economic activities, and efficiency effects indicated by the level of utilisation of energy for producing output. Growth in energy demand is mostly attributed to activity effect as rise in scale of economy demands higher energy. Developing countries have experienced faster growth in energy demand due to the low initial energy use level and subsequent higher economic growth. It is a challenge to fulfil growing energy demand from clean energy source and become self-reliant.

Energy security is a crucial element for energy-related policymaking. It deals with efficient energy accessibility at an affordable price. Becoming self-reliant on energy supply is an important policy target for energy importing countries. Geopolitical tensions, fluctuations in energy prices make energy security vulnerable. Further, it also causes macroeconomic imbalances in energy importing countries. Hence, the development of RE source and energy-efficient technologies (EETs) cater a balances path for energy security and environmental protection, pragmatically. Among different clean technology, the adoption of EETs has vast energy saving potential across different sectors of the economy. As it provides positive financial returns, along with GHG emissions reduction. Adoption of EETs differ across sectors owing to the difference in energy requirement. Industrial sector demands huge amount of energy for its production process. Therefore, various EETs for industrial application has been developed.

Most Industrial production (cement, iron and steel, paper and pulp) relied on colossal energy consumption for different activities. Industrial sectors are taking energy services for process and assembly, steam and cogeneration, heating, cooling and lighting etc. Further, the mechanisation of production process necessitates an even higher volume of energy. It accounted for 37 per cent of total global final energy use in 2017 (IEA, 2019). Throughout 2010-17, Industrial energy demand in India has shown the most significant growth of 3.9 per cent annually, followed by China (WEO, 2018). Industrial emission has been categorised as direct and indirect emission as per sources. Emission from fossil-fuel combustion during the production process is labelled as direct emission while emission from electricity generation (purchased from outside) constitute indirect emission which is a significant source of emission and grows faster than direct emission (Hertwich & Wood, 2018). Therefore, there is significant increase in the electricity demand overtaking coal in industrial energy demand and owing to its diverse use (IEA, 2020a).

Energy requirement depends upon the nature of the industry, which can be categorised as (a) Energy-intensive manufacturing, (b). Non-energy-intensive manufacturing and (c). Non-manufacturing. Energy-intensive manufacturing demands almost half of industrial energy demand. It mainly includes food, pulp and paper, basic chemicals, refining, iron and steel, nonferrous metals, fertiliser and cement industry (IEA, 2019). Since developed countries follow stringent environmental regulations, it is gradually shifting to developing countries as it emits a large chunk of energy-related CO_2 emission. Energy demand is primarily driven by a long-term upward trend in the energy-intensive manufacturing. Hence its energy efficiency remain at the centre to improve economy-wide energy efficiency as it drive overall energy efficiency.

Traditionally, reduction in energy per unit of output (or increase in output per unit of energy) is considered as an improvement in energy efficiency (energy productivity). The output per unit of energy used has been increased globally from 126 USD/GJ to 144 USD/GJ (IEA, 2018a). The growth in energy efficiency has been varying vastly across countries. European and North American countries experience the highest growth. In contrast, China and India experience moderate growth, while African and Eurasian countries experience a slight decline in energy efficiency (Table 1.1). Highest improvement has been seen in developed countries (IEA, 2018a).

In the Asia Pacific region, China has a larger share in industrial energy efficiency investment which was 27 per cent of the global energy efficiency investment in the year 2017 (IEA, 2018a). In terms of sectors, the building and transport sector received 59 and 26 per cent of global energy efficiency investment, respectively. Industry sector investment fell by 8 per cent to USD 35 billion in 2017 (IEA, 2018b). Mandatory energy efficiency programme, innovative technology and waste energy recovery have enabled European and North American countries to experience the highest gain in energy efficiency. IEA (2019) emphasised on importance of energy efficiency gain by stating that "If no efficiency improvements had occurred, energy use would have increased by 65 per cent instead of one-third". Hence, several countries have started mandatory energy efficiency improvement programme and aim to achieve cost-effective GHG emission reduction.

Table 1.1: Energy productivity across world in USD/Giga Joule

Year	Global	Europe	North America	Central & South America	Africa	Middle East	Eurasia	China	India
2010	126.47	237.60	202.91	151.32	146.29	117.05	57.71	59.79	60.22
2014	134.98	256.38	249.71	166.41	147.38	110.27	62.59	72.35	62.87
2017	144.32	268.85	255.93	165.85	138.13	119.03	55.36	88.29	71.01

Source: IEA (2018a)

1.2: Overview of energy demand and policy in India

After economic reform of 1991, the Indian economy has been experiencing an exponential growth. It was triggered by the private sector and opening the domestic market. Particularly, rapid industrialisation drives the economy towards a higher level of resource utilisation. Lifting restriction on foreign investment enables huge investment into manufacturing and service sector. Hence, energy demand has been accelerated across different sectors of the economy. The mechanisation of agricultural production (motor pump, tractor and processing machine) pushed the demand for energy in the agricultural sector. Further, development of transport infrastructure and the surge in private vehicle leads to the enormous demand for fuel, particularly oil. India's oil demand rose by 5 per cent in 2018 against 2017 and it imports around 82 per cent of crude oil. (IEA, 2020b). It creates an obstacle in energy security of Indian economy and also churning huge amount of emission.

Per capita energy consumption in India is 0.6 tonnes of oil equivalent (TOE) which is relatively very low against the world average of 1.8 TOE. In the near future, energy demand may increase to reduce energy poverty. National Energy Policy (NEP) targeted to achieve 24x7 electricity across the country by 2022, which requires tremendous amount of energy. India improves on the front of grid-connected electricity access and moving in a desirable direction to align with SDGs. The trend of energy demand by sectors shows an increasing trend in each sector (Figure 1.1). It has been driven by industrial sector which has 42 per cent share in total primary energy consumption. While residential sector has the second largest share of 29 per cent followed by transport sector having 17 per cent share in total primary energy consumption.

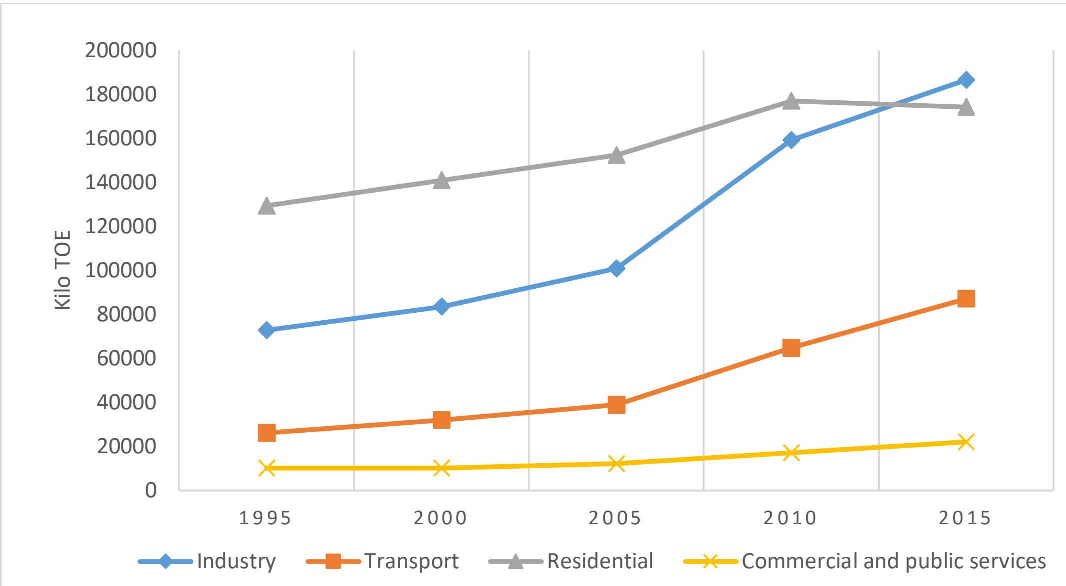

Figure 1.1: Primary Energy Consumption by sectors in India
Source: IEA (2020b)

Major part of energy demand is fulfilled by fossil fuel source of which coal contributes about 45 per cent followed by oil with 25 per cent share (Figure 1.2). Bioenergy and waste are the third largest source of total primary energy supply with 20 per cent share. Since coal and oil have relatively higher emission factor than natural gas, these sources need to be discouraged. Natural gas (cleanest among fossil-fuel) is only contributing to 6 per cent of total primary energy supply (IEA, 2020b). Though the supply of natural gas is limited, it has versatile use from domestic (cooking) to the manufacturing sector (fertilisers, industrial heat, and electricity generation). Both the energy- and emission- intensity of GDP have decreased by around 20 per cent during the last ten years (IEA, 2020b). Per capita CO_2 emission in India is around 1.6 tonnes and relatively low compared to the world average of 4.4 tonnes. It has a 6.4 per cent share in world CO_2 emissions (IEA, 2020b). Hence, India's absolute CO_2 emissions have profoundly impacted world emission and doubled since 2005 (IEA, 2020b). To mitigate GHG emissions, India has been implementing a set of climate change policies that is cost-effective and market-based. It has an ambitious target of 175 Giga Watt (GW) of renewable energy generation (IEA, 2020b).

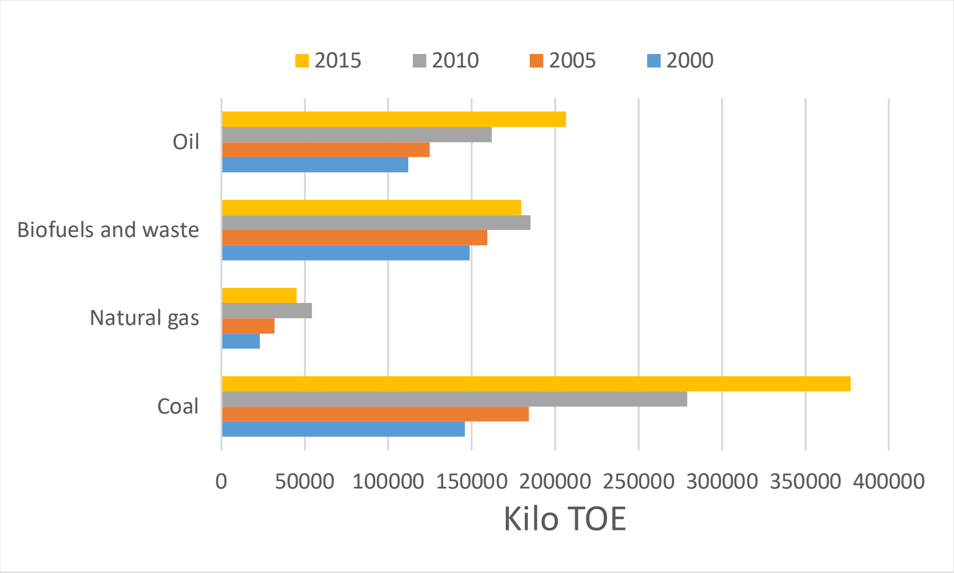

Figure 1.2: Energy Mix of TPE supply in India (2019)
Source: WEO (2019)

India is actively participating in international negotiation to formulate and implement the climate change action plan. It has committed to nationally determined contribution under the Paris agreement to reduce the emissions intensity of GDP by 30-35 per cent by the year 2030 (IEA, 2020b). In 2008, India implemented the National Action Plan on Climate Change (NAPCC) to reduce environmental impact and build a sustainable development model of the economy. The key objectives of NAPCC is to improve the stake of RE in electricity generation and extending carbon sink through increasing forest and tree cover (Figure 1.3). One crucial scheme under NAPCC is National Mission for Enhanced Energy Efficiency (NMEEE). It aims at enhancing energy efficiency across different sectors of the economy. Over the period of 2000-18, energy efficiency improvement offset 15 per cent of annual energy demand and 300 million tonnes (MT) of CO_2 emissions (IEA, 2020b). Government of India (GOI) effectively implemented large-scale deployment of LED bulbs and other efficient appliances through star rating[2]. It significantly reduces energy consumption from the residential and commercial building sector. It benefited the country by creating the market and job to produce LEDs bulb and spread awareness on energy efficiency.

Figure 1.3: Flow Chart of India Climate change policy
Source: IEA (2020b)

1.3: A brief overview of the Indian industrial energy use and efficiency

Indian industrial energy use has increased by 128 per cent since 2000 and has 42 per cent share in total final energy consumption in 2017 (IEA, 2020b)[3]. Coal and oil account for 36 and 23 per cent, while natural gas has 13 per cent share in industrial energy use and gradually increasing. Industrial units are still facing power shortage and uses in-house captive power generation. It has around 80 GW of installed power generation capacity of which 56 per cent is coal-based power generation (IEA, 2020b). Most captive power is used by large-scale firms that has a higher energy requirement. They faced with relatively higher electricity price due to cross-subsidisation to agricultural and residential sector. Government need to rationalise the electricity price and reduce its outage as it is one of major obstruct for conducting production activity (World Bank, 2020). It also reduces productivity and growth of the manufacturing sector as captive power generation is not relatively cost-efficient at small-scale (Abeberese,

[2] Star rating is issued by the Bureau of Energy Efficiency based on energy efficiency of appliances.
[3] It includes construction and non-energy process industries.

2017). There are some innovative measures like real-time monitoring and management of energy use with better understanding and optimisation of on-site energy use. It can facilitate reductions in energy use by on average of 10–20 per cent (IEA, 2020b). Large-scale firms have ability to adopt such measures to reduce their energy cost. While some policy measures have been taken for micro, small and medium-sized enterprises (MSMEs) as they have less technical and financial capacity.

Indian industrial sector operates with almost 63.4 MSMEs, which consumes 68 million tonnes of oil equivalent (MTOE) of energy per year (Bureau of Energy Efficiency (BEE), 2019). There is a big challenge to enhance energy efficiency of MSMEs which has around 200 energy-intensive clusters across the country (IEA, 2020b). It has a crucial role to supplement the operation of large-scale industry and fulfil local and customise demand. Metal casting and re-rolling are significant production activity operated by MSMEs of the energy-intensive sector. GOI initiated Zero Defect and Zero Effect programme to diffuse energy efficiency measures and awareness for best practices across MSMEs (IEA, 2020b). Further, financial assistance has been given in the form of partial risk guarantee, venture capital fund and low-interest rate. GOI has a good institutional set-up for implementing mandatory energy efficiency programme.

The Energy Conservation Act 2001 provides a legal framework for formulating an energy efficiency scheme and the BEE has been established under this act as a regulatory institution. Four different action plans are implemented under NMEEE (Figure 1.4). For energy-intensive firms, Perform, Achieve and Trade (PAT) scheme has been implemented as a mandatory energy efficiency improvement programme. It is a multi-phase and market-based programme launched in 2012. It aims to work akin to "cap and trade scheme" of emission trading but based on energy saving certificates to enhance cost-effectiveness.

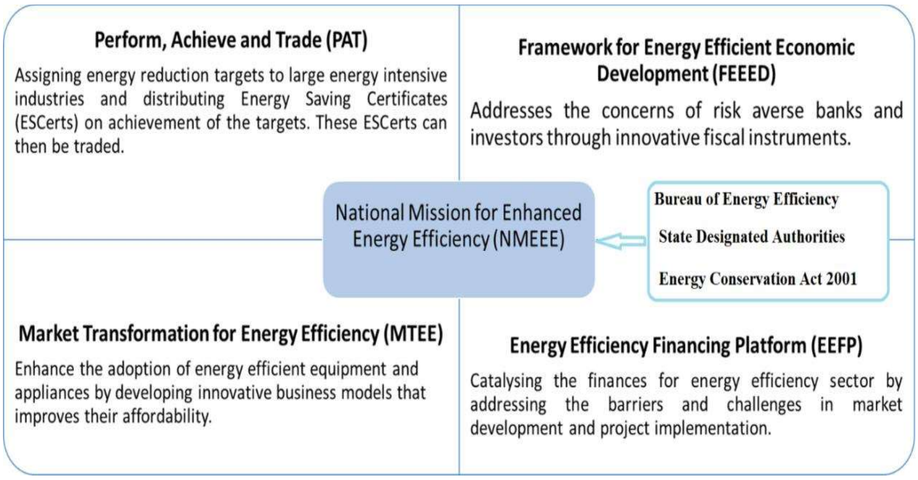

Figure 1.4: Industrial Energy Efficiency programme in India

Source: BEE (2020)

Indian firms are far from the world best practices in terms of energy efficiency level. Though investment in EETs is financially beneficial but still significant "energy efficiency gap" exist. It was argued that the presence of financial, technical and organisational barriers leads to underinvestment in EETs. PAT scheme aims to cater a transparent, flexible, and cost-effective mechanism to achieve higher energy efficiency. It considers the highest energy-consuming plant within each selected sector based on specific cut-off criteria of energy consumption[4] known as designated consumers (DCs). PAT cycle I has 478 DCs from eight energy-intensive industries over the year 2012-2015. It achieved the energy reduction of 6.68 MTOE[5] while the second phase (Cycle II) targeted energy saving of 8.869 MTOE (BEE, 2012). The second cycle included 143 additional DCs and extended its coverage to Refineries, Railways and DISCOMs sectors. Each DC is assigned a unique target to reduce its gate-to-gate specific energy consumption (SEC). Target reduction is based on baseline SEC and best performing plant's SEC. The baseline SEC has been subjected to revision in each cycle, and the target is expected to be more stringent. It obligated monitoring and verification of the claimed energy saving by the independent energy auditors. Therefore, a crucial role has been assigned to the auditors to precisely evaluate actual energy saving for issuing energy-saving certificate. The success of PAT scheme will be contingent on several factors, including enforcement strategy, administrative costs, expert & independent energy auditors and the functioning of the trading platform (Stern, 2008). Greater emphasis is required on commercialisation of EETs and addressing the technical difficulties to install prevailing advance energy saving equipment.

Energy management and advance conservation technique like waste heat recovery (WHR) have enormous energy-saving potential (IEA, 2019). Hence prevailing traditional technology needs to be replaced with modern technology. The government has also started demonstrating and promoting some such techniques while some large-scale firms are gradually adopting it. The energy saving needs to adopt at both supply-and demand-side. It is quite important to develop an efficient supply infrastructure. The electricity transmission and distribution losses are relatively high in India though some losses are inevitable ranges between 6 and 8 per cent. It was brought down from 30 per cent to 22 per cent over the last ten years. With technical management and smart grid, it can reduce it to the world average of 10 per cent or even to 7

[4] These industries are cement, iron and steel, chlor-alkali, aluminum, thermal power plants, pulp and paper, fertilizer and textiles.
[5] All sectors over achieved the target with overall about 30 per cent over achievement except thermal power plant which slightly missed the target.

per cent of the US (EIA, 2015). Japan has provided smart grid technology to enhance power distribution efficiency and minimise pilferage through proper monitoring. Approximately 10,000 smart meters for demonstration project has been completed in Panipat, Haryana (EIA, 2015). India needs to widely-adopt such technology that makes our economy energy efficient. Priority should be given to those areas where huge energy saving potential exists such as EIM sector. Among non-energy sector, iron and steel industry has considerable opportunities for energy saving.

1.4: A brief overview of the Indian Iron and steel industry

Industrial energy use in India is projected to increase rapidly driven by the EIM. Iron and steel industry is the backbone of economic development and contributes 2 per cent of Indian GDP (Firoz, 2014). The industry has experienced phenomenal growth of 8 per cent per annum after the economic reform of 1991. It has a current capacity of 120 MT and expects to produce 300 MT in the year 2030 (GOI, 2017). Ministry of Steel (MOS) aims to enhance per capita steel consumption which is currently one third of world average (224.5kg). It envisages to enhance steel-intensive infrastructure development and increase steel demand to 160 MT annually. It farmed policy to develop steel cluster with special focus on secondary steel and steel ancillary units[6]. Development of Eastern steel hub has been initiated, which has around 80 per cent of country's iron ore reserves and improved transport facility (GOI, 2020). Hence, the eastern region has huge growth potential for steel production. MOS framed policy to incentivise long-term investment through greenfield channel. It also promotes scrap steel recycling as it is cost-effective and requires less energy and raw material. There will be requirement of 50 MT of Scarp steel for secondary steel production based on the electric-route (GOI, 2020).

There is strong growth in electric-route of steel production. Currently electric arc furnace (EAF) and induction furnace (IF) has 25 and 30 per cent share in total crude steel production, respectively. Nevertheless, basic oxygen furnace (BOF) route dominate with around 45 per cent share and relatively higher energy intensity as it uses iron ore and coal. Average energy intensity of Indian iron and steel production is 6.9 Giga calories per tonne of crude steel (Gcal/tcs) against the world average of 4.5 Gcal/tcs (TERI, 2013). Hence, there is a huge potential for energy saving in the iron and steel industry. Though some fundamental barriers that confine the diffusion and adoption of EETs. There is a need for a pro-active energy

[6] A steel cluster is regional concentration of units for different process with ancillary and secondary steel units around the integrated steel plant or near the demand centre.

efficiency programme to minimise risk and transaction costs associated with investment in EETs. The government need to provide financial and technical support for cost-effective reduction of energy use.

Given the dominance of private sector, they should equally involve in adopting EETs for commercial purpose. It requires optimal incentive and regulatory mechanism to tap huge energy-saving potential. India has been the largest producer of coal-based direct reduced iron (DRI) and generates 2.7 tonnes of CO_2 per tonne of crude steel (TCS). While this route is inherently pollution-intensive, a large amount of char and un-burnt coal (225-461 kg char per TCS), dust and kiln accretion are churned out (CSE, 2012). It requires nearly $3.3m^3$ of water for one TCS and caution on surface water availability (CSE, 2012). It requires long-term investment in clean technology, which can be manage through long term favourable finance. It may also reduce energy cost substantially and provide clean environment. Since Cooking and non-cooking coal is the major energy input in BOF route it is imperative to use coal and its by-product efficiently.

BOF route of steel making is dominated across the world with around 70 per cent share in crude steel production (WSA, 2021) This route churns out vast amount of waste gases and energy which can be recover and re-use (IEA, 2018b). The iron and steel industry needs to adopt circular economy framework to recycle its off-gas and heat. There is some recent advancement like Coke Dry Quenching (CDQ) and Pulverised coal injection (PCI) that enable to use coal efficiently in a blast furnace. CDQ is used to improve the quality of coke which decreases the coke consumption in the blast furnace by about 2 per cent (International Energy Agency, 2007). Top Recovery Turbine Generator and Coal Moisture Control can also applied to enhance energy efficiency. It requires long-term investment for integrated steel plant which can be promoted through tax concession policy. Developing countries firms lack technical know-how and other constraint so unable to tap vast energy saving potential through these technology.

1.5: Problem Statement

There is an extensive literature on energy efficiency analysis in the case of developed countries as they have more stringent environmental law and energy efficiency scheme. Little attention has been paid to developing one. Developing countries face relatively more significant barriers (financial and organisational), which obstruct firms to achieve full energy efficiency. India, being a developing country, require more energy for growing population and infrastructure. Hence, for sustainable development, it requires RE sources and efficient utilisation of resources. Energy efficiency is one of the cost-effective options to cope up with issues like energy security, energy conservation and global warming. A smaller number of studies examine the issues of energy efficiency in the case of Indian manufacturing sector. While among manufacturing, iron and steel industry is highly energy intensive industry. Hence an extensive research is required for energy and environmental performance analysis from an economic point of view. However, some studies have analysed energy intensity through decomposition or trend analysis. The underlying energy efficiency may differ from energy intensity which needs to be estimated with appropriate statistical tools. Tracking energy efficiency performance over time is quite pertinent in a dynamic world. Therefore, there is a need to undertake a comprehensive study to evaluate the energy efficiency performance of the India iron and steel industry and benchmark its performance in term of relative efficiency.

There is a growing concern about the regional performance of the industry as performance may be contingent upon some region-specific business environment and state-level policies. So, it may lead to regional differences in energy efficiency and technological gap across the states in India. Hence, it should be considered from regional policy planning and coordination on energy policy. Further, there are different channels of technological innovation that can improve energy efficiency as technological up-gradation improve overall production process as well as induce different energy conservation measures. The study provides policy implication for taping energy saving potential and enable better energy efficiency level from an economic point of view. Overall, this study comprehensively analyses the potential to enhance energy efficiency (at state- and firm-level) and reveal the underlying root-cause of different energy and environmental performance outcome. It shed insights to improve energy efficiency and comprehends the pragmatic measures. This will assist policymakers and corporate managers of energy-intensive industry (like iron and steel) in analysing different energy conservation measures to adopt.

Several sector-specific factors cause non-comparability of energy efficiency of different sectors. This study has chosen the iron and steel sector industry due to the energy-intensive nature of the industry. The industry has been recognised as highly polluting industries in the country. In the production of one TCS, 3.5 to 5.0 tonnes of raw material is required. Therefore, monitoring the energy efficiency performance can provide valuable inputs for evaluating the efficacy of energy efficiency programme. It helps to reduce fossil-fuel consumption also as a way to achieve sustainable development through cost-effective methods.

1.6: Objectives and Hypotheses of the Study

The main aim of the thesis is to quantify the energy efficiency level across states and firms with benchmarking tools of economics. It tries to estimate the energy-saving potential in the iron and steel industry. Further, the thesis explored the potential drivers of energy efficiency like technological and managerial factors.

The specific objectives of the study are as follows:

1. To quantify the technical and energy efficiency performance of the iron and steel industry at the state level.

2. To quantify the technological and managerial gap in the energy efficiency of the iron and steel industry in India across different regions.

3. To find out the potential driving factors of adoption of environmental management system (EMS) and assess indicators of energy and environmental performance.

4. To quantify energy efficiency at firm-level and investigate the role of innovative capability on energy efficiency performance.

Based on the above objectives, the following hypothesis is formulated:

(i) There is considerable potential for energy efficiency improvement.

(ii) There is substantial technological gap across states and firms.

(iii) There is a positive association between firms' resources and EMS.

(iv) Technological and innovation activities enhance firms' energy efficiency.

1.7: Data and Methodology

The thesis follows the National Industrial Classification at three-digit level (iron and steel) to source data from the *Annual Survey of Industries* (ASI). State-level ASI data has been extracted consolidated from EPW Research Foundation, while plant-level ASI data has been taken from ICSSR Data Service. Firm-level data has been taken from the *Prowess Database* of the Centre for Monitoring Indian Economy (CMIE). It provides data from the annual balance sheet of registered companies. Further sustainability reports of the companies have been taken from the Global Reporting Initiative (GRI). It is used to do a comparative analysis of the energy and environmental performance of the Indian iron and steel industry in greater details.

The thesis mainly considers data envelopment analysis (DEA) to estimate energy efficiency at state-level and firm-level. It is widely applied in performance evaluation in various situation. It allows greater flexibility in examining energy efficiency and technological gap. It examines the potential factors that influence decision to adopt an EMS through logistic regression. Further, a Bayesian Stochastic frontier analysis has been conducted to examine firm-level energy efficiency. It aims to tackle the firm-level heterogeneity through random coefficient model. Later a truncated regression analysis has been done to analyse the potential driver of energy efficiency.

1.8: Scope of the Study

The thesis considers state-level and firm-level variation in energy efficiency based on the aggregate production function approach. It departed from the conventional approach of energy-intensity (energy-output ratio) to total factor productivity framework. It has used underlying productivity and efficiency that is important for energy policymaking at management and regional level. The best practice approach has been adopted in this study and advocates a pragmatic approach to proceed towards energy efficiency improvement. It applied stochastic frontier and data envelopment analysis to estimate production frontier to consider factors at the managerial level. It is able to capture production-level heterogeneous in terms of resources and capabilities. Scope for various technological improvement has been explored for a smooth transition towards better energy efficiency. Four indicators (Research & Development activity, patenting activity, embodied and disembodied technology) have been considered. Further, this study provides an understanding of the decision factors to adopt an EMS. ISO 14001 has the potential to enhance energy and environmental efficiency. Therefore, it examines whether EMS offer an effective measure to tap energy saving potential. The study has adopted a statistical approach where factors beyond control are taken into account and focused on relative efficiency. It can be viewed as the energy efficiency gap from best performing states or firms.

Sustainability report analysis of four top Indian iron and steel companies and a foreign company (Posco steel) have revealed some crucial performance parameter and policies.

1.9: Chapter Scheme

The thesis has been organised into six chapters. First chapter provides a broad introductory remark on global energy demand, energy intensity and development of international negotiations. An overview of India's energy demand and supply, energy efficiency policy and a summary of Indian iron and steel industry are presented. It also includes research issues, objectives and scope of the study. In chapter two, state-level energy efficiency analysis is discussed. Chapter three explores firm-level energy efficiency and technological gap in energy efficiency across regions. Chapter four examines the potential driver of EMS adoption and presents a comparative analysis of top Indian iron and steel companies' energy and environmental indicators. In chapter five, the effect of different channel of innovation and EMS adoption on firm-level energy efficiency are estimated. The last chapter provides a summary of the thesis, policy implications and limitations of the study.

Chapter 2

Energy use Efficiency of Iron and Steel industry: A Regional Perspective

2.1: Introduction

The environmental impacts of the industrial sector have become an increasingly important topic of public debate. World industry accounts for 28 per cent of global energy demand and contributes about 21 per cent of the global greenhouse gas emissions (GHG) (International Energy Agency, 2019)[7]. Technological advancement enables to improve energy utilisation and conservation and delivers impressive impact on energy-related GHG emission. Industrial sector requires huge amount of energy for processing raw material and producing better quality end-use product. Particularly, basic industries like iron and steel, cement, paper, textile and chemical industry, are major contributors of global industrial energy demand. Iron and steel, one of the most energy-intensive industrial sub-sectors, contributes about 7 to 9 per cent of total anthropogenic CO_2 emissions (World Steel Association (WSA), 2020). The role of energy in the economic growth came into picture after the oil price shocks of 1970s and later recognised as a major factor contributing to climate change. The energy intensity of the industrial sector has steadily declined in most countries since the oil price shocks of the 1970s (Dasgupta and Roy, 2016). A wide range of technologies can reduce GHG emissions, of which energy efficiency is one of the most cost-effective ways to achieve it.

Two different definitions of energy efficiency are found in the literature. First, according to the engineering point of view which measure the lowest possible energy consumption through theoretical thermodynamic law. Second, from an economic point of view, which measures energy efficiency from real-world best practice, through benchmarking with the current level of technology. It is challenging to realize the whole energy efficiency measured from an engineering perspective due to factors beyond the control. There are some barriers which cause non-realization of full benefit from energy-efficient technologies (EETs). Although energy-efficient technology outweighs the cost associated with it, presence of economic and organizational barriers result in "energy efficiency gap" (Hochman and Timilsina, 2017).

[7] Industrial sector includes all manufacturing other than electricity and heat generating sector.

Therefore, an economic analysis of energy use efficiency and energy-saving potential can help to quantify the magnitude of barriers.

Globalization and international competitiveness have directed the emerging economies to adopt an efficient production system, including energy efficiency. More importantly, the growing energy demand has resulted in voluminous quantities of environmental hazards and thereby questioned the sustainability of the ecological and environmental system. Besides, increased energy consumption has also resulted in national energy security concerns. With the issues of energy accessibility, high energy prices, global warming and environmental sustainability, economies both individually and in collaboration are exercising some market-oriented and regulatory mechanism to improve their energy efficiency level as one of the cost-effective options. Energy demand has increased more than double during the last decade and proved an important imputes for the growth of the economy. But the story has some other side, where people are facing the major challenge of climate change and global warming.

Most of the crude steel/steel produced in India is by Integrated Steel Plants (ISP) using Direct Reducing Iron (DRI) – Electric Arc Furnace (EAF) process. Most industrial processes use at least 50 per cent more than the theoretical minimum energy requirement determined by the laws of thermodynamics, suggesting a large potential for energy-efficiency improvement and GHG emission mitigation (IEA, 2006). Iron and steel industry in India are covered under the Environment Protection Act as well as Environment Protection Rules & Regulations enacted by the Ministry of Environment, Forest and Climate Change. They are monitored by Central/State Pollution Control Boards. The above facts depict the importance of Indian iron and steel industry for the GHG mitigation concern and environmental management. This sector is also essential for infrastructural development and future growth of the economy. Indian iron and steel firms also lack in terms of energy efficiency like other developing countries. So, it is a critical factor for improvement in the overall industry performance.

To enhance the energy efficiency, the government of India (GOI) has enacted the Energy Conservation Act 2002 and established the Bureau of Energy Efficiency (hereafter BEE). Different industrial energy efficiency schemes were devised to gain efficiency in energy consumption. Against this backdrop, this chapter examines the energy efficiency performance of Indian iron and steel industry. It has analysed whether energy efficiency has increased over time and if there is any scope for improvement in energy efficiency. This will help in designing a better industrial energy efficiency program. Particularly at the regional level, it will help energy-inefficient states to imitate energy-efficient states. State-government policies also play a crucial role in steering firms to adopt eco-friendly operation, as they are the actual regulatory body at ground level.

Rest of the chapter is arranged as follow. Section 2.2 documents related literature review. Section 2.3 provides methods and data used in this chapter while results and discussion is presented in section 2.4. Finally, section 2.5 concludes the chapter.

2.2: Literature Review

The literature on energy efficiency analysis can be broadly classified into two parts. First, literature based on partial factor framework (takes only energy consumption into account) while second, literature based on production frontier or total factor productivity (TFP). Energy use changes decomposition literature has analyzed the contribution of scale, intensity and structural effect (Paul and Bhattacharya, 2004; Das and Paul, 2014; Xu et al., 2014; Tandon and Ahmad, 2016). These scholars have mainly applied the structural and the index decomposition analysis (IDA)[8] to estimate the effect of these changes on energy or carbon emission changes over time. IDA does not consider other factors of production and lack a comprehensive analysis of energy efficiency. Countries like New Zealand, Canada, and United States have applied the IDA technique to track the energy use trend over the period of time.

Second classification based on TFP uses the concepts of the production function. There are two main approach to estimates production frontier, first is data envelopment analysis (DEA) while second is stochastic frontier analysis (SFA). DEA is a flexible and non-parametric approach easily modified to apply in energy and environment across various energy-consuming units in an economy or across the economies. It is a widely applied benchmarking technique for assessing relative performance in the energy use at sectoral or economy level and quantifying energy saving potential with current technology (Hu and Wang, 2006; Mukherjee, 2008; Zhang et al, 2011).

DEA is a popular technique for a comparative analysis of energy efficiency and policy designing. Recently DEA has been applied in characterizing different production system and energy use performance. Mardani et al. (2017) applied the DEA methodology for the energy

[8] A detailed account of IDA has been provided in Ang and Zhang (2000).

efficiency where the feasibility of the production function is either virtually absent or very hard to frame. Applying a slacks-based measure (SBM) of DEA, Chen and Jia (2017) found that except certain developed regions, the environmental efficiency of China’s industry is low, varied across regions and not showing any signs of improvement over the study period 2008-2012. Li and Tao (2017) provided an illustrious review of various methodologies and policies used in energy efficiency performance of high energy-consuming industries. Moon and Min (2017) pointed out the sensitivity of overall energy efficiency to the pure energy efficiency of the manufacturing firms in Korea. Zhu et al. (2017) highlighted the better performance of natural resource utilization in mainland China at the cost of substantial natural resource consumption. Liu and Lin (2018) documented the evidence of ladder-like distribution of energy efficiency of the inter-provincial China's transport sector, with eastern region found to be more efficient followed by central and western regions.

On the contrary, SFA is a purely statistical method used to estimate efficiency frontier. SFA is a parametric approach to efficiency analysis that imposes a parametric form of the production function. Feijoo et al. (2002) employed a Cobb-Douglas SFA model to examine the energy efficiency of the Spanish industry. Buck and Young (2007) conducted a cross-sectional energy efficiency analysis of Canadian commercial buildings applying SFA. Boyd (2008) suggested the use of SFA technique to examine plant-level energy use efficiency. Recently Zhou et al. (2012) have employed the parametric frontier approach to measure the economy-wide energy efficiency position in case of a sample of OECD countries. Lin et al. (2011) evaluated China’s steel industry energy efficiency with that of Japan as a baseline, found that more than 200 million tonnes of coal equivalent energy saving and it would be able to become fully energy efficient in 2020. Lin and Moubarak (2014) estimated the energy-saving potential in China’s paper industry and found energy price, industry structure, profit margin and technology affecting the energy intensity negatively. Kong et al. (2013) described the role of energy audit and found 967.8 tera joules of energy-saving potential from nine energy-saving opportunities.

The energy and environmental efficiency of other industry have also been analysed in the literature like in transport and gas industry (Goncharuk, 2008, 2009). Castro and Frazzon (2017) reviewing the benchmarking of best practices classify academic literature into DEA and non-DEA studies. They found that DEA is more flexible and accommodate different situation. Apart from energy and environmental performance DEA has been applied in estimating technical efficiency and productivity of different service providing industry like telecom operators, banking services and integrated water management (Gilsa et al., 2017). DEA can also be applied in cost and allocative efficiency analysis (Sarkar, 2017).

Though India is facing the problem of energy security, energy efficiency evaluation has not been conducted very exhaustively. Some earlier studies like Srivastava (1997), Nag and Parikh (2000) and Bhattacharya and Paul (2001) analyzed the energy and carbon emissions trend and its deriving factor. Schumacher et al. (1999) made an experimental appraisal of India's paper industry in terms of productivity and energy efficiency for the period 1973-74 to 1993-94. Mukherjee (2008) made use of DEA technique for an interstate analysis of energy efficiency of the aggregate manufacturing sector. The study further found a passive role of relative energy prices in improving the efficiency standards and poor execution of power sector reforms does not result in improvement in energy efficiency.

Gielen and Taylor (2008) found that the industrial sector is heterogeneous as far as efficiency standards is concerned. Low carbon growth can be achieved through improved energy efficiency as there is complementarity between energy efficiency and low carbon growth measures. Mandal and Madheswaran (2011) analyzed the energy efficiency of Indian cement industry by applying DEA and reported the existence of a considerable potential for energy saving, varying across the firms. Sahu and Narayanan (2013) evaluated the nature of the relationship between labour and energy intensity in case of paper industry of Indian manufacturing. Using the unit level data, the authors documented an inverted U shaped relationship between the two, implying the substitutability between these two-factor inputs. Dasgupta and Roy (2016) examined the energy intensity trends in case of seven highly energy-intensive industries and aggregate manufacturing in India. They found that energy demand is dominantly augmented by activity growth. Reddy and Ray (2011) have analysed energy intensity of five energy-intensive sectors of India. They found that energy intensity of iron and steel industry is decreasing from 5.17 per cent by alloy steel to almost 60 per cent by ferroalloys over the period of 1991–2005 but remain higher as compared to developed countries. In the Indian context, a smaller number of studies are found that have systematically analyzed the energy efficiency level of industrial sector.

Studies that analyzed the energy efficiency of the aggregate manufacturing sector may suffer from aggregation bias as energy consumption differ significantly across industries. At the same time, some studies analyzed energy efficiency of specific industry like paper and cement industry. Further, most of the studies are based on partial factor framework that takes only energy output ratio as an indicator of energy efficiency. These studies lack to capture underlying energy efficiency while not considering input substitution (Mukherjee, 2010). To overcome the above limitations, this study analyzes the energy efficiency of the iron and steel industry, which is one of the most energy-intensive industry. So far no study has conducted the energy efficiency analysis of Indian iron and steel industry taking the production theoretic approach.

Contrary to other studies, a panel of 19 major states of India is used over the period from 2004-05 to 2013-14. A total-factor productivity framework is employed that takes factor substitution and production frontier into account. It measures relative technical and energy efficiency through a benchmarking technique that is data envelopment analysis (DEA). Four input factors of production and a single output (desirable output) is taken into account. The data has been consolidated from the Annual Survey of Industries (ASI). In the absence of data of undesirable output (mainly carbon emission from energy consumption), focus is on energy use as that also has implication for environmental quality. Data of carbon emission is derived from energy input and minimization of energy consumption leads to a reduction in carbon emission. Therefore, one can get a reliable energy efficiency score in the absence of undesirable output data that ultimately reduces carbon emission SBM of DEA advanced by Tone (2010) is employed to get a comprehensive measure of energy efficiency along with radial measure of efficiency at regional level.

2.3: Methodology and Data

In the non-parametric approach, Charnes, Cooper & Rhodes (1978) were first to proposed DEA method to evaluate the efficiency of decision-making units (DMUs). It assumes an input orientation and constant returns to scale and called as CCR model. In this model, technical efficiency is obtained as the ratio of *minimum* (optimal) achievable input bundle to the actual input bundle in an input-oriented measure of efficiency[9]. Subsequently, Banker, Charnes, & Cooper (1984) developed an efficiency measure based on variable returns to scale (VRS) called as BCC model. This method is actually based on linear programming which creates a piecewise linear best practice frontier based on the observed input-output data. Based on above two models, various modification and refinement have been made and different version of DEA appeared in the literature.

[9]Technical efficiency can also be measured upon an output orientation which is the ratio of actual level of output to *maximum* (optimal) achievable level of output.

As it is very flexible, DEA is a widely applied and well-established method of energy and environmental evaluation. DEA is recognized in the literature as a powerful method, more suitable for performance measurement than traditional, econometric methods such as regression analysis and simple ratio analysis (Castro and Frazzon, 2017; Mardani et al. 2017). Owing to its flexible nature DEA has been applied in energy efficiency evaluation[10]. This method is applied here to arrive at a relative measure of energy efficiency. For an overall view of the methodology applied in the study, a flowchart is given (Figure 2.1). The Flowchart shows two variants of DEA (radial and non-radial) measures of technical efficiency were applied initially and subsequently, the corresponding energy efficiency scores were calculated to arrive at the energy-saving target for inefficient states and identify benchmark states. Further, pure energy efficiency is differentiated from scale efficiency.

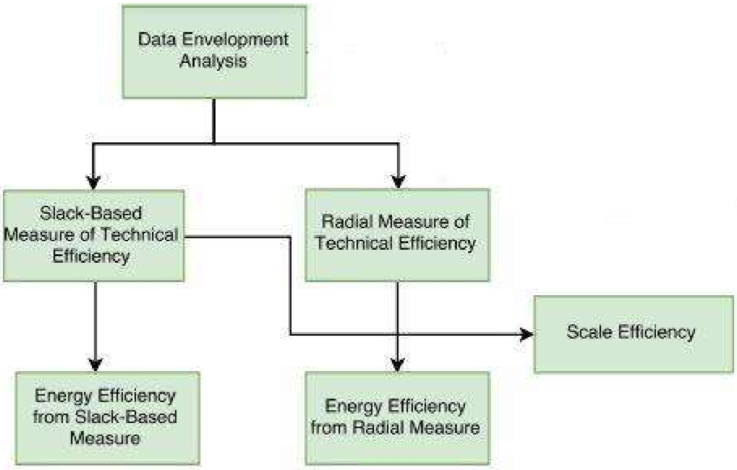

Figure 2.1: Flowchart of Method
Source: Author's calculation (2019)

2.3.1: Radial Measure of Efficiency

Here two variant of DEA are used, radial and non-radial adjustment. Radial measure allows only proportional reduction in all inputs while non-radial measure uses a non-proportional reduction in all inputs. In this study input-oriented BCC variant of DEA is used for radial measure of technical efficiency and then radial energy efficiency is derived. The following section formally defines the model.

Suppose that a typical firm produces a single output y by employing m inputs $x = (x_1, x_2, \dots\dots, x_m)$. Let there are n number of firms (j = 1, 2, ……n) to be evaluated, y_j be the

[10] For more details on application of DEA in energy and environmental evaluations, refer to Mardani et al. (2017).

output and $x_j$be the input bundle of the j[th] firms. The production possibility set (PPS) can be specified as:

$$p(x) = \{(x, y) \in R \ : x \ can \ produce \ y\} \qquad (2.1)$$

P includes all the feasible input and output vector assumed to satisfy typical regularity condition of a production function like a closed and bounded set. Give the observed input-output combinations with free disposability assumption, an input-oriented BCC efficiency measure minimizes all input in an equal proportion to arrive at an optimal input bundle. The efficiency of a particular DMU with the input-output bundle (x_0, y_o) can be estimated through the following BCC model.

$$\theta^* = min\,\theta \qquad 2.2(a)$$

Subjected to

$$\sum_{j=1}^{n} x_{ij}\lambda_j \le \theta x_{i0} \qquad 2.2(b)$$

$$\sum_{j=1}^{n} y_j\lambda_j \ge \theta y_0 \qquad 2.2(c)$$

$$\sum_{j=1}^{n} \lambda_j = 1 \qquad 2.2(d)$$

$$\lambda_j \ge 0, j = 1, 2, \ldots.., n$$

Where x and y are the vector of inputs and outputs respectively. i is an index of inputs; capital, labour, material, and energy; j is an index of firms under consideration. λ_j is a vector by which all the inputs of an inefficient firm to be reduced to reach at the frontier point. θ measures the technical efficiency of the firms through the proportionate reduction in all the inputs.

The BCC model specified above has the objective to minimise all inputs by the same proportion to reach the production frontier. Constraint 2(c) ensure that output will not reduce from current level of production and 2(d) implies VRS technology. The value of θ lies between 0 and 1, an efficient firm will assign the value of θ* = 1, meaning that no proportional reduction in inputs is feasible, whereas inefficient firms will have θ* < 1. Note that radial measure of efficiency does not take slacks into accounts with a particular input, if slacks exit, further reduction in that input is feasible. Therefore, a radial measure of efficiency has low discriminatory power. Here slacks with each input are calculated residually and then added to proportional reduction in that input to arrive at minimum input requirement. For energy efficiency, it will be the ratio of minimum energy requirement to actual energy use. This measure of energy efficiency is BCC energy efficiency denoted by γ^*. If no slack exists with respect to energy input then $\gamma^* = \theta^*$. However, it does not consider maximum distance to frontier which SBM deal with taking inputs and output slacks directly to gauge the whole aspect of inefficiency (Tone, 2001).

2.3.2: Slacks-Based Measure of Efficiency

In order to overcome the problem of radial measure of efficiency, recent studies have applied non-radial variant of DEA. SBM is the most popular non-radial approach with desirable features. It directly takes input and output slacks into account and provides more comprehensive efficiency measurement. In this chapter, SBM developed by Tone (2001) is applied which can be viewed as a product of input and output inefficiency. Therefore, it has higher discriminatory power and suitable for energy efficiency analysis.

Based on the production possibility test, SBM has following scheme:

$$\text{Minimize } \rho = \frac{1-(1/m)\sum_{i=1}^{m} s_i^- / x_{i0}}{1+(1/s)\sum_{r=1}^{s} s_r^+ / y_{r0}} \qquad 2.3(a)$$

$$\text{Subject to } x_0 = x\lambda + s^- \qquad 2.3(b)$$

$$y_0 = y\lambda - s^+ \qquad 2.3(c)$$

$$\lambda \geq 0,\ s^- \geq 0,\ s^+ \geq 0$$

A graphical illustration depicts the advantage of the SBM model over traditional radial measures of efficiency (Figure 2.2). The SBM finds the furthest point on the efficiency frontier by maximizing the amount of slack in the objective function. It is assumed that the isoquant curve Q is constructed from the combinations of energy and non-energy inputs that produce the same quantity of output. Points lie on the isoquant curve are technically efficient but points above the isoquant curve are inefficient because they employ extra inputs to produce the same quantity of output. For example, at point “a” the radial measures of efficiency is given by distance measurement (od/oa). While SBM projects the reduction in the energy inputs to point “b” the “farthest point” on the efficient frontier. Energy efficiency score of the firm at the point “a” is given by distance measurement (bk/ak). This is called SBM energy efficiency.

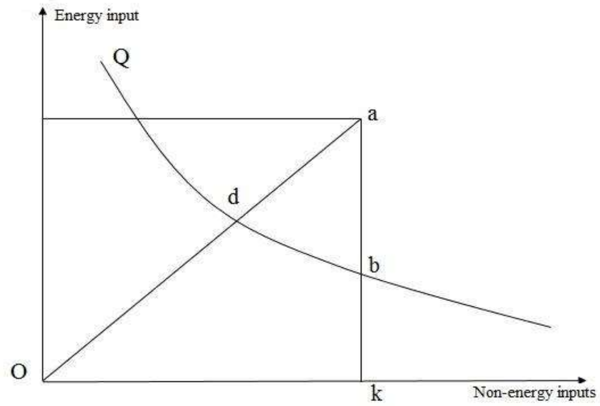

Figure. 2.2: Radial versus SBM of energy efficiency
Source: Author's calculation (2019)

Above fractional form can easily be transformed into an equivalent linear programme through the Charnes-Cooper transformation as used in the CCR model (Charnes et al., 1978)

Let *t* be a scalar term (t > 0), and multiply t to both the denominator and the numerator in (3a); this will not cause any change in ρ. *t* will be adjusted such that denominator becomes 1. Then the denominator term will move to the list of constraint. Then the model becomes;

Minimize $\tau = t - \frac{1}{m}\sum_{i=1}^{m} ts_i^- / x_{i0}$ 2.4(a)

Subject to $1 = t + \frac{1}{s}\sum_{r=1}^{s} ts_r^+ / y_{r0}$ 2.4(b)

$x_0 = x\lambda + s^-$ 2.4(c)

$y_0 = y\lambda - s^+$ 2.4(d)

$\lambda \geq 0,\ s^- \geq 0,\ s^+ \geq 0,\ t \geq 0$

The model given above becomes nonlinear programming problem due to the presence of the nonlinear term ts_r^+ $(r = 1, \ldots\ldots, s)$. However, it can be easily transferred into linear programming as follow:

$$S^- = ts^-,\ S^+ = ts^+, and \quad \Lambda = t\lambda$$

Minimise $\tau = t - \frac{1}{m}\sum_{i=1}^{m} S_i^- / x_{i0}$ 2.5(a)

Subject $1 = t + \frac{1}{s}\sum_{r=1}^{s} S_r^+ / y_{r0}$ 2.5(b)

$tx_0 = X\Lambda + s^-$ 2.5(c)

$ty_0 = Y\Lambda - s^+$ 2.5(d)

$$\Lambda \geq 0,\ S^{-} \geq 0,\ S^{+} \geq 0,\ t \geq 0.$$

If an optimal solution of linear programming be;

$$\tau^{*}, t^{*}, \Lambda^{*}, S^{-*}, S^{+*}$$

Then it can provide an optimal solution of SBM as follows;

$$\rho^{*} = \tau^{*},\ \lambda^{*} = \Lambda^{*} / t^{*},\ \ s^{-*} = S^{-*} / t^{*}\ \ s^{+*} = S^{+*} / t^{*}$$

Through the optimal solution of above parameter, it can be easily determined whether a firm is being efficient or not. Energy efficiency measure can be calculated as follows;

$$Energy\ efficiency = \frac{TEI}{AEI} = \frac{(AEI - ES)}{AEI} = 1 - \frac{ES}{AEI} \qquad (2.6)$$

Where *TEI*: target energy input; *AEI*: actual energy input; ES: energy slack. Energy slack is calculated from the model (5a -5d). The energy efficiency level of each state is estimated. The hallmark of the SBM model lies in its method to calculate the efficiency of any specific input, for example, energy efficiency in this study. Hu and Wang (2006) and Zhou and Ang (2008) applied similar method, where they have derived the energy efficiency index in total factor productivity framework. Following Zhang and Choi (2013), SBM is applied here to derive energy efficiency in case of Indian iron and steel sector.

By imposing a restriction of $\lambda = 1$, one can get an estimate of energy efficiency under VRS technology as described in BCC model. This energy efficiency score is called as pure energy efficiency score. Following Wei et al. (2011), total energy efficiency is decomposed into two components; pure energy efficiency (PEE) and scale efficiency (SE).

$$Energy\ efficiency = pure\ energy\ efficiency \times scale\ efficiency \qquad (2.7)$$

If scale efficiency equal to 1, means the firm is operating under optimal scale size. It can also verify whether energy inefficiency stems from inefficiency in the scale of operation and management, sub-optimal scale, or both (Wei et al., 2011).

2.3.3: Data Consolidation

State-level data is extracted from the ASI for the period of 2004-05 to 2013-14 based on the National Industrial Classification of 2004 and 2008 (Basic Iron & Steel, Code-271 & 241). This analysis covers 19 major states which account for more than 95% of total Iron and Steel produced in India. Four input variables and a single output variable is used for the analysis. Input variable includes (a) labour, (b) capital, (c) energy and (d) materials measured as total persons engaged, fixed capital, fuel consumption and expenditure on materials respectively. The gross value of output is taken as output variable.

Following Mukherjee (2008), in order to investigate energy efficiency performance of a 'typical firm' in a state, all variables are divided by the total number of factories in the state. All variables are measured in lakh ₹ and converted in real terms by deflating with respective price index using the base year of 2004-05[11], since no data was available for state-level price index, national-level price index is used for all variables except labour as it is measured in numbers. It is justifiable to the extent that these inputs are often be purchased in the national market and are relatively more mobile, nevertheless, it is an imperfect measure[12].

Table 2.1: Descriptive Statistics and Correlation Matrix

Variable	Fixed Capital	Labour	Energy use	Materials	Gross Output
Mean	35.85	119.30	4.99	30.74	60.68
Median	15.25	77.492	3.88	27.66	49.92
Maximum	284.13	453.06	26.17	102.7	202.24
Minimum	0.587	14.179	0.125	0.774	1.37
Std. Dev.	50.72	101.17	4.366	19.73	41.84
Correlation matrix	Fixed Capital	Labour	Energy use	Materials	Gross Output
Fixed Capital	1				
Labour	0.720	1			
Energy use	0.558	0.736	1		
Materials	0.557	0.508	0.504	1	
Gross Output	0.759	0.739	0.703	0.880	1

Source: Author's calculation (2019)

Descriptive statistics (Table 2.1) show maximum variation exists for labour inputs and lowest variation for energy inputs. There also exists a difference between mean and median which shows considerable heterogeneity in the distribution of the variation. Further correlation matrix shows a relatively high correlation among variables. All inputs variable highly correlated with output.

[11] Fixed capital, fuel consumption, expenditure on materials and Gross value of output are deflated by wholesale price index (WPI) of machinery and machine tools, WPI of fuel and power, weighted WPI of non-food primary article and WPI of iron and steel.

[12] Same measure is adopted by Mukherjee (2008) for whole manufacturing industries.

2.4: Results and Discussion

2.4.1: Results

DEA estimates production frontier and provides underlying technical and energy efficiency of the states over the period of time. The main focus is on energy efficiency which is derived from technical efficiency model. This will show the energy-saving targets for states that lies below the production frontier. Different sources of energy are used in the production of iron and steel which varies significantly across countries. Coal and electricity (purchased and generated) are major components of energy consumption in the Indian iron and steel sector. Due to unavailability of data regarding different sources of energy and energy use in physical unit, monetary measure of energy (fuel expenditure) is considered.

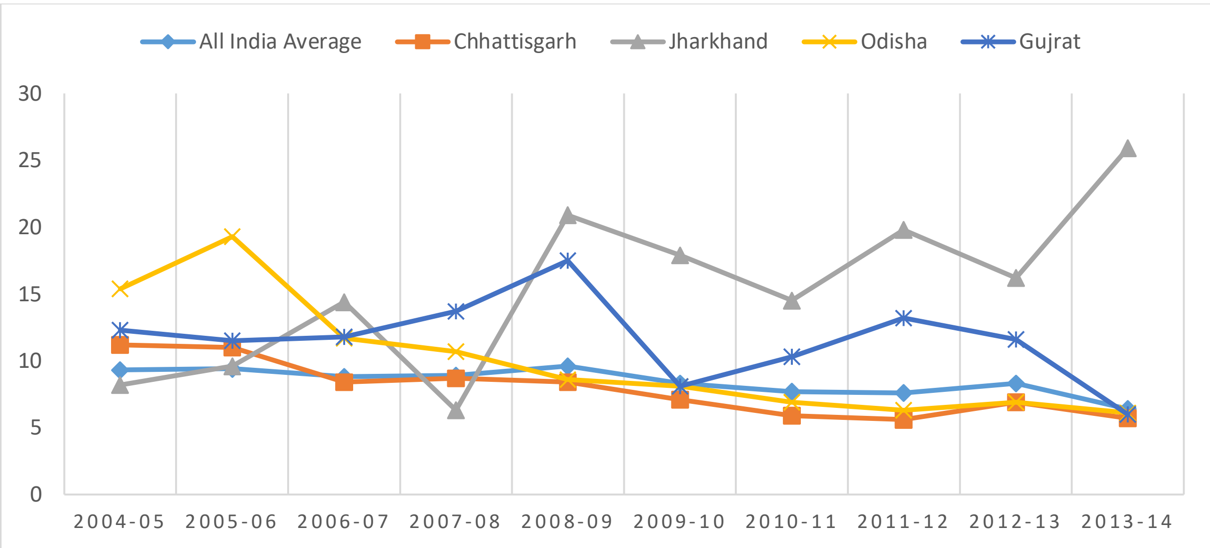

Figure 2.3: Energy intensity in Indian rupee (per cent)
Source: Author's calculation (2019)

First, differences in energy intensity across the region is examined, a simple measure of energy efficiency is calculated as the ratio of fuel consumption to gross output. The average level of energy intensity at the national level is 0.08 over the period of study. This means that producing ₹1 worth of iron and steel product require INR 0.08 worth of energy expenditure. Over the period of study, the industry experienced a meagre decline in energy intensity from 0.09 to 0.06 at the national level. Energy intensity trend of four major iron and steel producing state; Chhattisgarh, Odisha, Gujarat and Jharkhand. Gujarat and Jharkhand are the most energy-intensive states (Figure 2.3). The energy intensity for all states is also calculated which is given in appendix I for all years.

Table 2.2: BCC Technical Efficiency Score

State	2004 - 05	2005 - 06	2006 - 07	2007 - 08	2008 - 09	2009 - 10	2010 - 11	2011 - 12	2012 - 13	2013 - 14	Average
AP	0.895	0.856	0.933	0.935	0.938	0.988	0.907	0.906	1.000	1.000	0.936
AS	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
BI	1.000	1.000	1.000	1.000	1.000	1.000	0.916	1.000	1.000	1.000	0.992
CT	1.000	0.930	1.000	0.859	1.000	1.000	0.970	0.891	0.967	0.828	0.945
GU	1.000	0.915	0.967	0.989	0.932	1.000	0.927	0.880	0.765	1.000	0.938
HA	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
HM	1.000	1.000	0.963	1.000	1.000	1.000	0.847	0.866	1.000	1.000	0.968
JH	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
KA	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.903	0.990
KE	1.000	0.907	1.000	0.894	1.000	0.958	1.000	1.000	0.954	1.000	0.971
MP	0.939	1.000	1.000	1.000	1.000	1.000	1.000	0.992	1.000	1.000	0.993
MA	1.000	1.000	1.000	1.000	1.000	0.930	0.902	0.873	0.937	0.864	0.951
OD	0.810	0.792	0.902	0.689	1.000	1.000	1.000	1.000	1.000	1.000	0.919
PU	1.000	0.885	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.988
RA	0.969	0.859	1.000	1.000	0.955	1.000	1.000	1.000	0.917	1.000	0.970
TN	1.000	0.909	0.874	0.866	0.993	1.000	1.000	1.000	0.994	0.830	0.947
UK	1.000	1.000	1.000	1.000	0.989	0.918	0.940	0.923	0.922	1.000	0.969
UP	0.976	0.950	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.993
WB	0.879	0.923	1.000	0.908	1.000	1.000	1.000	1.000	0.969	1.000	0.968
Average	0.972	0.943	0.981	0.955	0.990	0.989	0.969	0.965	0.970	0.970	0.970

AP—Andhra Pradesh, AS—Assam, BI—Bihar, CT—Chattisgarh, GA—Goa, GU—Gujarat, HA—Haryana, HM—Himachal Pradesh, JH—Jharkhand, KA—Karnataka, KE—Kerala, MP—Madhya Pradesh, MA—Maharashtra, OD—Odisha, PU—Punjab, RA—Rajasthan, TN—Tamil Nadu, UP—Uttar Pradesh, and WB—West Bengal
Source: Author's calculation (2019)

VRS is employed to get a precise estimate of production frontier to accommodate market imperfection and observable heterogeneity. First, radial measure of technical efficiency is estimated (Table 2.2). BCC model shows a maximum proportional reduction in all inputs while keeping output level not less than what is being actually produced. The overall average level of technical efficiency of the states during the study period was 0.970 which implies that it would be feasible to reduce all the inputs proportionally by 3 per cent and still able to produce the same level of output. Jharkhand, Haryana and Assam show 100 per cent technical efficiency throughout the years. While states like Gujarat and Andhra Pradesh can reduce even more than average level, up to 7 per cent while Odisha can reduce 9 per cent of all the inputs with the same level of output.

Table 2.3: BCC Energy Efficiency Score

States	2004 - 05	2005 - 06	2006 - 07	2007 - 08	2008 - 09	2009 - 10	2010 - 11	2011 - 12	2012 - 13	2013 - 14	Average
AP	0.783	0.856	0.933	0.872	0.938	0.988	0.878	0.906	1.000	1.000	0.91
AS	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.00
BI	1.000	1.000	1.000	1.000	1.000	1.000	0.583	1.000	1.000	1.000	0.95
CT	1.000	0.704	1.000	0.859	1.000	1.000	0.970	0.891	0.967	0.828	0.92
GU	1.000	0.616	0.512	0.545	0.480	1.000	0.507	0.497	0.448	1.000	0.66
HA	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.00
HM	1.000	1.000	0.912	1.000	1.000	1.000	0.709	0.866	1.000	1.000	0.94
JH	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.00
KA	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.182	0.91
KE	0.998	0.468	1.000	0.860	1.000	0.615	1.000	1.000	0.922	1.000	0.88
MP	0.939	1.000	1.000	1.000	1.000	1.000	1.000	0.992	1.000	1.000	0.99
MA	1.000	1.000	1.000	1.000	1.000	0.930	0.886	0.610	0.843	0.782	0.90
OR	0.525	0.494	0.902	0.605	1.000	1.000	1.000	1.000	1.000	1.000	0.85
PU	1.000	0.643	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.96
RA	0.925	0.837	1.000	1.000	0.955	1.000	1.000	1.000	0.917	1.000	0.96
TN	1.000	0.892	0.874	0.721	0.993	1.000	1.000	1.000	0.456	0.803	0.87
UK	1.000	1.000	1.000	1.000	0.722	0.631	0.551	0.905	0.873	1.000	0.86
UP	0.469	0.950	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.94
WB	0.879	0.777	1.000	0.908	1.000	1.000	1.000	1.000	0.969	1.000	0.95
Average	0.927	0.925	0.927	0.923	0.918	0.919	0.922	0.923	0.923	0.923	0.92

Source: Author's calculation (2019)

Benchmarking the energy use and identifying the relatively inefficient states provides key insights to the policy maker to imitate best practices. The energy efficiency score of BCC model is estimated (Table 2.3). The overall average level of energy efficiency of the states during the study period was 0.923 which implies that it would be feasible to reduce energy inputs by 8 per cent with the same level of output. One thing to be noted here is that the states which show 100 per cent technical efficiency by definition will have no slacks and so energy efficient. States like Gujarat, Odisha and Uttarakhand show vast potential for more than proportional reduction in energy consumption. While states like Tamil Nadu, Kerala and Andhra Pradesh can also reduce even more than average level of 8 per cent with the same level of output.

Table 2.4: SBM Technical Energy Efficiency Score

States	2004 - 05	2005 - 06	2006 - 07	2007 - 08	2008 - 09	2009 - 10	2010 - 11	2011 - 12	2012 - 13	2013 - 14	Average
AP	0.822	0.742	0.816	0.826	0.859	0.867	0.778	0.587	1.000	1.000	0.830
AS	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
BI	1.000	1.000	1.000	1.000	1.000	1.000	0.715	1.000	1.000	1.000	0.972
CT	1.000	0.830	1.000	0.800	1.000	1.000	0.839	0.710	0.790	0.707	0.868
GU	1.000	0.769	0.802	0.816	0.706	1.000	0.686	0.513	0.486	1.000	0.778
HA	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
HM	1.000	1.000	0.923	1.000	1.000	1.000	0.756	0.766	1.000	1.000	0.944
JH	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
KA	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.542	0.954
KE	0.951	0.600	1.000	0.807	1.000	0.851	1.000	1.000	0.893	1.000	0.910
MP	0.807	1.000	1.000	1.000	1.000	1.000	1.000	0.844	1.000	1.000	0.965
MA	1.000	1.000	1.000	1.000	1.000	0.837	0.747	0.750	0.797	0.721	0.885
OR	0.642	0.568	0.596	0.558	1.000	1.000	1.000	1.000	1.000	1.000	0.836
PU	1.000	0.707	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.971
RA	0.946	0.795	1.000	1.000	0.890	1.000	1.000	1.000	0.887	1.000	0.952
TN	1.000	0.788	0.768	0.675	0.961	1.000	1.000	1.000	0.729	0.659	0.858
UK	1.000	1.000	1.000	1.000	0.894	0.817	0.765	0.736	0.870	1.000	0.908
UP	0.833	0.776	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.961
WB	0.740	0.789	1.000	0.796	1.000	1.000	1.000	1.000	0.818	1.000	0.914
Average	0.934	0.861	0.942	0.909	0.964	0.967	0.910	0.890	0.909	0.928	0.921

Source: Author's calculation (2019)

As noted in section 3, SBM of efficiency directly takes slacks into account. It has more discriminatory power hence it will provide efficiency score less than that of radial measures of efficiency. SBM technical efficiency is estimated (Table 2.4). The overall average level of technical efficiency of the states during the study period was 0.921 that is less than radial measure of efficiency. This implies that it would be feasible to reduce inputs by 8 per cent and still able to produce the same level of output. Technical efficiency score reveals for most of the states, there is considerable variation in the average performance across states. Under SBM method, Jharkhand, Haryana and Assam show 100 per cent technical efficiency throughout the years. This show each input should be adjusted in different proportion to arrive at the benchmark level.

Table 2.5: SBM Energy Efficiency Score

States	2004 - 05	2005 - 06	2006 - 07	2007 - 08	2008 - 09	2009 - 10	2010 - 11	2011 - 12	2012 - 13	2013 - 14	Average
AP	0.694	0.713	0.588	0.656	0.937	1.000	0.652	0.640	1.000	1.000	0.788
AS	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
BI	1.000	1.000	1.000	1.000	1.000	1.000	0.545	1.000	1.000	1.000	0.955
CT	1.000	0.648	1.000	0.620	1.000	1.000	0.985	0.735	0.687	0.801	0.848
GU	1.000	0.509	0.377	0.589	0.468	1.000	0.497	0.407	0.477	1.000	0.632
HA	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
HM	1.000	1.000	0.904	1.000	1.000	1.000	0.648	0.663	1.000	1.000	0.922
JH	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
KA	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.162	0.916
KE	0.980	0.449	1.000	0.497	1.000	0.583	1.000	1.000	0.921	1.000	0.843
MP	0.659	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.966
MA	1.000	1.000	1.000	1.000	1.000	0.715	0.695	0.579	0.659	0.643	0.829
OR	0.506	0.439	0.401	0.605	1.000	1.000	1.000	1.000	1.000	1.000	0.795
PU	1.000	0.626	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.963
RA	0.949	0.658	1.000	1.000	1.000	1.000	1.000	1.000	0.910	1.000	0.952
TN	1.000	0.843	0.723	0.564	1.000	1.000	1.000	1.000	0.454	0.773	0.836
UK	1.000	1.000	1.000	1.000	0.786	0.657	0.460	0.516	0.645	1.000	0.806
UP	0.428	0.779	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.921
WB	0.680	0.740	1.000	0.740	1.000	1.000	1.000	1.000	0.767	1.000	0.893
Average	0.922	0.922	0.921	0.922	0.922	0.922	0.922	0.922	0.922	0.922	0.922

Source: Author's calculation (2019)

Finally, SBM of energy efficiency score is estimated which finds the maximum possible reduction in energy input. The estimated energy efficiency is based on minimal energy used to produce the current level of output. Results of SBM of energy efficiency shows the relative performance of the states in terms of energy use. The energy efficiency score provides a target to achieve minimal energy use given by benchmark states. Considering complementarity among inputs, this measure is a more relevant measure of energy efficiency in TFP framework. The SBM energy efficiency score is estimated (Table 2.5). The overall average level of energy efficiency is 0.922, which is exactly same as estimated through BCC model. Nevertheless, it differs from that of BCC at the individual state level. It shows the highest average possible reduction of 37 per cent of energy input in case of Gujarat. In contrast, Andhra Pradesh, Odisha, Tamil Nadu, Kerala, Maharashtra and Chhattisgarh it ranges from 22 to 16 per cent. States like Bihar, Punjab, Madhya Pradesh and Rajasthan are closed to efficiency frontier. Therefore, for these states less scope exists for improvements in energy efficiency level. State average energy efficiency score over the years remains stagnant. In some states, it increases very marginally because the adaptation rate of energy-saving technology is very low. This shows poor implementation of industrial energy efficiency programme initiated by BEE, India.

Based on technological specification regarding returns to scale, the scale efficiency of energy consumption is calculated (Table 2.6). This is the ratio of energy efficiency score under the constant return to scale to VRS. As of 2013-14, average scale efficiency was 0.89 which shows energy inefficiency caused by scale inefficiency. Therefore, it is also contributing to some extent of total energy inefficiency.

Table 2.6: Scale Efficiency of Iron and steel sector

States	2004 - 05	2005 - 06	2006 - 07	2007 - 08	2008 - 09	2009 - 10	2010 - 11	2011 - 12	2012 - 13	2013 - 14	Average
AP	1.000	1.000	1.000	1.000	0.993	1.000	0.943	0.995	1.000	0.819	0.975
AS	0.750	0.789	0.885	0.493	0.899	1.000	1.000	0.896	0.600	0.665	0.798
BI	0.411	0.419	0.401	0.631	0.410	1.000	0.840	0.452	1.000	1.000	0.656
CT	1.000	1.000	1.000	0.992	1.000	1.000	0.885	0.958	1.000	1.000	0.983
GU	1.000	1.000	0.917	0.798	0.841	1.000	0.985	0.728	0.909	1.000	0.918
HA	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
HM	0.752	1.000	0.868	1.000	1.000	1.000	0.879	1.000	1.000	0.745	0.924
JH	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.269	0.745	0.901
KA	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.758	1.000	0.960	0.972
KE	0.618	0.986	1.000	0.729	0.847	1.000	0.600	1.000	0.875	0.945	0.860
MP	0.941	1.000	1.000	1.000	1.000	1.000	1.000	0.990	1.000	1.000	0.993
MA	0.447	0.781	0.723	1.000	1.000	1.000	0.970	0.969	1.000	1.000	0.889
OR	1.000	1.000	0.987	0.966	1.000	1.000	0.802	0.622	0.624	0.829	0.883
PU	1.000	0.995	1.000	1.000	1.000	1.000	0.735	0.948	1.000	0.664	0.934
RA	0.920	0.978	1.000	1.000	0.946	1.000	1.000	1.000	0.776	1.000	0.962
TN	1.000	0.999	0.948	0.799	0.969	0.960	1.000	1.000	0.844	0.961	0.948
UK	1.000	1.000	1.000	1.000	1.000	0.992	0.978	1.000	0.828	0.603	0.940
UP	0.947	0.893	1.000	0.729	1.000	0.971	1.000	1.000	1.000	1.000	0.954
WB	1.000	1.000	0.954	0.985	1.000	1.000	1.000	0.539	0.774	1.000	0.925
Average	0.883	0.939	0.931	0.901	0.942	0.996	0.927	0.887	0.868	0.891	0.917

Source: Author’s calculation (2019)

2.4.2: Discussion on Results

The results of both BCC and SBM of energy efficiency show 8 per cent reduction of energy on an average level. Comparing our SBM of energy efficiency with traditional energy efficiency indicator that is energy intensity shows that lower energy-intensive states like Assam, Haryana, Rajasthan and Punjab have also higher energy efficiency. But the case is different for states like Bihar and Jharkhand with higher energy efficiency score also have a higher level of energy intensity. This particular contrary result shows the weakness of traditional energy efficiency indicator. Overall energy intensity has declined by 31 per cent over the period of study. The rate of decline in energy intensity level is very low as compared to other energy-intensive industry. Iron and steel industry needs special attention from the standpoint of energy efficiency to achieve cleaner and sustainable production. Kernel density estimates of the average energy efficiency level over the period of study is given (Figure 2.4). The plot of kernel density function shows considerable variation exists among states which are further visualized through box plot. Box plot of average energy efficiency score is given (Figure 2.5) which shows most of the states lie below the average level of energy efficiency.

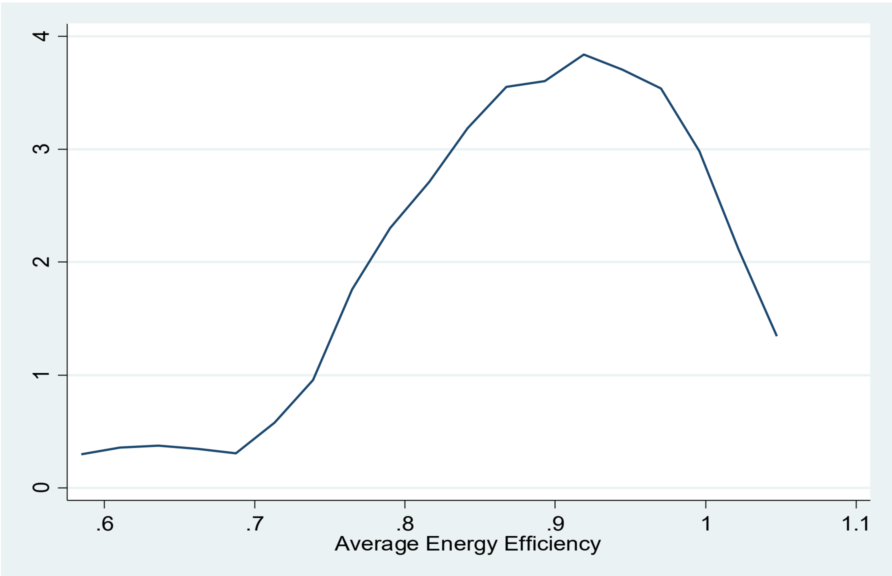

Figure 2.4: Kernel density plot of average energy efficiency
Source: Author's calculation (2019)

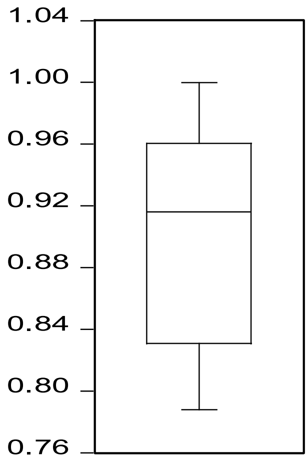

Figure 2.5: Box plot of average energy efficiency
Source: Author's calculation (2019)

The variation in the energy efficiency level across states mainly depend upon the technology used, the final product (crude steel, Ferroalloy and sponge iron etc.), raw materials and type of fuel (coal or gas). There may be some mismatch in the fuel used and raw material employed in the production process. Notably, large amount of available fine iron ore remains unsuitable for Indian plants (GOI, 2011). Another main reason is the large-scale coal-based DRI production carried out in some states like Andhra Pradesh, Karnataka, Odisha and Chhattisgarh remain energy inefficient. There is also natural gas-based DRI production in these states which is energy efficient but remains stagnant due to scarcity of natural gas (GOI, 2011). Coal-dominated production need special attention due to low-quality coal and technological obsolescence. EAF route of producing steel through steel scrap requires less energy as it requires only to melt the scrap and hence its production needs to be enhanced to achieve higher energy efficiency.

Some advance energy-efficient technology; Oxygen assisted melting, oxygen-fuel burner may enhance energy efficiency but not employed due to financial and organizational constraint. But these technologies need to employ in all the large-scale plant through regulatory and market incentive. GOI have to put specific regulation and create financial incentive to invest in energy-efficient technology. The Green Rating Project (GRP) of the Centre for Science and Environment (CSE) is an independent programme that rates environmental and resource efficiency of industry after a rigorous process of data collection and verification.

GRP rating of iron and steel industry shows very poor performance of large integrated steel plant. Ispat industries limited located in Maharashtra and Essar steel limited, Hazira, Gujrat got first and second rank respectively. These plants run on the gas module which is one of the largest and most efficient in the country (CSE, 2017). The small and medium enterprises engaged in steel re-rolling dominantly in Punjab, Haryana and Rajasthan region achieved some level of energy efficiency by government initiatives (GOI, 2015). Therefore, condition in which firms operate and state government intervention results in differences in energy efficiency level. Odisha, Chhattisgarh and Jharkhand (iron ore-rich states) are the leading states in terms of plant, production and investment. Inadequate transport facility (especially for raw materials and fuel) is another factor that hinders other states from investing in the large integrated plant.

There is a dire need for a regional-level policy to provide adequate incentive to firms for investment in energy-efficient technology. This will help in enhancing technical and cost efficiency. Only Kerala and Andhra Pradesh have some mandate for energy-saving target for several industries operating through energy management centre. Therefore, state-level action plan and audit system is a most needed step and should be well adopted by all the states (Sarkar et al., 2016). This study recommends the sector-specific policy stance and negotiation with the industry to deliver quality institutional and regulatory mechanism.

2.5: Conclusion

There is growing concern about global warming and GHG mitigation, addressing through international negotiations. Different policy options are being implemented like carbon trading and environmental regulation to move in desired and conductive directions. Adherence to the past trends of steady improvement in energy efficiency, it remains as the most cost-effective option. Therefore, this study estimates the energy efficiency level of Indian iron and steel sector by using regional level data over the period of 2004-05 to 2013-14. Radial and non-radial variant of DEA is employed to estimate energy saving potential and also identified the relative position of sample states.

A simple indicator of energy efficiency that is energy to output ratio is examined. It shows declining trends over time, but for states like Bihar, Jharkhand, Gujrat and Uttarakhand, it does not decrease much. The main aim of the study is to estimate the energy efficiency level in TFP framework and uncover energy-saving potential for different states. SBM of energy efficiency is employed to get a more comprehensive measure of energy efficiency along with radial measure (BCC model) of energy efficiency. SBM of energy efficiency shows an overall average of 8 per cent of energy-saving potential without reducing output level.

Further, scale efficiency is also calculated which shows the overall average level of scale efficiency as 0.91. So, scale inefficiency also contributed to total energy inefficiency. Therefore, an optimal scale of operation should be devised to implement standard energy efficiency program. Finally, this study recommends policy initiative to propagate energy efficiency program through the market based and regulatory mechanism to tap vast energy-saving potential.

Chapter 3

Quantifying Technological Gap in Energy Efficiency

3.1: Introduction

Improvement in energy efficiency become inevitable to combat climate change and improve energy security. It is one of the critical factors in enhancing firms' performance and environmental sustainability. Higher energy-efficient firms have low-cost production and provide a competitive advantage over energy-inefficient firms (Prasad and Mishra, 2017). It provides one of the best solutions for reducing pollution from energy-intensive firms. Notwithstanding wide-ranging environmental regulations, lack of effective enforcement has demanded a market-based mechanism for cost-effective industrial pollution reduction (Kumar and Shetty, 2018). The market-based mechanism is straightforward, effective and easy to compliance and leads to efficiency gain in management. Therefore, the government has shifted the policy from Command and Control regulations to market-based policy in order to enhance energy efficiency and other environmental performance.

The International Energy Agency (IEA, 2015) projected that India would demand one-fourth of the world energy by 2040. Further, the share of fossil fuel source of energy will increase from 72 per cent at present to 81 per cent in 2040, which poses a challenge for sustainable development and energy security. Under Perform Achieve & Trade (PAT), target specific energy consumption (SEC) reduction of identified production units is based on the concept of "Relative SEC" of similar profile unit. There is low participation from the iron and steel industry during PAT cycle-I, only 67 units have given energy-saving target, which is notified as designated consumers (Bureau of Energy Efficiency (BEE), 2017). Industrialised countries are leading in energy efficiency programme to enhance energy efficiency, like the Energy Star system, ISO 50001 and Environmental Management Programme. These programmes are implemented in developed countries and unpopular in developing countries (Moon and Min, 2017).

Iron and steel sector is dominated by the private sector, as it has market share of around 91 per cent of the total production in the country. The speciality of Indian iron and steel industry lies in hosting world's largest coal-based direct reduced iron (DRI) production[13]. Coal (cooking and non-cooking) is widely used in DRI production, which accounts for around 90 per cent of total DRI in the country (Reddy and Ray, 2011). Iron and steel production in India requires a significant amount of energy input. It consumes around 21 per cent of the total industrial energy consumption. Average energy cost varies between 20 to 40 per cent of total manufacturing cost (Ramakrishnan et al., 2013). There may be an emerging demand for iron and steel in the near future for urbanization and infrastructure. So, the energy demand for iron and steel industry may increase from the current 46 MTOE to around 200 MTOE over the period to 2040 IEA (2015).

Most of the Indian iron and steel firms require 6.5 Giga calorie per tonne of crude steel (Gcal/tcs) against the world average of 3.5 Gcal/tcs (Ramakrishnan et al., 2013). As compared to the cement and aluminum industry, iron and steel, fertilizer, textile and paper are still relatively higher energy-intensive industry (Mandal & Madheswaran, 2011). Several market-based reform was enacted overtime for energy conservation and technological up-gradation but the energy-intensity in most Indian industry remain stagnant. Hence there require a detailed analysis of iron and steel industry's energy efficiency evaluation. This chapter tries to provide better insight to understand the energy efficiency of Indian iron and steel industry. It will contribute to implementation of energy efficiency scheme and meeting the target reduction of CO_2 emission at national-level.

As far as the Indian iron and steel industry is concerned, no study has been done a meta-frontier analysis and incorporates regional heterogeneity. Indian economy is geographically very diverse in terms of industrial development and resource endowment (Kumar, 2014). Greater emphasis has been given on regional planning and maintaining a balanced regional growth. But economic development varies across states due to regional heterogeneity and other external factors. Therefore, energy efficiency analysis needs to consider it into analysis. As economic growth and environmental conservation (energy-saving) is the primary concern of our country. A comprehensive analysis is needed to provide region-level insight on technological gap.

This chapter has made several contributions to the literature. Firstly, a comprehensive analysis of energy efficiency has been conducted with the objective of energy conservation. Secondly, research on energy efficiency analysis assumes similar production technology across regions.

[13] DRI is also called sponge iron which is produced by reducing iron oxides to metallic iron at temperatures below the melting point of iron.

This may lead to biased energy efficiency estimation. Hence this chapter incorporated regional heterogeneity in production through meta-frontier analysis. Thirdly, slack-based measure (SBM) of efficiency is combined with meta-frontier analysis to derive an unbiased measure of energy efficiency. Lastly, the technological gap ratio and other indicators were derived to examine regional heterogeneity and cause of energy inefficiency through the decomposition of the total energy inefficiency. It is crucial for designing regional energy efficiency policy and long-term planning. This chapter has two main objectives:

(a) To estimate the technological gap in energy efficiency across the four regions and
(b) To estimate the energy-saving potential at firm-level.

3.2: Literature review

Efficiency in the empirical literature is generally defined with respect to some benchmark (relative efficiency) or ideal condition that acts in accordance with the market mechanism. Here energy efficiency is analysed in production theocratic framework in which inputs (energy and non-energy inputs) used to produce output. It relies on constructing a production frontier which is used as a benchmark to measure relative efficiency. In the non-parametric framework, Charnes et al. (1978) proposed data envelopment analysis (DEA) for performance evaluation of decision-making units (DMUs). Since then, various modification and refinement have been done to accommodate different research purpose. It is flexible to incorporate multiple inputs and multiple output and is widely applied in energy and environmental evaluation.[14] Hence different variants of DEA exist to incorporate production function heterogeneity. It can also incorporate undesirable output like CO_2 emission or water pollution from production through changes in the production function specification. Beside DEA, there is also growing number of studies that adopted stochastic frontier analysis (SFA) to construct production function. SFA is a parametric approach and its major advantage lies considering error term in the analysis.
The notion of meta-frontier was proposed by Hayami (1969) and Hayami and Ruttan (1973) that takes the production technology heterogeneity faced by different DMUs. It can incorporates heterogeneity concerning the region, type, scale and other inherent attributes. For this purpose, DMUs under study should be divided into different groups according to the sources of technological heterogeneity. Production frontier for each group should be estimated separately using group frontier. Finally, a meta-frontier DEA can be estimated by enveloping all the group frontiers. In most of the studies, group-and meta-frontier are estimated by using

[14] For more detail on application of DEA in energy and environmental evaluation, (Sueyoshi et al., 2017) provide a literature survey.

regional categorisation of DMUs. It is assumed that firms in one region operate under similar external factors like material availability, climatic condition, regional policy and input market for labour and energy. It shows the external economies of scale or industrial agglomeration. These factors enable firms to imitate better performing peer firms in the region. Hence group frontier energy efficiency (GEE) may be improved by effective management, while meta-frontier energy efficiency (MEE) may be improved by reducing the technological gap (Li & Lin, 2015).

Several studies used meta-frontier DEA to examine regional heterogeneity in energy efficiency. In case of China, three regions are considered that is east, central and west. Wang et al. (2013) found that technological gap is significantly high and causes energy inefficiency across central and west China. Tian and Lin (2018) found that eastern China has more advanced technology that should stimulate its diffusion in other regions. Yu et al. (2019) applied Super-SBM and Meta-frontier DEA. They found that eastern China has higher energy efficiency while significant improvement has been experienced by central and western China. Zhang et al. (2015) constructed an ecological-based energy efficiency by combining SBM with meta-frontier. They have shown that significant technological gap exists in case of all three regions. Li and Lin (2015) show the regional heterogeneities caused by inefficiency at the managerial level for the eastern and western regions and the technological gap for the central region. Cheng et al. (2020) estimated directional distance function of DEA with meta-frontier and further investigated spatial convergence of energy efficiency. They found the least technological gap for west region followed by the central and eastern region. Further technological gap has not converged across these regions as it has been widening over time. Ouyang et al. (2021) combine SFA with meta-frontier and estimated energy efficiency of industrial sector of China. They have adopted statistical clustering tool to form three groups of provinces based on energy intensity. They found that better energy efficiency for eastern region while technological gap is seen as discrete source of inefficiency for other regions. Moreover average energy efficiency was found to be around 0.439 and specifies vast energy saving potential.

Chiu et al. (2012) have estimated meta-frontier environmental efficiency of 90 countries. They have formed four groups based on cluster analysis of competitiveness and income level. They documented that high competitiveness countries outperform other groups. In contrast, the upper-middle group has a larger technological gap than lower-middle and low competitiveness groups. Zhang et al. (2013) have applied meta-frontier DEA to measure the CO_2 emission efficiency and differences between coal-fired and oil-fired electricity generating Korean firms.

They document that coal-fired based production has a lower technological gap. Therefore, more efficient technologies require for the oil-fired plant. Most of the above studies adopted an SBM of DEA with meta-frontier DEA. It has more discretionary power than radial measure of efficiency. As it directly considers slack associated with inputs and output variables.

In case of India, firm-level energy efficiency literature is inclined towards coal-fired power generation sector and some studies have analysed energy saving potential of energy-intensive industry. Most of power generation is coal-based and produced considerable amount of pollution hence evaluating its energy and environmental efficiency performance is crucial. Kumar and Jain (2019) measured productivity of 56 coal-based power plant using SFA with meta-frontier model. They have considered CO_2 emission and technological differences between plant operated by central and regional government. They found that state run plant have higher potential for CO_2 emission reduction, while centrally run plant experiences better growth in productivity. Murthy and Nagpal (2019) has estimated the cost that firms bear to reduce to mitigate one unit of CO_2 emission know as marginal abetment cost (MAC). They found that MAC varies across coal-fired power plant, on average it is 85 USD/metric-ton in 2015. Therefore, emission trading and Pigouvian tax can be implemented to reduce emission cost-effectively. Oak and Bansal (2019) found that PAT scheme was effective in reducing the energy intensity of cement and fertilizer industry, but not in case of paper industry. Dasgupta and Roy (2015) estimated the driving factors of energy demand for manufacturing industry and found technical progress and energy input are negatively related with energy use. There is also evidence of partial rebound effect. Hence improvement in energy efficiency has been partially offset by growing energy demand. Sahoo et al. (2017) found that target reduction for thermal power plant under PAT was substantially lower than actual potential energy saving estimated through DEA.

3.3: Methodology

3.3.1: Energy efficiency based on group and meta-frontier

There are several forms of heterogeneity that exist among DMUs, which create difficulties in group formation of firms. Some studies rely on cluster analysis which is data-driven based group formation. Battese et al. (2004) and O'Donnell (2008) have suggested a pragmatic solution. They urged that the geographically adjacent films typically operate under relatively similar condition. Hence regional categorisation can solve the problem of grouping. Industrial development varies across Indian states due to resource endowment, infrastructure advancement and government interference. Therefore, firms are categorised into four groups according to states' geographical distribution into north, south, east and west. This categorisation is generally followed in literature and intuitive to analyse regional technological heterogeneity for two primary reasons. First, it captures heterogeneity in resource endowment and the effect of the industrial cluster in the different industrial belt of the south and east region of India. These two regions have a more significant number of firms. Second, different climatic conditions prevail across these regions.

In order to measure the energy efficiency of Indian iron and steel producing firms incorporating technological heterogeneity, let's suppose there are n = 1,…, N number of firms (DMUs) and each firm uses $x \in R_+^m$ input vector to produce the output vector $y \in R_+^R$. In this chapter, four inputs viz capital, labour, energy and material are taken with a single output variable. Production units (firms) are divided into h = 1,…, H independent groups with N_h number of firms in h^{th} group. Production units are assumed to face the same production technologies in each group, and the technological gap exists only among different groups (Battese et al., 2004). Thus, the DEA method will be applied to construct the production using linear programming with the given data set.

The production technology set with Input and output bundle of a particular group is presented in model (3.1).

$$T^{group} = \left\{ (x, y) : \sum_{n=1}^{N_h} \lambda_n^h x_{mn} \leq x_m , m = 1,...,M, \right.$$

$$\sum_{n=1}^{N} \lambda_n^h y_{rn} \geq y_r , r = 1,....,R, \tag{3.1}$$

$$\left. \lambda_n^h \geq 0, n = 1,....,N. \right\}$$

Where λ_n^h is a non-negative vector of scaling factor for constructing the production frontier using a convex combination of input and output. Model (3.1) is assumed to satisfy the regularity condition of the well-behaved production function. The envelopment of group production technology will provide a frontier technology of a particular group h. Similarly, each group's production frontier can be enveloped under meta-frontier using data on input and output of all firms. Following SBM proposed by Tone (2001), following model is formulated and applied data of each group to estimate group energy efficiency (GEE) of Indian iron and steel industry.

$$\rho^* = \min \frac{1-(1/M)\sum_{m=1}^{M} s_{m0}^{x} / x_{m0}}{1+(1/R)\sum_{r=1}^{R} s_{r0}^{y} / y_{r0}}$$

$$\sum_{n=1}^{n_h} \lambda_n^h x_{mn} = x_{m0} + s_{m0}^{x} \tag{3.2}$$

$$\sum_{n=1}^{N_h} \lambda_n^h y_{rn} = y_{r0} - s_{r0}^{y}$$

$$s_{m0}^{x} \geq 0, s_{r0}^{y} \geq 0, \lambda_n^h \geq 0$$

Where M index for inputs variable, r = 1, 2,…,R is index of outputs variable. s_{m0}^{x} is slack associated with the input vector while s_{r0}^{y} is slack associated with output vector. Equation (3.3) is used to calculate energy efficiency derived from input-oriented SBM efficiency model (3.2).

$$GEE = \frac{OEU}{AEU} = \frac{AEU - ES}{AEU} \tag{3.3}$$

Where *OEU*: optimal energy use; *AEU*: actual energy use; ES: energy slacks. In SBM, the amount of reduction in energy input required to reach the production frontier is captured in associated slacks. SBM model able to precisely estimate the inefficiency in the use of any particular input, in this case, it is inefficiency in the energy use.

Suppose that there are N_h observations for group h. Technically, the non-parametric meta-frontier production technology can be expressed as Model (3.4).

$$T^{meta} = \left\{ (x, y) : \sum_{h=1}^{H} \sum_{n=1}^{N_h} \mu_n^h x_{mn} \leq x_m, m = 1, ..., M, \right.$$

$$\sum_{h=1}^{H} \sum_{n=1}^{n_h} \mu_n^h y_{rn} \geq y_r, r = 1, ..., R, \tag{3.4}$$

$$\left. \mu_n^h \geq 0, n = 1, ..., N_h, h = 1, ...H. \right\}$$

Where μ_n^h is a non-negative multiplier vector applied in building meta-frontier by putting linear programming technique. Model (3.4) indicates the pooling of data on all firms of all groups to construct the meta-frontier. The production possibility set of meta-frontier technology: $T_m = \{T_1 \cup T_2 \cup .... \cup T_H\}$, envelop all groups frontier technologies. Further, variable returns to scale (VRS) has been used to adjust the imperfect market and other factors as it makes frontier more smooth (O'Donnell et al., 2008). Combining the SBM model (3.2) with the meta-frontier production technology given in model (3.4) provide the meta-energy efficiency (MEE) which will be used to derive technological gap in energy utilisation across regions (groups).

$$\rho^* = \min \frac{1-(1/M)\sum_{m=1}^{M} s_{m0}^x / x_{m0}}{1+(1/R)\sum_{r=1}^{R} s_{r0}^y / y_{r0}}$$

S.T.

$$\sum_{h=1}^{H}\sum_{n=1}^{N_h} \mu_n^h x_{mn} = x_{m0} + s_{m0}^x$$

$$\sum_{h=1}^{H}\sum_{n=1}^{N_h} \mu_n^h y_{rn} = y_{r0} - s_{r0}^y \tag{3.5}$$

$$\sum_{h=1}^{H}\sum_{n=1}^{N_h} \mu_n^h = 1 \qquad \text{(VRS assumption)}$$

$$s_{m0}^x \geq 0, s_{r0}^y \geq 0, \mu_n^h \geq 0$$

Model (3.5) pooled the data of all firms and construct a meta-frontier using nation-wide best technology. It applies the linear programming technique to get the optimal value of all inputs and output variables. MEE can be estimated similarly as GEE, given in equation (3.3). Both the efficiency scores range from 0 to 1, where 0 means fully inefficient and 1 means fully efficient. Also, MEE is always lower than GEE as it envelops group frontier.

3.3.2: Technological gap in energy use efficiency

MEE provides the relative performance of firms with reference to nation-wide technology while GEE score is based on relative performance within the group. Therefore, the gap between MEE and GEE needs to be analysed. O'Donnell et al. (2008) show that the gap between them as the technological gap ratio (TGR), a measure of distance between MEE and GEE. Higher the TGR score lower the gap between group and meta-frontier, and if TGR=1 implies no gap between them. Hence TGR of nth firm in the hth group can be constructed as given in equation (3.6) while the average level of TGR of a particular group (*h*) can be as given in equation (3.7).

$$TGR_n^h = \frac{MEE_n^h}{GEE_n^h} \qquad (3.6)$$

$$TGR^h = \frac{\sum_{n=1}^{N_h} TGR_n^h}{N^h} \qquad (3.7)$$

Since the energy efficiency from group frontier is a sub-set of meta-frontier based energy efficiency, MEE ≤ GEE will consistently hold. Hence the score of TGR ranges between 0 and 1. If TGR is getting closer to 1 means smaller, the gap between group-and meta-frontier and vice-versa.

3.3.3: Decomposition of total energy inefficiency

Total energy inefficiency has been decomposed into two parts: technology gap inefficiency (TGI) and group managerial inefficiency (GMI), as given in equation (3.7) and (3.8). The firms within the same group supposed to have similar production technology. Thus, the inefficiency in energy use measured through group frontier in a general sense can be viewed as managerial inefficiency rather purely technical factor. Whereas the gap between MEE and GEE score is considered as inefficiency due to technical factors. Total energy inefficiency equals TGI and GMI, which equals the meta-frontier energy inefficiency given in equation (3.10).

$$TGI_n^h = GEE_n^h \left(1 - TGR_n^h\right) \qquad (3.8)$$

$$GMI_n^h = 1 - GEE_n^h \qquad (3.9)$$

$$TGI_n^h + GMI_n^h = 1 - MEE \qquad (3.10)$$

3.3.4: Data and variable

Firm-level data for the analysis is collected from the electronic database *PROWESS* managed by the Centre for Monitoring Indian Economy. The database contains an updated information from the company's annual balance sheets. Data of Indian iron and steel industry is extracted as per classification provided by national industry classification 2008. Four inputs; capital, labour, energy, and materials and a single output have been conceptualised in the production function. Labour is taken as wages and salaries expenses in the absence of data in the physical term, energy as expenditure on power and fuel, and materials as raw material expenditure. Gross fixed asset as capital employed and net sale value for output used in the analysis. Hence all variables are given in monetary term and adjusted to take account of the price level.

Original data of all variables are given in monetary terms, which needs to be adjusted to take account of the price level. Hence all variables are adjusted to account for nominal changes by following studies that use prowess data of firm-level (Balakrishnan and Pushpangadan, 1994; Balakrishnan et al., 2000). After cleaning the data, there are 97 firms operate across four different regions. Regional disparity, in terms of industrial structure and factor endowment, leads to geographical barriers across states to access and employ nation-wide technology. Therefore, energy efficiency may differ significantly and can be captured through regional categorisation. Following the literature on the meta-frontier analysis, four regions are created. Firms are geographically divided as per their office of operation. The number of firms and states assign under different regions are given in table 3.1[15].

Table 3.1: Division of states and region formation

Region	states	No of Firms
North	Delhi, Punjab, Haryana, Uttarakhand, Himachal Pradesh	22
South	Andhra Pradesh, Kerala, Tamil Nadu, Telangana	22
East	Chhattisgarh, Jharkhand, Odisha, West Bengal	27
West	Maharashtra, Gujarat, Goa	26

Source: Author's calculation (2019)

There are two government enterprises and eleven are private group affiliates, while others are private (domestic and foreign) firms. Data for the selected sample firms produced around 65 per cent of the total iron and steel production in the country. Hence the firms under study adequately represent the industry and the analysis provides average energy saving potential for this particular industry. The period of 2003-04 to 2015-16 is chosen for the analysis based on changing structure of Indian economy and data availability.

[15] In group formation, Madhya Pradesh and Chhattisgarh come under central region but no firms fall under Madhya Pradesh, and Chhattisgarh is close to eastern region and with similar industrial structure hence included in eastern region.

3.4: Empirical analysis and discussion

3.4.1: Group-and Meta-frontier energy efficiency

After categorisation, group- and meta-frontier DEA are estimated as specified in equation 3.2 & 3.5. The Box plot of GEE and MEE at firm-level (Figure 3.1) shows the distribution of firms in four quantile based on average GEE and MEE score. Line within the box provides median energy efficiency. It is evident that GEE is higher than MEE with median of 0.80 and 0.40, respectively. Half of sample firms have above 0.80 GEE score over the rage of 0 to 1, hence firms are concentrated in upper quantile, while less number of firms lie in middle and lower quantile. Distribution of firms is different in case of MEE, as half of the sample firms have MEE score below 0.40, while MEE score of upper quantile firms range between 0.70 to 1. The lower-middle quantile in concentrated between 0.30 to 0.40. Firms are evenly distributed in case of MEE and relatively downward concentrated in contrary with GEE. Therefore, firms have significant potentials for energy saving with reference to nation-wide best practices.

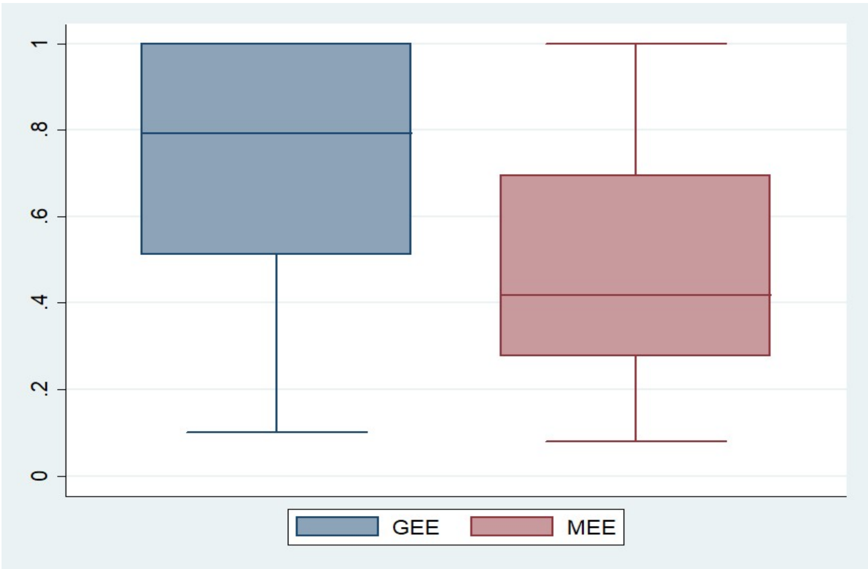

Figure 3.1: Box plot of firm-level GEE and MEE
Source: Author's calculation (2019)

The energy efficiency of the firms under four different groups is measured through SMB variant of DEA proposed by Tone (2001). Table 3.2 shows average energy efficiency under group-and meta-frontier from the year 2004 to 2016. The average energy efficiency level under group frontier from 2004 to 2016 is 0.90, 0.64, 0.73 and 0.57 for the north, south, east and west region respectively. The northern region has the highest energy efficiency level, followed by east, south and west. Energy efficiency difference is highest in the western region. Eastern region experiences the highest increase in energy efficiency from 0.55 to 0.86 for 2004-2016.

North and west have experienced minimal changes while the southern region experienced a decline over the same period.

The northern region has better infrastructure in terms of transport. Further, it is relatively environmentally sensitive area hence public awareness and regulatory pressure lead to better pollution control through energy efficiency improvement. The small and medium enterprises engaged in steel re-rolling dominantly in the northern region have achieved some level of energy efficiency by government initiatives (GOI, 2015). But it still lagged behind and incapable for implementing standard energy efficient technologies (EETs) Therefore, the condition in which the firms operate and state government intervention results in differences in energy efficiency level.

Eastern region is endowed with rich mineral and coal resources used in the production of iron and steel and historically very sound industrial base. It has more of the large-scale integrated plants operated by the large corporate houses in India and some government-owned plant. Better energy efficiency in the eastern region supports the role of industrial agglomeration in achieving higher energy efficiency (Otsuka et al., 2014). In the western region, Maharashtra accounts for a larger portion of firms. It has less energy efficient region which has surplus energy resources like electricity and gas. The southern area is also moderate energy efficiency level may be due to the energy efficiency programme. Interestingly, west and south have more significant energy efficiency variation across firms. In contrast, north and east have relatively less variation across firms.

Similarly, meta-frontier is estimated based on the whole sample and takes best energy-efficient units across the nation as a benchmark which capture technological gap across different groups. The overall average energy efficiency under meta-frontier for north, south, east and west are 0.42, 0.48, 0.48 and 0.43 respectively. As noted in the previous section, MEE will be lower than that of group frontier. East and south have an increasing trend over time while the other two regions remain relatively stagnant. The northern region is the best performer under group frontier, but this is not the case when it comes to meta-frontier. This shows that it is not necessary that best within the group also perform well under meta-frontier because the frontier is constructed here based on nation-wide best technological employment.

Table 3.2: Average energy efficiency under group and meta-frontier

Region	North		South		EAST		West	
Year	GEE	MEE	GEE	MEE	GEE	MEE	GEE	MEE
2004	0.938	0.466	0.739	0.477	0.558	0.362	0.656	0.472
2005	0.947	0.414	0.673	0.429	0.594	0.426	0.514	0.398
2006	0.925	0.354	0.544	0.438	0.704	0.358	0.455	0.322
2007	0.912	0.419	0.561	0.402	0.723	0.380	0.521	0.328
2008	0.929	0.410	0.646	0.420	0.659	0.788	0.507	0.340
2009	0.874	0.380	0.669	0.366	0.719	0.464	0.599	0.350
2010	0.917	0.508	0.617	0.433	0.736	0.522	0.585	0.517
2011	0.864	0.471	0.642	0.498	0.800	0.442	0.622	0.452
2012	0.873	0.457	0.666	0.531	0.920	0.550	0.499	0.427
2013	0.784	0.458	0.704	0.598	0.852	0.570	0.559	0.514
2014	0.905	0.473	0.610	0.575	0.828	0.529	0.587	0.518
2015	0.900	0.311	0.662	0.573	0.644	0.466	0.685	0.482
2016	0.957	0.440	0.689	0.575	0.865	0.426	0.636	0.510
Average	0.902	0.428	0.648	0.486	0.739	0.483	0.571	0.433

Note: GEE: Group-frontier Energy Efficiency MEE: Meta-frontier Energy Efficiency
Source: Author's calculation (2019)

3.4.2: Technological gap ratio

In order to analyse the existence of the technological gap in energy efficiency across four groups, TGR of energy efficiency is calculated according to equation 3.6 & 3.7. The graph of TGR over the sample period is given (Figure 3.2). Higher the level of TGR, lower the gap in the production technology between group-and meta-frontier. Overall west and south have better technological advancement in energy utilisation, thus having better TGR score. At the same time, east and North remain less efficient in employing nation-wide technology and having a considerable technological gap in energy utilisation. Therefore, it indicates production technique need to be calibrated and take across-regional technology into account. This particular result is exciting in the Indian context in designing regional energy efficiency policy where considerable heterogeneity exists across regions and demand for quick spillovers of advanced technologies across the regions.

In the context of TGR, the production system of nation-wide energy-efficient firms in the southern and western region should be imitated to reduce regional heterogeneity. Over time, TGR increases for almost all four regions with some fluctuations in 2009-2010 and 2014-2015. There is no smooth increasing trend of TGR over time, as in the group-and meta-frontier efficiency. Especially there is a decline in energy efficiency and TGR during and latter period of financial crisis 2008. This shows the effect of the financial crisis on energy efficiency. Financial and economic barriers are the major cause of non-realisation of full energy-saving potential. Therefore, the government should provide financial and institutional support to foster energy efficiency programme.

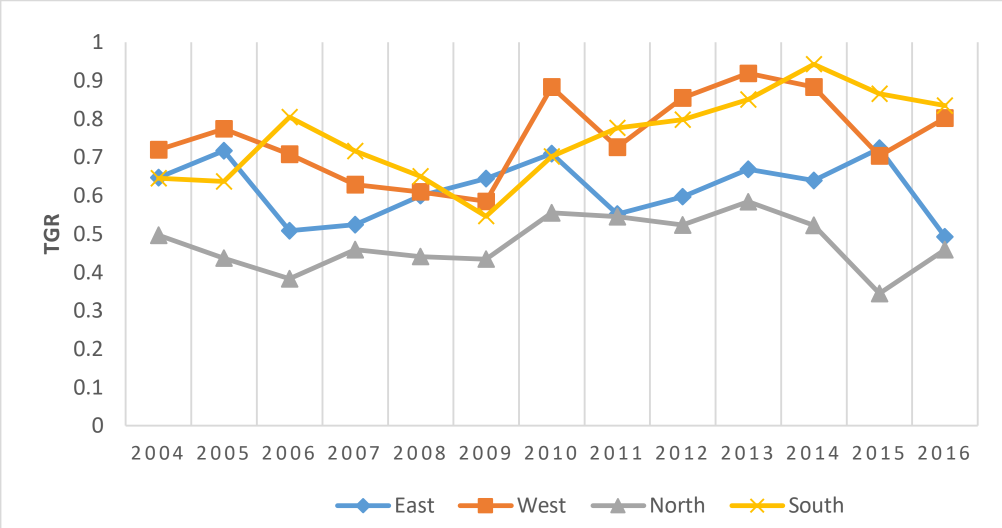

Figure 3.2. Technology gap ratio in the east, west north and south.

Source: Author's calculation (2019)

3.4.3: Decomposition of energy inefficiency

Energy inefficiency is decomposed into two parts: TGI and GMI, attributed to the technological gap and managerial inefficiency as per formula given in equation 3.8 & 3.9. In south and west, energy inefficiency is more caused by GMI, while for the north, it is heavily caused by TGI (Figure 3.3). Energy inefficiency in the eastern region is equally caused by both TGI and GMI. This result highlights the role of managerial efficiency in improving total energy efficiency in south and western region while more focus on technological advancement should be given in the northern region. At the firm level, adoption of EETs can help in reducing the technological gap. Diffusion of commercially available EETs through knowledge exchange and other means will reduce the energy efficiency gap. The energy inefficiency caused by GMI to a larger extent in south and west region should adopt better management system of energy use with employee awareness, environmental management system. Even though good opportunities are available, lower energy prices and lack of effective institutional set-up lead to ignorance of energy efficiency improvement (Acharya & Sadath, 2017; Yang, 2006). Some large-scale integrated plants have adopted as they have sound energy saving strategy and innovative management (GOI, 2015).

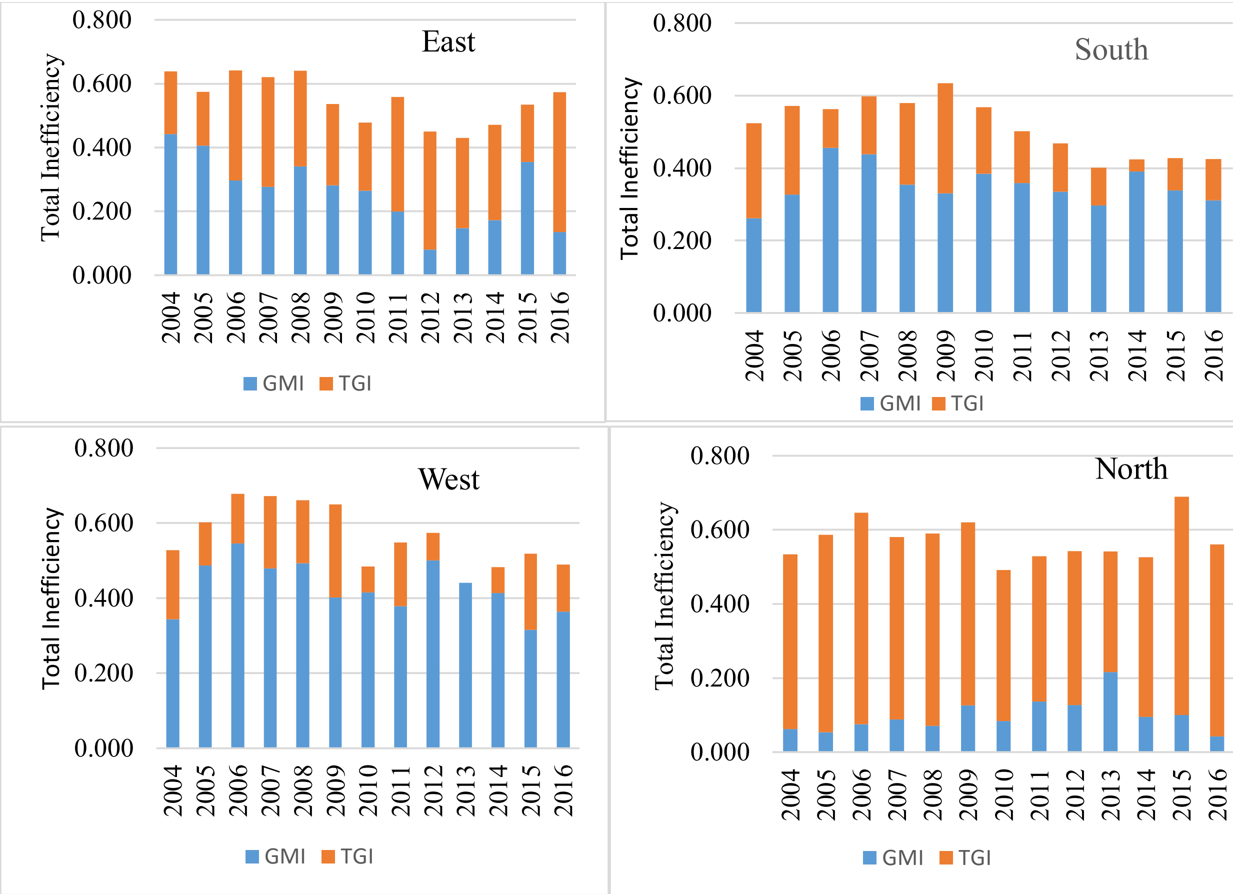

Figure 3.3. Decomposition of Technological Gap
Source: Author's calculation (2019)

3.4.4: Firms categorisation with energy efficiency

In order to analyse the structure of firms in terms of energy efficiency level, firms are categorized into three groups according to their level of energy efficiency score obtained from group-frontier. Firms with energy use efficiency less than 50 per cent are categorized as inefficient, with efficiency score lying in the interval of 50 –75 per cent categorised as medium-efficient and firms with energy efficiency more than 75 per cent are categorized as highly efficient firms. The distribution of firms according to their performance in energy efficiency level given in percentage of total number of firms in the group is presented (Table 3.3). It shows heterogeneity in the distribution of firms. 82 per cent of the firms are highly efficient in the northern region while 46 and 44 per cent in the South and East region respectively. In the western region, greater number of firms (42 per cent) lie in inefficient firm categories followed by highly efficient category (35 per cent). Therefore, most firms are either energy-efficient or inefficient. The variation in energy efficiency score across firms may be due to several factors such as varieties of production, quality of raw material, commitment for energy-saving and scale of production. (GOI, 2011).

Table 3.3: Distribution of Firm according to energy efficiency (in per cent)

	Number of firms		
Group	Inefficient	Medium efficient	Highly efficient
North	4	14	82
South	36	18	46
East	15	41	44
West	42	23	35

Note : Number of firms in percentage of total firm in the group
Source: Author's calculation (2019)

Further, it is tested whether energy efficiency distribution differs across four regions. So, the non-parametric test known as the Kruskal–Wallis test is adopted with the assumption that no difference exists across four regions. The result shows that the test statistic of Kruskal–Wallis method is 36.17, which is much higher than the lower critical value at 1per cent significance. Thus, the null hypothesis of all four regions come from the same gross is not supported which means the energy efficiency level across all four regions (east, west, north and south) are really significantly different.

3.4.5: Analysis of actual and potential energy intensity

Most of the time, in designing energy-saving target and energy efficiency improvement energy, most countries and regions take insights from the index of energy intensity (Cornillie and Fankhauser, 2004; Liddle, 2010). On the contrary, the estimation of energy efficiency applied in this case is based on relative efficiency in a total factor productivity framework. So, there is a methodological difference between energy intensity indicator as energy efficiency (a single-factor based efficiency index) and energy efficiency derived from total factor productivity framework. However, there are also some conceptual connection between these two types of indices. After the constraint of inputs is taken into account, the optimized combination of energy consumption under the group-and meta-frontier is given by $\left(GEE_n^h\right)e$ and $\left(MEE_n^h\right)e$ respectively. Similarly, the optimal energy intensity under two frontiers can be calculated as $\left(GEE_n^h\right)e/y$ and $\left(MEE_n^h\right)e/y$ respectively.

A comparison of national actual energy intensity and potential energy intensity during 2004 to 2016 under the meta-frontier energy efficiency model is presented (Figure 3.4). The trend over time of actual energy intensity and potential energy intensity is mostly stable. Still, there is a significant gap between both where actual energy intensity is considerably higher than potential energy intensity. The apparent gap between actual energy intensity and potential energy intensity has been widening since 2011. This particular phenomenon verdicts that substantial energy-saving potential exists for Indian iron and steel industry. Overall energy intensity has been declined over the period of study. The rate of decline in energy intensity level is very low as compared to other energy-intensive industry. Thus, the iron and steel industry need special attention from the standpoint of energy efficiency to achieve cleaner and sustainable production.

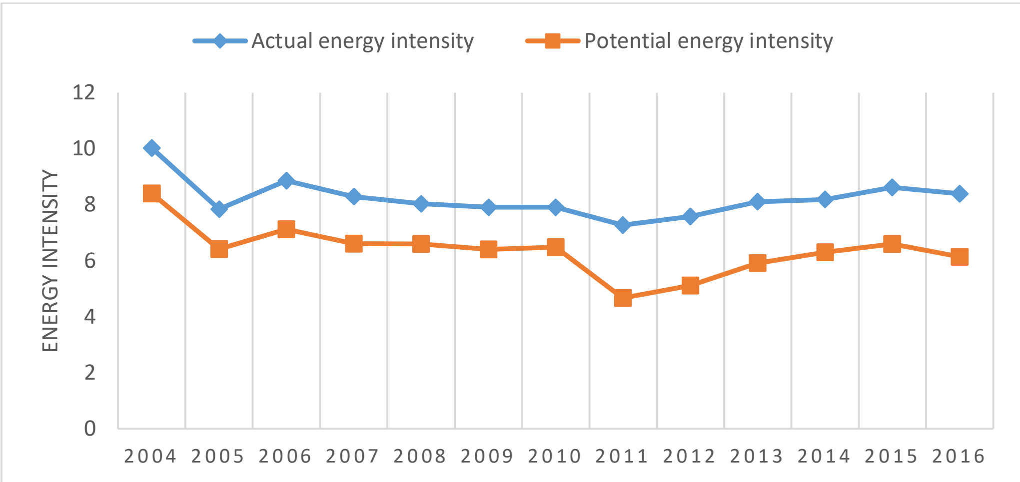

Figure 3.4. Comparison of actual and potential energy intensity
Source: Author's calculation (2019)

There is a need for massive investment in EETs through market-based mechanism which can be channelised through some financial incentive to the private sector. The green rating project of centre for science and environment (CSE) has found that large-scale integrated steel plants perform very pitiable, mainly located in Odisha and Chhattisgarh, among which Steel Authority of India (SAIL) a public sector company is worth mentioning (CSE, 2012). Hasanbeigi et al. (2014) calculated the comparable energy intensity level of 14.90 GJ/tcs in the U.S. while it is 23.11 GJ/tcs in China in the year 2006. Nevertheless, India is at 3rd position in the production of crude steel but having a significant gap in the energy intensity level as compared to the U.S. and China. Hence there is an urgent need for technological spillovers through the adoption of EETs at large scale to lower the energy efficiency gap.

The existence of different barriers (like economic and organisational barriers) needs to be addressed to enhance the level of investment in EETs. Even though several EETs (Coke Dry Quenching and combine heat and power) are commercialised and ready to adopt. But unawareness and financial constraint at the organisational and managerial level lead to underinvestment in the EETs (Nagesha and Balachandra, 2006). GOI has taken certain policy action recently under the bureau of energy efficiency (BEE) as PAT programme in 2012, but it lacks support from the regional government. As regional government play a crucial role in governance, they have to actively participate in enhancing energy efficiency and setting their energy-saving target. Two states, Maharashtra and Tamil Nadu, came forward and started setting their own goal of energy saving from the industrial sector (GOI, 2018). Hence coordination and energy efficiency scheme at the regional level is required to bridge the technological gap across regions and to achieve higher EETs penetration rate. There are different energy efficiency programmes launched under BEE but special policy focus is needed for enhancing energy efficiency in the iron and steel sector. Because it requires massive investment in EETs. There is a need to provide an incentive to iron and steel firms to build-up energy saving plan and energy performance evaluation. At the firm-level, long-term energy plan should be designed to reduce energy cost and also enhance the overall performance. Further, there should be EETs spillovers across regions.

3.5: Conclusion

The energy-intensive industries provide the industrial base of a country but also produce a large chunk of pollution. There is a different option that can be exercised to minimise environmental degradation along with economic growth. Enhancing energy utilisation efficiency is one of the cost-effective options for sustainable development. However, it requires a comprehensive examination of the current energy efficiency level, past trends and differences across firms. Given the fact that the relatively higher energy cost of the energy-intensive industry, there is an urgent need for energy use management and adopting EETs to unleash the energy-saving potential. The existence of heterogeneity across regions in terms of economic development, industrial concentration, resource endowment and development create geographical barriers and leads to a technological gap. Therefore, this study incorporates regional heterogeneity in the production function through meta-frontier DEA to get an unbiased energy efficiency measure. With the objective of sustainable development (energy conservation with economic growth), this study estimated the energy efficiency of Indian iron and steel industry using firm-level data.

Energy efficiency under group frontier shows maximum feasible energy saving under existing technology with the improvements at the managerial level. While meta-frontier energy efficiency provides information on potential energy saving under the utilisation of nation-wide best technology. The result shows that the northern states, including Delhi, Punjab, Haryana, Uttarakhand, Himachal Pradesh, have the highest energy efficiency level, followed by east, south and west under group frontier. Eastern region, including Chhattisgarh, Jharkhand, Odisha, West Bengal have experienced the highest increase in energy efficiency from 0.55 to 0.86 from 2004 to 2016.

The average level of energy efficiency under meta-frontier is higher for the south and east region and lower for north and west region. It is not necessary that the best within the group also perform well under the meta-frontier because the meta-frontier is based on nation-wide technology. Better energy efficiency in the eastern region, where the iron and steel industry is dominant in the industrial sector supports the role of industrial agglomeration in achieving higher energy efficiency. Low TGR shows that west and south regions have better technological advancement need to spillovers across north and east region. While energy inefficiency in the west and south are relatively more attributed to GMI whereas north and east region are significantly caused by TGI. Hence the overall results highlighted the role of managerial efficiency in improving total energy efficiency in south and western region while more focus on technological advancement should be given in the northern region.

Energy efficiency varies significantly across four regions and states, and the energy-saving target is also quite different. Therefore, when designing energy efficiency programme at the national level, the potentials and conditions of each region and states should also be taken into account. It is essential to bridge the significant technological gap to enhance the energy efficiency, particularly in the northern and eastern region. Further, relatively more emphasis should be given on enhancing material and human skill in south and western region. Technically, calibrating production process with suitable energy efficiency measure should be put in position along with the standard energy management system. At the firm-level some standard certification scheme like ISO 14001, 50001 should be implemented to enhance energy and environmental performance.

Chapter 4

Adoption of Environmental Management System and Energy use

4.1: Introduction

The devastating impact of climate change evident from the continuous increase in the temperature level, flood and drought, air and water pollution entail a rethinking on the development path. The disastrous impact is further intense on the livelihoods, society, culture and health of people in the developing countries (Gu et al., 2019). The apparent impact of industrial pollution provokes the dire need of policy mandate from government and businesses to integrate the flipside of economic development. In recent years, there has been growing concern over the environmental impact of heavily polluting industries. Institutional voices have been raised over the corporate environmental responsibility (CER) or in more general corporate social responsibility (CSR) (Earnhart et al., 2014; Nurunnabi, 2016).

To fix the environmental issues, developed countries implemented stringent environmental law with vigorous enforcement while developing countries lack the enforcement due to weak institutional capacity. This resulted in non-compliance with the perception of the high cost of mitigation and low probability of being caught (Berliner and Prakash, 2013; Blackman, 2012). Alternative cost-effective options are proposed and promoted to supplement weak environmental regulation, which is self-governed and market-oriented. Moreover, modern business firms recognise their CER and voluntarily adopt environmental management system (EMS). It is seen as a corporate strategy to strategically minimise its environmental impact (Jayashree et al., 2016; Zobel, 2016).

Among different EMS, ISO 14000 series has gained more popularity and widely adopted in developed countries (Japan and European countries). Later it has been spread to developing countries (Qi et al., 2011). It has several other benefits than better environmental performance. ISO 14000 series, notably ISO 14001, is the most widely adopted EMS, which has international standard and recognition. It systematically enhances the managerial capacity and quest for continuous improvement in the environmental performance prescribed by the International Organization for Standardization (ISO) guidelines. It comprises continuous appraisal and identification of the different dimension of potential environmental improvement. After identification, it requires a clear goal-setting which ensures that the environmental pollutants are within the stipulated limits. The firm needs to achieve the target beyond the limit and implement the more stringent standard as per the regulators or corporate guidelines. The implementation of ISO 14001 is regularly monitored through the audits by internal as well as external agencies. The firm can then apply for a formal certification through an independent accredited body after the external audit as it adheres to the prescribed ISO standards. Hence, it grants a broader set of goals to enhance environmental and resources utilisation efficiency which firm can wish to target (Kumar and Shetty, 2018; To and Lee, 2014).

Formal ISO 14001 certification is instrumental in signalling the market and regulator on compliance with the environmental standard. Previous literature shows that peer competition and stakeholder pressures are significant factors that lead firms to adopt ISO14001 standard (Neumayer and Perkins, 2004; Prajogo et al., 2012; Prakash and Potoski, 2007). The effectiveness of ISO 14001 in improving environmental performance remains questionable as it is generally a market-driven activity (Iatridis and Kesidou, 2018; Zobel, 2013). The motivation for adopting ISO14001 standard may vary counties to countries and industry to industry. Most of the previous studies examine the driving factor of EMS adoption in case of advanced countries while a growing body of literature is available in case of developing countries. Salim et al. (2018) sketched the global trend of research related to ISO 14001 or other EMS programme. They have done the bibliometric analysis and revealed the concentration of research in developed countries. Particularly between 2000 and 2016, the published research originate from Europe (40 per cent), North America (21 per cent), and China (11 per cent).

Recent studies conducted in case of developing countries have used survey data and small sample which may suffer from selection bias (Singh et al., 2014). Motivation may also depend on some industry-specific factors as regulation depends on magnitude of pollution caused by the industry. Hence, it has significant policy importance to reveal the key factors that push firms to adopt an EMS like ISO 14001in the pollution-intensive industry. Therefore, the objective of this chapter is to find out the key motivational factors that influence firms to adopt an EMS. For this purpose, a larger plant-level dataset from Indian iron and steel industry has been considered. ISO 14000 series adoption and other explanatory variables are taken for the year 2014-15 from the Annual Survey of Industry (ASI). After cleaning the data, 907 plants have been considered. Logistic regression analysis revealed the influential factors like firms characteristic: age, size, ownership, behind the adoption of ISO 14000 standard. Further, a thematic analysis of sustainability reports of top four Indian steel firms and one foreign company (Posco steel) have been conducted.

Rest of the chapter is arranged as follows. Section 4.2 discusses the EMS trend in India, section 4.3 provides theoretical and empirical insight from the existing literature on the adoption and effectiveness of EMS. Section 4.4 discusses method and data source of the analysis while section 4.5 provides the results and discussion. Section 4.6 sketches the thematic analysis of sustainability reports and section 4.7 concludes the chapter.

4.2: Trend of EMS adoption

There is considerable heterogeneity across firms in the implementation of EMS and environmental disclosure, which typically depend on organisational behaviour and characteristics. Indian industry is lagged behind the EMS initiative, environmental disclosure and reporting. It can be evident from the fact that only 37 companies published corporate sustainability reports in 2011-12, which has increased to 137 companies in 2014 after the mandatory reporting provision by the Securities and Exchange Board of India (Prasad et al., 2017). Further, after the implementation of Companies Act 2013, there is a provision of mandatory expenditure on CSR activities that include environment-related expenditure. Similarly, in case of ISO 14001, there is a shift in the trend in the year 2013 (Figure 4.1). Although the number of certifications grew from mere 111 in 1999 to 4286 in 2012, it drastically increased to 7887 in 2017. In case of EMS implemented until recently by Indian firms, are confined to environmental policy and ISO 14000 certification. Therefore, it documents that after government initiatives, companies inclined to consider the environmental issues and follow the EMS programme.

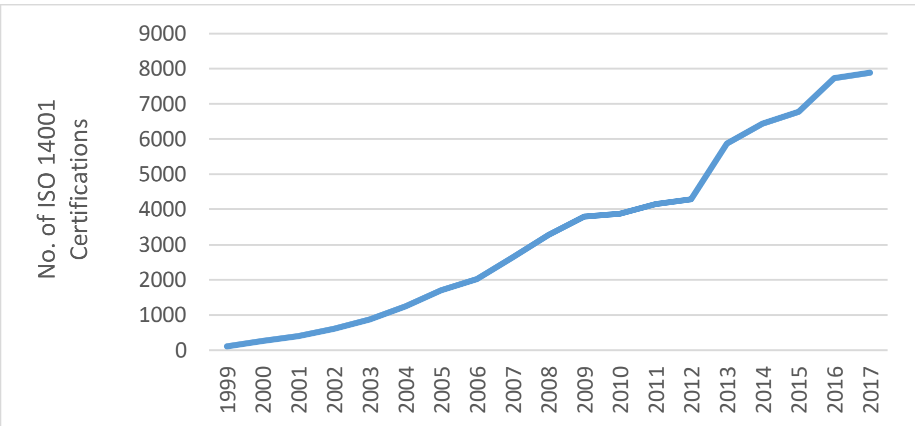

Figure 4.1: Trends of ISO 14001 certifications in India
Source: Author's calculation (2019)

The Indian government also promotes the adoption of ISO 14000 certification and grants up to 50 per cent of the expenditure to obtain the certificate to the export-oriented units (Singh et al., 2014). During the last five years, the number of ISO 14001 certification in India has been doubled. However, it is a pertinent question whether recent ISO 14001 uptake has resulted in concrete environmental improvement at this moment. There are nascent studies due to a dearth of research in this area and limited data availability as Indian firms vacillate to provide environment related data (Kumar and Shetty, 2018). Hence, this study aims to provide insights to motivating factors that lead to ISO14001 penetration among Indian firms with limited insight to its effectiveness through thematic content analysis. This is a preliminary step towards on-going research into the success and effectiveness of EMS implementation in India.

The global trend of ISO 14001 is very uneven. European countries are leading in the adoption of ISO 14001 while Asia and the Pacific regions envisage immense growth. China has the highest number of ISO14001 certification that is 1,65,665, which is 23,901 for Japan, while India is lagged and having only 7,887 ISO14001 certifications in 2017 (ISO Survey, 2019). A quick view of industry-wise uptake of ISO14001 certifications from the year 2011 and 2015 shows that basic metal & fabricated metal products adopted highest number of certifications (doubled from 338 to 658), followed by the chemical, electrical and auto equipment industries (Table 4.1).

Table 4.1: Industry-wise distribution of ISO 14001 certifications in India

Industry (Year)	2011	2015
Basic metal & fabricated metal products	338	658
Chemicals, chemical products & fibres	262	280
Electrical and optical equipment	228	303
Machinery and equipment	154	226
Rubber and plastic products	107	254
Food products, beverage and tobacco	81	95
Pharmaceuticals	73	77

Source: Author's calculation (2019)

Indian firms are revealing interest in the EMS programme. One thing should be noted that adoption of the EMS is lower in other pollution-intensive industry like pharma, food and beverage products and tobacco industry etc. Iron and steel industry has a significant share in the number of ISO 14001. It is essential from the pollution control point of view that the industry should use ISO 14001 effectively. Admitting the fact that small and medium enterprises (SME) causing 80 per cent of industrial pollution has greater potential to improve. However, it is a big challenge of widespread diffusion of ISO 14001 in SME due to the high cost associated with it. Government of India (GOI) extend their support in terms of reimbursement of 75 per cent of expenditure incurred in getting ISO-9000/ISO-14001/Hazard Analysis Critical Control Point certification (GOI, 2015).

4.3: Literature Review

4.3.1: Theoretical insights on EMS adoption

There is a cost associated with the adoption of EMS: ISO 14001, which may influence the firm's decision to adopt such an EMS. Particularly, in developing countries, there are no systematic regulatory and market supports. Hence, a rational firm may consider it as a burden to the goal of profit maximisation. There are several modern organisational theories in the corporate management system that hypothesises motivation behind the firm's behaviour on the environmental practices. The argument lies at the heart of literature is that firms use ISO 14001 to signal their eco-friendly practises and conciliate the pressures from a variety of institutions (Matouq, 2000; Prakash and Potoski, 2006; Bae et al., 2018).

Firms' motivation for embracing EMS can be seen from the different magnifying glass of organisation theory. These motivations can be categorised as relational, motivational, operational and other business motives. Legitimacy theory argued firms want to maximise their benefits from the social player by creating a legitimate business image. As firms operate under direct and indirect pressures from various stakeholders, EMS may potentially build a reputation of the firm (Prasad et al., 2017). The firm's legitimacy may be susceptible to civil society if the firm does not account for its environmental impact of the operation. Stakeholder theory explains the relationship between management and other stakeholders, pressure from stakeholders for better environmental performance. Environmental disclosure increases corporate transparency, reputation, and trust to the stakeholders. Environmental practices are seen as a part of the strategic practice that will benefit firms in tangible and intangible form. Hence, it justifies the rationality of adopting an EMS in the competitive world (Fikru, 2014a; Khanna, 2010).

ISO 14001 accentuates continuous progress, strategic management and appraisal that assist firms in assessing their internal operations and thereby improving operational efficiency and cost reductions. ISO 14001 certification encompasses considerable employee involvement and helps acquire new skills that will further distinguish the firm from competitors. While the resource-based view (RBV) reflected the role of internal firms structure and capability and argued that better resource firms could efficiently allocate resources to acquire ISO 14001 certification (Jabbour, 2015). Moreover, there seems to be complementarity among total quality management, other ISO management standards, pollution control policies, technological advancement and innovative capability of the firm (Neves et al., 2017; Qi et al., 2011).

With the recent emergence of CER in developing country setting, Earnhart et al. (2014) attempted to hypothesise the corporate behaviour on environmental strategy from four significant dimensions of business environment (Figure 4.2). Input market pressures depend upon the extent of investor and employees perspective on environmental management and energy and material procurement strategy. While output market pressure derives from customer demand for eco-friendly products, especially by foreign customers. Civil society, environmental regulation and local ethics also shape the environmental practices of corporates. Therefore, to provide a trustworthy indication to different stakeholder, ISO 14001 possibly provides a potential signal when firms operate under a weak regulatory framework.

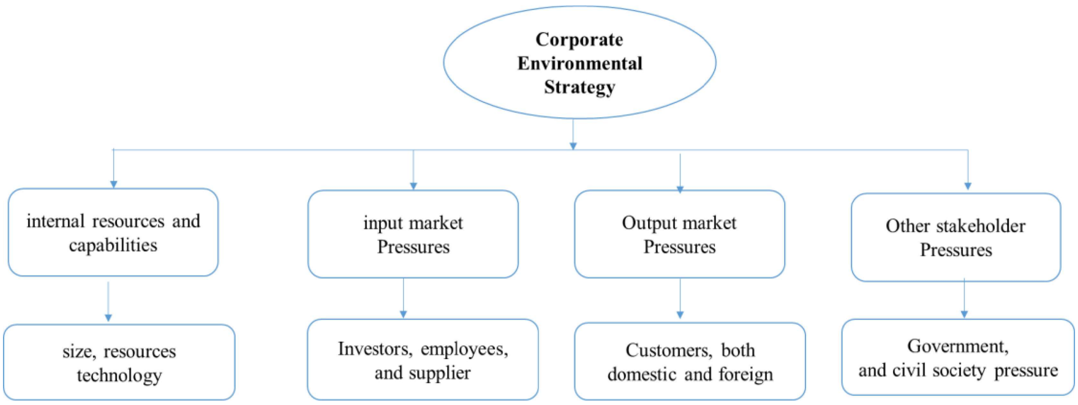

Figure 4.2: Theoretical model of corporate environmental strategy

Source: Author's calculation (2019)

4.3.2: Empirical Literature

Early empirical studies examine the role of different output and input market factors on per capita diffusion of ISO 14001 standard across countries (Corbett and Kirsch, 2001; Bae et al., 2018; Potoski and Prakash, 2013; Prakash and Potoski, 2007). These studies show that export orientation of firms and particularly country to which firms primarily export (developed countries) influence the ISO 14001 adoption. Country that highly inclined to ISO 14001 standards may seek similar standards for exporting firms. It is also envisaged that exporting to

Japan and Europe (relatively higher number of ISO 14001 certifications) influence the certifications in exporting countries. Larger size firms and prior experience with ISO 9000 standard firms are greatly inclined to adopt ISO 14001 (Fikru, 2014b). Several other factors, like efficiency gain, enhancing corporate image and international recognition, motivate firms to adopt ISO 14001 standard. Blackman (2012) shows that along with different motives of firms' regulation, as measured by a penalty within the last three years, increases the probability of ISO 14001 certification.

Motivation to adopt the ISO certification remains unclear in developing countries firm while bureaucratic regulation and enforcement, unionised labour force, granting of permits, and higher rates for emission charges are more effective in such practice (Earnhart et al., 2014; Fikru, 2014a; Frondel et al., 2018; Iatridis and Kesidou, 2018). Hence, certified firms are in a privileged position as it signals regulatory authority on compliance. Supply chain dynamics, foreign ownership and foreign customers are also significant factors that lead to ISO 14001 adoption (Dasgupta, 2000; Qadir and Gorman, 2008; Turaga and Gupta, 2018). Along with this, international banks as creditors that have a vision of sustainable operation, analyse investment from sustainability-related risk and disseminate standards to the customer about its CSR (Fikru, 2016, 2014b).

Recent literature tries to establish the efficacy of different channel of institutional pressure for adopting EMS and found mixed results for different countries. There is a perceived dualism between EMS adoption and actual environmental performance of the firm, which is consistently documented in the literature (Iatridis and Kesidou, 2018; Zobel, 2013). As in polluting industries, a considerable amount of resources require which may be undermined by the firm's prime objective of profitability. Hence top management may undermine real efforts required for greening. There are mixed results on the efficacy of ISO 14001 or other EMS programmes in reducing the firm's pollution level (Ferrón Vílchez, 2017; Hazudin et al., 2015; Heras-Saizarbitoria et al., 2011). Most of the studies found that internationalisation using either trade, investment or ownership has a profound impact on the propensity to adopt an EMS.

In case of Indian industry, there is a meagre amount of literature that analysed the motivation of firms to adopt ISO 14001 standard. Singh et al. (2014) found that large-sized firms with better financial resources and public visibility are more likely to adopt an EMS. Given the higher cost of EMS setup and operative cost, larger and experienced firms may realise the long-term benefits from ISO14001 certification more effectively. Turaga and Gupta (2018) found that exporting to foreign markets, particularly to China, firm size, and innovation are positively associated with the likelihood of getting ISO 14001 certification. Kumar and Shetty (2018) examine the determinants of different voluntary environment programmes (VEPs) undertaken by Indian firms. They found that firm's size, its location, export orientation, and intangible valuation have a positive relationship with the number of VEPs undertaken by the firm.

Most of the studies are survey-based and selected the sample based on data availability which is a major challenge for research in this area. Some researchers have taken data through the right to information act, a unique way to get pollution-related information at firm-level (Kumar and Shetty, 2018). In the case of Indian SME, Singh et al. (2015) found that ISO 14001 certification enables effective waste minimisation. Shetty and Kumar (2017) did not find any significant relationship between VEPs and environmental performance for a sample of Indian polluting industry's firms. The focus of this study is iron and steel, which is highly polluting and resource-intensive, hence requires special attention.

4.4: Method and Data

Plant level Data for the study has been collected from the Annual Survey of Industry (ASI) for 2014-15. After cleaning data, 907 plant-level data has been taken for the iron and steel industry (NIC code 241), which is relatively larger. It was the latest available data from ASI. Further, no common identifier has been given in ASI data which makes it impossible to construct a panel data at plant level. ASI provides data on whether a plant has IS0 14000 series certification, which pertains to EMS standard. From the whole sample, 21 per cent of firms have IS0 14000 series certification. The data covers plant operated across 22 Indian states and of different size. Table 4.2 provides details of data construction and variables symbol used in the regression and descriptive statistics. Geographical distribution of firms has been given in Appendix II which shows the distribution of the certified and total number of firms across states. There is an agglomeration of steel plants in the northern part of the country (Jharkhand, Chhattisgarh, and West Bengal). The correlation analysis among the variables is given in Appendix III. The correlation of ISO 14000 series adoption is positive with age, export, capital intensity, regulation, and large and medium-sized firms. At the same time, it is negative with small size firms and both measures of energy intensity.

Table 4.2: Variable Description

Variables	Symbol	Measurement	Mean (S.D.)
ISO 14000	ISO	ISO 14000 certification =1 otherwise 0	0.21 (.4140716)
Size	size_m for medium firms size_l for large firm	Dummy variable Large >= 100 employees Medium >=20 and <=99 Small >=5 and <=19 small is the reference category in all the analyses	Large = 0.7233 (0.45) Medium = 0.10 (0.15)
Export orientation	export	Dummy variable = 1 if a firm exported in 2014-15 otherwise 0	0.0981 (0.2976)
Age	age	Years since the establishment of the plant	1997 (30.17)
Ownership	own	Dummy variable Classification Owd= 1 if Wholly Private otherwise 0 Public sector use as a reference category	
Regulation	regulation	State-level environmental regulation index was taken from Lovo (2015)	
Energy intensity	EI_1	The ratio of energy to output	0.11(11.11)
Energy intensity (Dummy variable)	EI_2	EI_1 = 1 for firms whose energy intensity is lower than average energy intensity Otherwise 0 Higher average energy intensity categories kept for reference	0.64(.4784)
Capital intensity	capint	The ratio of fixed capital and output	0.720707(1.283)
Interaction of Ownership and size	own_m	Ownership * size_m	0.0893 (0.286)
Interaction of Ownership and size	own_l	Ownership * size_l	0.48952
Interaction of export and size	ex_m	Export * size_m	0.005(0.074)
Interaction of export and size	ex_l	Export * size_l	0.08820 (0.283)

Source: Author's calculation (2019)

Firm size is measured as a categorical variable based on the number of employees. Firm-level data is not available in case of regulation. So state-wise differences are used to test whether states level regulation resulted in ISO 14000 series EMS adoption. Export orientation is measured as a dummy variable based on whether a firm has exported in the year 2014-15 or not, and only 9 per cent of firms have exported. Energy intensity is measured as the ratio of energy consumption and gross output both in monetary term. One more indicator of energy intensity is used as a dummy variable based on the average energy intensity level. Above-average energy intensity level is assigned 0 and lower than average is assigned one. This provides some insight, on an average level, whether the differences in firm's energy intensity assert some influence on the ISO 14000 uptake. Around 76 per cent of firms are wholly private-owned hence it is essential to test whether there is any difference in the ISO 14000 take off between public and private sector. Further, some interaction dummy has been used to test the interaction of large and small size firms with ownership and export orientation influences the EMS adoption. Logit model has been applied as our dependent variable is binary. It provides the likelihood of firms being certified.

4.5: Results and Discussion

In the sample, among large-size firms, 26 per cent of firms have the certification; on the contrary, only 6 per cent of small size firms have the certification. In the case of state-wise distribution Goa, Karnataka and Jharkhand have the highest share of certified firms while Gujarat, Bihar and Kerala have the lowest share of certified firms. Looking at ownership wise distribution, government enterprises have largest share of the certified firms while the private sector has the lowest number of the certified firms.

Table 4.3 shows the results of logistic regression model consist of six different models using a different combination of motivational factors and indicators. Model 1 is a baseline model that includes firms characteristic, while in model 2, the second measure of energy intensity (EI_2) has been introduced. Model 3 further includes capital intensity as an explanatory variable, while model 4 and model 5 introduce an interaction term of size with export and ownership. Finally, the state-level regulatory index has been included in model 6. Model 1 shows that large and medium-size firms are more likely to be certified than small-size firms. The positive likelihood of getting certified in both large and medium-size firms is consistent in all other models and supports existing literature.

The coefficient of export is insignificant in model 1, whereas it turns to be significant at the 10 per cent level in other models. Hence, export as demand-side pressure does not drive in Indian iron and steel. This is contrary to existing studies which strongly supported the role of pressure from importing countries customer to adopt EMS. Simple measure of energy intensity, EI_1, is not significant in model 1. To further explore the role energy intensity, it is replaced by a second measure of energy intensity, EI_2. This measure provides whether firms with higher than average energy intensity are more likely to get the certification. The result from model 2-6, consistently shows that firms with lower than average energy intensity, are less likely to get certified. Therefore, higher than average energy intensity may motivate firms to implement an EMS to lower their SEC. However, the significance of results is weak as it is significant at the 10 per cent level. At the same time, the energy output ratio is also not significant.

Table 4.3: Logistics Regression Results

Variables	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
size_m	1.070**	1.045**	1.049**	3.544**	1.112**	0.986*
size_l	1.266***	1.265***	1.271***	2.556**	1.318***	1.199
own	-0.863***	-0.892***	-0.893***	0.649	-0.89***	-0.923***
age	0.013**	0.013**	0.013**	0.013**	0.013**	0.013***
EI_1	0.009					
EI_2		-0.326*	-0.327*	-0.322*	-0.328*	-0.338
export	0.448	0.455*	0.454*	0.470*	1.261	0.469*
capint			-0.010			
own_m				-2.907*		
own_l				-1.569		
ex_m					-1.054	
ex_l					-0.829	
Regulation						-0.506
Log pseudo likelihood	-414.537	-413.651	-413.641	-411.240	-413.435	-396.154
Pseudo R2	0.121	0.123	0.123	0.128	0.124	0.118

Notes: *, **** and ***** show the level of significance at the level of 1, 5, and 10 per cent level, respectively.

Source: Author's calculation (2019)

The positive coefficient of age shows that old firms are more likely to be certified. Given that old firms have more resources while new firms are financially constrained, higher-age firms are more likely to adopt an EMS. Age of firms play an essential role in the firm's mandate to reduce its environmental impact. The result is robust as it is statistically significant across all models. Ownership of firms also play a vital role in shaping corporate environmental practices and influencing firms to undertake an EMS. The results show that privately owned firms are less likely to adopt EMS than public sector firms. Public sectors firms feel more pressure from the regulatory authority and more visible than the private sector. Hence, they are more likely to undertake environmental practices. While private firms may see it as an extra burden under the weak regulatory scenario. Indian private firms do not feel great pressure from civil society and regulatory authority; hence, they do not take environmental practices seriously. Capital intensity turns to be insignificant and does not influence EMS practices. Interaction of size with export and ownership also turns to be insignificant except in the interaction of ownership and medium-sized firms. Hence, medium-sized private firms are more likely to adopt an EMS with respect to large and small private firms. Regulation index at the state level also does not influence the adoption of an EMS. It indicates that firms do not feel enough regulatory pressure to adopt an EMS voluntarily.

4.6: Thematic Analysis of Steel Companies

Many countries have initiated and made provision for companies to report their business sustainability and impact on the environment. Most of the multi-national companies based on the transparency principle report their sustainability and extend the involvement of different stakeholders worldwide. In this regard, the Global Reporting Initiative (GRI) has taken international initiative for business and other organisation to report its impact on climate change, labour and human rights. "GRI is the most trusted, recognised, and accepted organisation in the area of social, environmental, and economic information disclosure and sets the triple bottom line reporting guidelines to be more transparent, reliable, and comparable". It is the first global standards based on a common guideline for reporting and disseminates the report freely.

Different GRI reporting guidelines evolve over time, such as G1, G2, G3, G4, citing GRI, and non-GRI. In developing countries, the GRI reporting is increasing across the country. In 2016, 148 and 676 Indian and Chines firms reported to GRI. From the metal sector, only 10 Indian organisation reports its sustainability report to GRI. This study considers the G4 type report, which has 34 environment-related indicators. While it is 30 in the case of G3 and G3.1. G4 has some interesting comparable indicators which can be used to benchmark firms in terms of their environmental performance. Furthermore, biodiversity, life-cycle and supplier environmental assessment related information enrich the report's dimension.

Apart from empirical analysis on the firm's motivation to adopt ISO 14001 standard, this study conducted a thematic analysis of Sustainability Report. It is essentially a comparative analysis of indicators, like energy and emission intensity, water use and by-product. For this purpose, four Indian steel companies, TATA steel, JSW steel, Steel Authority of India Limited (SAIL) and Jindal power and steel, are taken which have reported to GRI. Along with these firms, one South Korean based steel companies Posco Steel has also been included in the analysis for benchmarking and reference purpose which recently opened a subsidiary in India known as POSCO Maharashtra Steel.

The Disclosure on Management Approach (DMA) which provides initiative and plans on environmental management by the companies has been studied. While there are 34 environment-related indicators in G4 type report, there is a difference in the number of indicators reported by companies which show environmental disclosure practices differ across companies. The comparative analysis has been done on the performance analysis in terms of Energy consumption and efficiency, Emission performance, Effluents and waste discharge, Water consumption and biodiversity and other environmental assessment.

4.6.1: Specific energy consumption (SEC) and efficiency performance:

Energy intensity is an important indicator that represents an efficiency parameter. The sustainability indicator of World Steel Association (WSA) has given the world average energy intensity of 4.77 Giga calories per tonne of crude steel (Gcal/tcs) and the Indian average is 6.9 Gcal/t (WSA, 2019). It shows a large gap exists for SEC. None of the considered companies has reached the world average and operates around average Indian SEC. TATA Steel performs well among them with 5.76 Gcal/tcs relatively close to Posco's SEC of 5.22 Gcal/tcs (Figure 4.3). Over the last three years, the SEC of TATA and SAIL has been decreasing while for JSW, increasing and becoming above the Indian average. Jindal steel and power operates with EAF production route, does not report its SEC.

Indian firms are moving towards an energy-inefficient production system of Coal-based sponge iron which requires, on average 8.5-9 Gcal/tcs (Kanchan, 2013). Moreover, lower energy price induces firms to ignore the issue of energy conservation. As they may employ commercially viable EETs and harness vast energy-saving potential. TATA has provided DMA on different energy conservation and technology absorption projects in detail. While SAIL has described shortly with notably one plant (Rourkela), has operated with Top Recovery Turbine Generator (TRTG) and plans to commission at other plants. While JSW highlighted the remarkable achievement of the 98.5 per cent waste gas utilisation and 71 per cent waste heat recovery (WHR) without describing details about the EETs employed and respected energy saving.

Though these big companies are sending money on energy conservation measures but in comparison to its turnover, it is lower. TATA Steel seems to outperform in energy saving through different measures like Coke Dry Quenching (CDQ), WHR and TRTG, widely applied EETs TRTG. Posco's application of different EETs enables them to utilise most off-gases generated during the production processes which is used for self-generation of electricity. Energy recovery facilities such as CDQ, TRTs and LNG combined cycle power plants cover 63 per cent of electricity use at Pohang and Gwangyang Works. Posco is developing innovative technology for reducing air pollution by capturing CO_2 emission and other gases. In the EAF route, Jindal has reported adoption of new oxygen furnace that reduces energy consumption to zero. The performance of Indian companies needs to be improved considerably in order to reach GBP. In this regard, the government should promote and incentivise firms towards self-generation of electricity through waste heat recovery and off-gas utilisation.

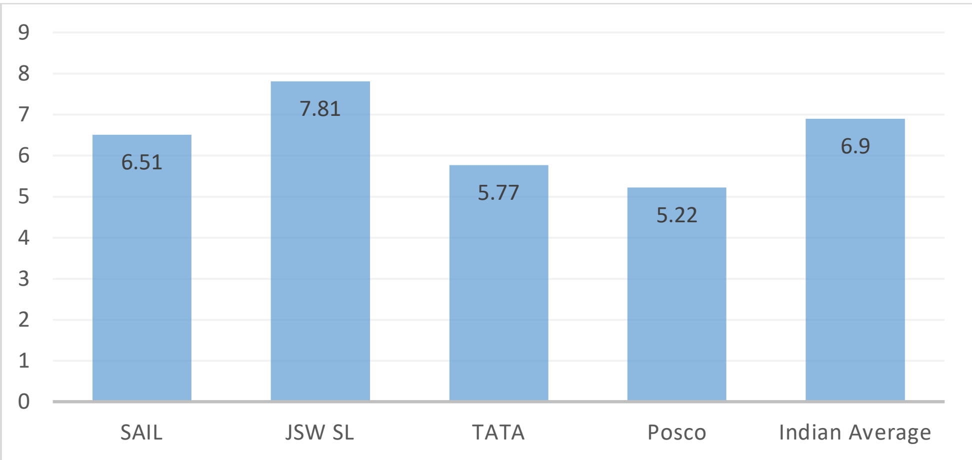

Figure 4.3: Specific energy Consumption (GCal/tcs) for the year 2015-16
Source: Author's calculation (2019)

4.6.2: Emission performance:

CO_2 emission is considered as a significant air pollutant due to consumption of large chunk of coal. WSA aims to provide benchmark data on CO_2 emission intensity and related technology. GBP around the world operate with 1.8 tCO_2 /tcs (WSA, 2019). Leading steel companies worldwide engage in in-house R & D activities to provide the best solution of minimising emission and effectively use it for another purpose. Posco engages with developing a different innovative method to minimise emissions. It captures CO_2 from off-gas and development of Pulsating Combustion Technology. Similarly, in the case of energy intensity, average Indian firms emit around 2.7 tCO_2 /tcs while TATA steel provides a national benchmark of 2.26 tCO_2 /tcs (Figure 4.4) Indian firms are far away from achieving GBP or Posco CO_2 emission intensity of 1.91 tCO_2 /tcs. Despite higher energy intensity, JSW has lower CO_2 emission intensity as compared to SAIL, which shows the importance of end of pipe technology for emission control.

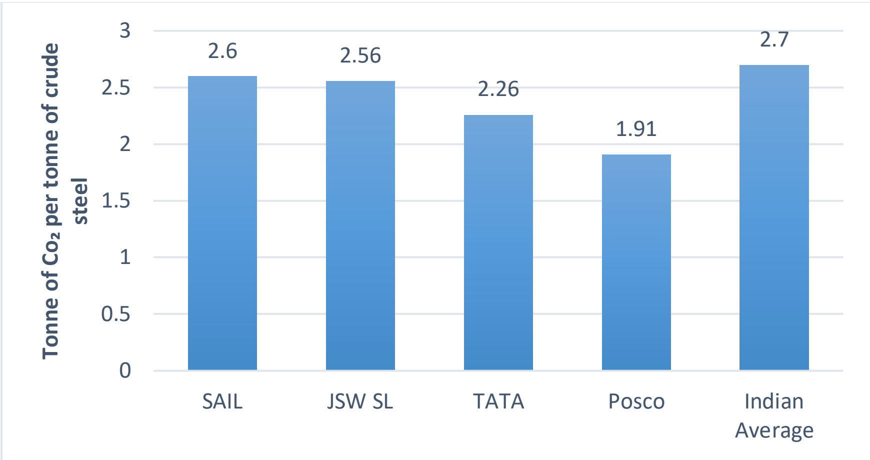

Figure 4.4: CO_2 emission intensity for the year 2015-16 (in t/tcs)
Source: Author's calculation (2019)

Sulphur oxides (SOx), Nitrogen oxides (NOx) and particulate matter (PM) are important pollutants, which is reported by TATA and JSW only. SAIL only reports PM emission stating that SOx and NOx are controlled and reduced by control equipment. Since these emissions have some regulatory limit so needs to be reported. But generally, companies state that these emissions are under the regulatory limit. NOx emission by TATA and JSW are relatively close to Posco level (Figure 4.5). In case of PM (dust) emission, TATA steel (0.57 kg/tcs) performed better than JSW (1.2 kg/tcs) and SAIL (0.81 kg/tcs). While in the case of Posco, it is 0.09 kg/tcs, depict a significant gap between India and GBP. Notably, SOx emissions are very high around 2.1 kg/tcs for JSW and 1.36 in case of TATA which is more than double of that reported by Posco (0.56 kg/tcs). Indian firms are very far from GBP by considering Posco emission level as best practice. These companies having vast resources and they do not care about these issues and do not install pollution control equipment. Local population has also been facing severe problem from heavy dust emissions like eye irritation and breathing problems.

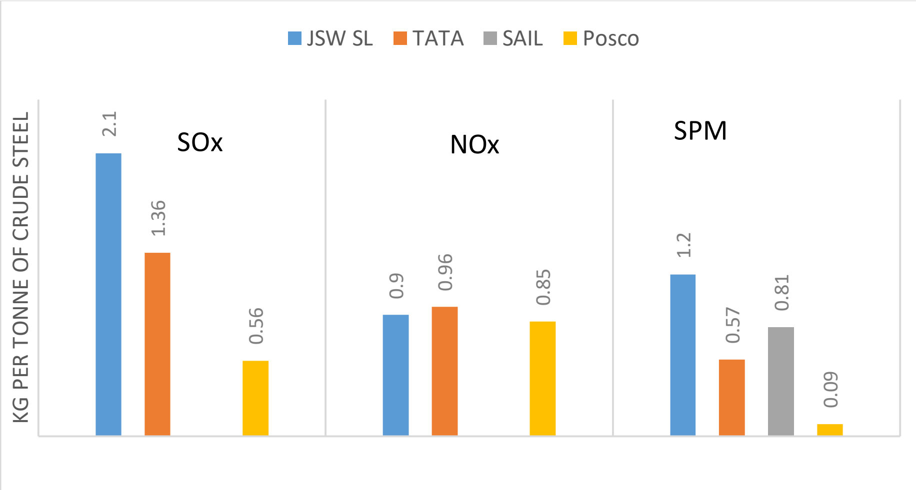

Figure 4.5: Other emission intensity for the year 2015-16 (in KG/tcs)
Source: Author's calculation (2019)

4.6.3: Effluents and waste management:

Vast amount of hazardous and non-hazardous waste gets generated during iron and steel production. Effluents constitute a significant part of water pollution which are directly discharged into surface water. There is not much mention about the effluents management while all companies acknowledge the need for zero liquid discharge (ZLD) and the importance of reuse and recycle. The average effluent discharge from Indian integrated steel plant is about 1.75 m3/tcs. TATA achieved near ZLD in 2015-16 while SAIL has proposed the plan for ZLD at different facilities. As per the GBP, plants should not release wastewater at all. Examining the average solid waste, the reports show that for every tonne of steel production churn out half a tonne of solid waste while the GBP is only 100 kg/tcs. Hence, recycling and reusing these wastes has become crucial. The average recycling rate of different kinds of solid waste are presented (Figure 4.6). Different kinds of slag can be easily converted into valuable products. Therefore, steel companies found it economical to utilise solid waste (cement and tiles production) and selected companies also utilise it up to 85 per cent. Practically these by-products can be utilised up to100 per cent as Posco does it around 98 per cent of waste generation. Companies across the world use these wastes to build roads and railway tracks.

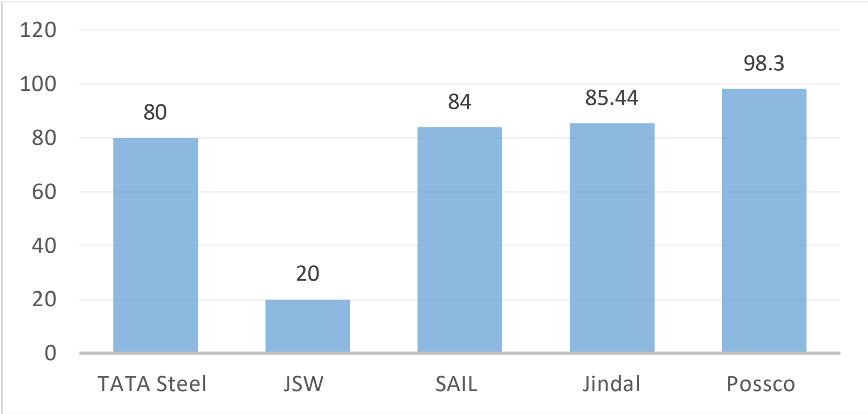

Figure 4.6: Solid waste utilisation for the year 2015-16 (percentage)
Source: Author's calculation (2019)

4.6.4:. Water consumption and biodiversity:

A general narrative has been asserted in the reports that "No negative impacts were observed on the water sources or the nearby water bodies because of operations". Though a large amount of surface water has been withdrawing to produce millions of tonnes of steel with recycling rate of around 25 per cent. On average, specific water consumption of Indian steel plant is very high at 3.5 m^3 per tonne of crude steel (Figure 4.7). Even TATA and JSW are consuming even more than the national average while SAIL is at the national average. This shows that top Indian steel companies remain inefficient in water consumption. Taking Posco for the benchmark, water consuming at 1.5 m^3/tcs, Indian industry can save more than half of the current consumption of water as it becomes a crucial importance for sustainable development. However, little concern has been seen to improve water consumption efficiency. Freshwater intake of steel companies has seen marginal decline over the last three years but it remains substantially high with regard to GBP. TATA and JSW have reported the water recycling rate of 23 and 30 per cent (as percentage makeup water requirement) respectively. All companies rely on surface water with little importance on water harvesting and management. All companies have reported concern over biodiversity conservation and associated with an external organisation to develop the biodiversity of the surrounding area. Tree plantation and ecological restoration steps have been taken by TATA and SAIL.

Figure 4.7. Specific Water Consumption for the year 2015-16 (in m3/tcs)
Source: Author's calculation (2019)

For emissions control, Jindal has installed air emissions protection equipment such as Electrostatic Precipitator, scrubber systems, cyclones, bag-houses, and waste heat recovery systems. As per the report, SAIL has spent 5000 crore rupees on pollution control schemes and 360 crores on energy efficiency improvement, while TATA has spent 133.80 crores on Research & Development and 340 crores on environmental expenditure. Nevertheless, these companies operate with more or less Indian average and far behind GBP. Posco can serve as a potential reference for technological transfer and pollution control strategy for Indian firms. Since Indian steel firms are relatively protected from foreign competition and safe from world fluctuation, it is favourable to manage the environmental impact. However, the industry is running with certain shortcoming of low-quality iron ore and coal. However, these can be effectively overcome by utilising advanced technology. Posco effectively manages total air pollution through a sintering exhaust gas cleaning device, which serves as a major reduction facility. It has been developing pollution control technologies that can reduce hazardous chemicals. With the basic effort, Posco has increased the number of educated managers in operation and use continuous monitoring of emission and effluents.

4.7: Conclusion

There has been growing interest among firms to adopt EMS like ISO 14001 and other ISO 14000 series standard. However, there is a paucity of research on the firm's motivation to adopt an EMS. Thus, in this chapter, potential factors at firms' level have been taken and the role of different firm-level motivational factor are explored that leads to the adoption of an EMS. For this purpose, plant-level data has been taken for the year 2014-15 from the Annual survey of industry. Further thematic analysis of the sustainability report of leading Indian steel companies has been done.

Different logit regression models have been estimated as our dependent variable (adoption of ISO 14000 series) is a binary variable. Results from the logit model validate the role of firm's size, age and ownership in motivating firms to adopt an EMS. In case of size, large and medium-sized firms are more likely to be certified as compared to small size firms. The results are consistent across all model which is supported by the recent literature. Age and ownership also influence the adoption of EMS as it is statistically significant across all models. Old firms are more likely to get EMS certification. Contrary to existing studies, results do not support demand-side pressure from international customers in case of Indian iron and steel. Further results do not support the role of regulatory pressure on the firm's adoption of an EMS, as the coefficient of the regulation index at state is insignificant.

The thematic analysis of top Indian steel companies viz TATA steel, SAIL, JSW Steel and Jindal steel along with foreign companies POSCO steel has been done. These indicators show that these Indian steel companies have a considerable gap with GBP and Posco steel and similar to the average performance of the Indian steel company. TATA steel having the largest production capacity outperforms other companies in terms of carbon emission intensity of 2.26 t/tcs as compared to average Indian firms of 2.7 tCO_2 /tcs and while much higher against Posco steel of 1.9 tCO_2 /tcs. Posco steel has achieved lower energy and emission intensity due to the adoption of advance EETs of which off-gas utilisation (waste gas like CO, SO_x, NO_x utilisation) and WHR has become prime importance. Further SO_x, NO_x and PM emissions are considerably higher than of Posco emission. Hence, the end of pipe technology should be applied in Indian steel industry. Though these emissions are under the lax regulatory limit but significantly higher than GBP. As technological advancement helps in reduction of emission level, the regulatory limit needs to be enhanced in order to move towards GBP. Finally, the voluntary environmental programme and BAT should be promoted in order to reduce the environmental consequences.

Chapter 5

Technological Innovation and Energy use Efficiency

5.1: Introduction

Growing industrial energy demand and its environmental impact pose a severe challenge to climate change. Thus, energy-intensive firms are under regulatory and market pressure to reduce their energy consumption and environmental impact. Energy efficiency has been seen as a crucial policy option to reduce energy use and prevent environmental degradation. It has huge potential and can save energy by 40 per cent in most industrial production processes (IEA, 2018b). It has remained largely untapped by developing countries' firms and hence there has been a persistence of the energy efficiency gap with reference to global best practices (GBP). Energy efficiency improvement can provide a better strategy to cope with uncertainty in energy price and environmental regulation. It will help to gain competitive advantage through cutting energy cost and upgrading technology. It works according to the market-based mechanism of investment, cost-effectiveness, ease of compliance, and efficiency gain in management (Na et al., 2019).

Success of energy efficiency improvement programme require continuous support regarding finance, technical know-how and effective management. Due to organisation inertia and project evaluation criteria, it does not get prime importance in corporate investment strategy particularly in developing countries. Hence, to effectively manage all these issues, the business model of Energy Service Company (ESCO) is crucial. It provides essential support through the assessment to implementation of energy-saving projects. This model has been accepted and established in advanced countries to provide energy related customise solution. However, in India, it is at the beginning stage and utilises only 5 per cent of its estimated potential (BEE, 2020). Diffusion and commercialisation of energy-efficient technologies (EETs) are limited to the government-driven demonstration, with low scale installation (Haider et al., 2019). It is mainly concentrated in the commercial building and consumer durables through implementing mandatory star labelling programme. Moreover, it is consumer-oriented and does not require considerable investment.

The industrial sector is lagging behind. Implementing the energy-saving project in industrial units can bring transformation in operational efficiency. Notably, technological, financial and managerial constraints restrict firms to adopt energy efficient operation in developing countries such as India (Prasad & Mishra, 2017). Longer expected payback period, technical risk and lack of capital are barriers for iron and steel firms in Germany (Arens et al., 2017). Generally, firms have the perception that pursuing eco-friendly operations will barricade their profit-maximising objective. However, organisation growth theories such as natural resource-based view (NRBV) recognise the importance of building environmentally-oriented innovative capacity to achieve long-term growth and competency (Hart & Dowell, 2011). Signalling and legitimacy theory asserts that eco-friendly production enables firms to create a legitimate image among stakeholders while enhancing their innovative capability (Alam et al., 2019). Hence, it will be a win-win game if firms strategically improve its energy and environmental performance through gain in their managerial and technological capacity.

Environmental management system (EMS) paves the way to build managerial capacity. In this context, ISO 14001 certification has gained vast popularity as innovative measure to reduce a firm's impact on the environment. Innovative capability can be defined as the firm's technological ability that results in superior production technology and competence to adopt an efficient production process. It is cumulative technical know-how that the firm gains through implementing different advance technologies that prevail or are new to the industry. It is essentially the firm's ability to effectively adapt, assimilate the better technology for commercial ends uses. Hence, it is multidimensional, which accrues to the firm over time through the different channel as discussed below.

Research and Development (R&D) investment enhances a firm's absorptive capacity and helps to upgrade its technology. R&D activities facilitate the learning of advanced technology and customise solutions pertaining to material and fuel efficiency. It creates quality human resources and technical know-how, which can reduce energy consumption without compromising on output. Successful R&D investment results in the product or process patenting, which create either a new product or a superior production process. Hence, it strengthens the firm's competitiveness and facilitates efficient utilisation of resources. Corporate R&D and patenting activities are crucial factors for building dynamic capability and promoting efficient use of energy input (Alam et al., 2019; Haider & Bhat, 2020). The transfer of advanced technology from developed countries to developing countries affirm up-gradation of old obsolete technology. It may be either through the import of efficient machinery (embodied technology) or outright/royalty-based purchase of the technical license or technical know-how (disembodied technology) (Aggarwal, 2018). These innovative measures and technical know-how need to be effectively assimilated into the firms' 'processes' through organisational and managerial restructuring. Hence, it should certainly improve the energy efficiency of highly energy-intensive firms, which can reflect the successful penetration of innovative measures. In the end, it is an empirical question to verify the impact of managerial and technological advancement on energy efficiency.

Indian iron and steel firms provide an excellent setting to study the issue. The iron and steel sector is one of India's fastest-growing industries, with India becoming the world's 2nd largest producer of crude steel in the year 2018, with an output of 106.4 Million Tonnes (MT). With the existing capacity of 138 MT, the National Steel Policy, 2017 aims to expand it by 300 MT in the country by 2030-31 (GOI, 2017). The industry requires massive amount of energy and other resources (water, raw materials and land). It has set a target to achieve CO_2 emission intensity of 2.2–2.4 tonnes per tonne of crude steel (TCS) by the terminal year of 2030 (GOI, 2017). This target is still short of the current GBP of 1.8 tons per TCS (WSA, 2019). Further, the industry is fragmented, 62 per cent of the total crude steel production comes from six big companies, while the rest is accounted for by many small-scale firms CSE, 2012). Therefore, monitoring the energy efficiency performance can provide valuable inputs for evaluating the efficacy of energy efficiency programme. It helps to reduce fossil-fuel consumption also as a way to achieve sustainable development through cost-effective methods.

With this background, this chapter has a two-fold objective. First, it quantifies the level of energy efficiency using a Bayesian version of stochastic frontier analysis (SFA) using the concept of the distance function. Second, it empirically assesses the impact of the firm's innovative performance on energy efficiency. This study contributes to the scant literature on the role of technological flow and certified EMS on the firm's energy efficiency at micro-level and provides insights for corporate policies. At the macro level there are studies that highlighted the role of technological progress on aggregate energy consumption. However, these have limited policy relevance at the firm-level. Insights to improve energy efficiency have been enumerated so that policymakers and corporate managers of energy-intensive industry (such as iron and steel) can adopt the same.

The rest of the chapter have been arranged as follows: Section 5.2 describes related literature and brief methodology review. Section 5.3 introduces the method applied in this chapter and data sources, while Section 5.4 provides empirical results and discussion. Finally, Section 5.5 draws the conclusion and states the policy implications.

5.2: Literature Review

There is vast economic literature on energy efficiency analysis as it provides policy implication for energy efficiency programme. Most studies applied some statistical method to determine the trend of energy efficiency over time and energy and CO_2 emission saving potential (Na et al., 2019). Emphasis has been given on firm-level heterogeneity that plays an essential role in shaping energy efficiency. There are several studies conducted to find out the environmental performance using CO_2 or other emissions as undesirable output. These studies aim to measure the highest possible emission and energy reduction while expanding production. The objective here is to estimate the efficiency score based on simultaneously supporting economic growth and environmental protection. As for developing countries, it is pertinent to maintain growth and employment and also to prevent environmental damage. So, it requires an optimal policy that simultaneously balances both aspects. Further, literature devoted much attention to finding the driving factors of energy efficiency. It is crucial to find policy-related variable that can potentially enhance energy efficiency. These studies have conducted regression analysis after estimating the energy efficiency or using energy intensity instead. Na et al. (2019) provide a methodological review of energy efficiency estimation and found that DEA and SFA are widely used to gain economic benefit.

The majority of studies have concentrated on the Chinese economy as it has a significant share in global CO_2 emission. Further, most of them are focused on provincial- and industry-level efficiency such as paper, iron and steel, chemical and cement industry. Fujii et al. (2010) examined the economic and environmental sensitivity productivity of 27 Chinese iron and steel firms based on DEA. They revealed that machinery up-gradation decreases economic productivity while it enhances environmental productivity. Ouyang et al. (2018) applied SFA to analyse energy efficiency and impact of factor price distortion on it. They found that allocative inefficiency occurs in energy due to lower energy price as compared to other input. They argue smooth cross-region technology transfer and speedy input price reform. Fan et al. (2017) examines the relationship between energy intensity and different indicators of financial performance. For most of the indicator of financial performance, it is positively related to energy intensity. Zhao & Lin (2019) conducted a detailed analysis of agglomeration effect on energy efficiency of the provincial-level textile industry. They reveal the threshold and non-linear effect of agglomeration, while the level of development, R & D, scale, and energy price have a positive relationship with energy efficiency. Liu et al. (2020) have investigated the impact of environmental regulation on energy efficiency through innovative and structural changes effect and documented a major shift in the energy mix and enhanced efficiency. Further, they found that technological innovation has mixed effects on energy efficiency, while structural change has a significant positive impact. Therefore, they advocated that market-based carbon emission trading has a crucial tool for enhancing efficiency and reducing carbon emission. Chen et al. (2015) estimated cost efficiency using data of Chinese electricity companies and recommended Bayesian SFA over classical SFA.

Lutz et al. (2017) applied SFA to find out energy efficiency and its driving factors for German manufacturing industries. They documented that exporting, innovating and investing in eco-friendly measures enhances energy efficiency. Boyd and Lee (2019) have estimated energy demand using SFA and found electric efficiency is higher than fuel efficiency in case of the metal-based manufacturing sector in the United States. While they reveal that inefficient firms can reduce 21 per cent of its total energy to reach an average efficient level. Moreover, new entrant firms have better energy efficiency. Imbruno and Ketterer (2018) showed that the import of intermediate goods enhances energy use efficiency by using a sample of Indonesian manufacturing firms. Therefore, the integration of input markets may be beneficial for technical efficiency and environment. Sun et al. (2019) found positive impact on green innovation and institutional quality on the energy efficiency for the panel of 71countries.

Some studies have been considered comparable cross-country data at firm-level or sectoral level and examine the relationship between energy efficiency and productivity improvement by taking indictors innovation, R & D expenditure, energy intensity, total factor productivity (TFP) and exporting. Alam et al. (2019) found a positive impact of R&D investment on environmental and energy intensity using the sample firms from G-6 countries. Some studies focused on technological and production (resource) efficiency to reduce emission level with improved energy efficiency. Takayabu et al. (2019) have examined the link between productivity improvement and CO_2 emission using 14 metal sectors across 40 countries. They have identified emission reduction potential of 354 Mt from 20 inefficient countries. Takayabu (2020) estimated the CO_2 emission saving potential from energy-intensive manufacturing sector across 34 countries. They found significant emission reduction can be possible through emission factor and energy intensity reduction.[16] Hence, they show that efficiency improvement has considerable potential for emission mitigation. Jebali et al. (2017) found a declining trend of energy efficiency for Mediterranean countries. They have also shown per

[16] Emission factor is defined as ratio of CO_2 emission to energy use, better energy quality have lesser emission factor.

capita income, population density and renewable energy are the major driving factor. Cantore et al. (2016) have investigated whether a trade-off exists between overall performance (TFP) and energy intensity taking a sample of manufacturing firms across 29 developing countries. They found that lower levels of energy intensity are associated with higher TFP in most of the cases.

There is a growing body of studies in the Indian context to evaluate the relationship between energy efficiency and innovative capability at sectorial and firm-level. Sahu and Sharma (2016) have undertaken plant-level analysis and found a non-linear relationship between output and energy intensity. Further, they have shown that higher productivity is associated with lower energy intensity. Aggarwal (2018) investigated the building of innovative capability from the Clean Development Mechanism (CDM). Using three indicators like R & D, TFP and fuel efficiency, it was found that CDM can serve the purpose of green technology transfer in developing countries but not effective in the current uneven form. There is scant literature on the firm-level analysis of underlying energy efficiency using a production function approach. There is a substantial research gap in conducting an energy efficiency analysis at micro-level in the context of India, particularly in the iron and steel industry which consumes a significant amount of industrial energy. This chapter tries to bridge that gap.

5.3: Method and Data

5.3.1: Energy efficiency as an input distance function

Quantification of energy efficiency or energy demand is one of the crucial areas of research and provide essential policy insight. Energy intensity is viewed as a traditional indicator of energy efficiency as it does not take other factors of production and structural changes into account (Zhao & Lin, 2019). There are different approaches to deal with this which can be broadly classified as either an engineering or economic or mixed approach[17]. Conservation supply curve (CSC) represents an engineering approach extensively used to quantify energy-saving potential. It can be derived through production function when inefficiency is present (Boyd & Lee, 2019). Assuming an implicit CSC, economic method of measuring efficiency can be applied to quantify the energy efficiency through the production function approach. It can be viewed as measuring the input distance function with reference to frontier technology.

[17] Broadly it has four categories that is thermodynamic, thermos-physical, thermo-economic and economic.

Standard production function can be modified to measure energy efficiency, which is considered to be Shephard's input distance function.

$$D_i\left(y,\ x;\ E\ \right)\ =\ sup\{\ \lambda\ >\ 0:\ \left(x/\lambda;\ E/\lambda,\ y\right)\in T\} \tag{5.1}$$

Equation (5.1) proposes a reduction in the use of all factor inputs, both energy and non-energy to the minimum possible without reducing the level of output. Analogously, non-energy inputs can also be fixed, and only the energy input can be minimised, and then the sub-vector input distance function can be written as:

$$D_{si}\left(y,\ x;\ E\ \right)\ =\ sup\{\ \lambda\ >\ 0:\ \left(x;\ E/\lambda,\ y\right)\in T\} \tag{5.2}$$

Assuming that the sub-vector input distance function is linearly homogeneous of degree one in energy and specifying a functional form of optimal energy input (E*) form as:

$$D_{si}\left(y,\ x;\ E\right)\ =\ E^{*}/E\ =f^{*}\left(y,\ x\right)\ /\ E \tag{5.3}$$

Where f*(y, x) is the optimal input requirement function. Taking logs on both sides of the equation and suppressing subscripts, Equation (5.3) can be written as:

$$ln\left(D_{si}\left(y,\ x;\ E\right)\right)\ =\ -ln\left(\ E\right)\ +\ ln\left(f^{*}\left(y,\ x\right)\right) \tag{5.4}$$

f*(y, x) can be approximated by a standard production function. In this case, the translog production function is used as it is flexible and provides a better approximation. Finally rearranging both sides of equation (5.4) and replacing f* (y, x) by a translog function and $ln\left(D_{si}\left(y,\ x;\ E\right)\right)$ as one-sided inefficiency term (-u_{it}) along with the usual measurement error term (v_{it}), following parameterisation has been used.

$$lnE_{it}=\left[\alpha+\sum_{j=1}^{4}\beta_j\ln X_{jit}+\frac{1}{2}\sum_{j=1}^{4}\sum_{k=1}^{4}\beta_{jk}\ln X_{jit}\ln X_{kit}+v_{it}\right]-u_{it} \tag{5.5}$$

Equation (5.5) is the SFA specification of production function where energy consumption is applied as the dependent variable, while output and non-energy inputs (labor, capital and materials) are used as the explanatory variables. The process of heterogeneity has been incorporated by including a dummy variable in the SFA model. The energy use also depends upon whether a firm operates with basic oxygen furnace (BOF), electric arc furnace (EAF) or induction furnace (IF) process. About 44 per cent of Indian firms operate under the BOF route, while 26 per cent are under the EAF route and 30 per cent are under the IF route (GOI, 2020). Hence, EAF/IF route has been assigned as reference route and assigned 0 for it, and 1 for the BOF route. Globally, the share of crude steel production by the EAF process increased from 38 per cent to 54.5 per cent over the period 2003 to 2017 (WSA, 2019). In a nutshell, distance from the frontier is represented by one-sided error term u_{it} that forces production function on or below the production frontier.

5.3.2: Bayesian SFA model

In order to incorporate statistical noise arising due to measurement errors and other random factors, SFA proves to be a better characterisation. It is a parametric approach to efficiency analysis usually applied in Economics. It recommends to apply at firm-level to control firm-level heterogeneity and measurement and other errors. It was initially developed by Aigner et al., (1977) and Meeusen and van de Broeck (1977). Classical SFA typically assumes homogeneous production function across firms which differ only in inefficiency level. It constructs a single production frontier and measures the relative efficiency of each firm with reference to the frontier. However, in real-world operation, production technology differs due to different factors (market friction, time lag, etc.) beyond the control of managers. Hence, it is not sensible to assume that each firm faces similar production technology. To deal with this issue, Tsionas (2002) proposed a random coefficient model in a Bayesian framework, which allows production frontier to vary across firms, hence incorporating heterogeneity in efficiency level. The computational scheme is arranged within Markov chain Monte Carlo (MCMC) methods, particularly with the help of Gibbs sampler provided by freely available software WinBUGS. Griffin and Steel (2007) illustrated the power of WinBUGS to estimate different Bayesian SFA. To illustrate, consider the following production function equation with a random coefficient:

$$E_{it} = \alpha + X_{it}^{'}\beta_i + v_{it} - u_{it}, \qquad i = 1,.....,N, t = 1,.....,T \qquad (5.6)$$

Where E_{it} is a vector of the dependent variable for the ith observation of year t, X_{it} is a vector of explanatory variables, v_{it} is a random disturbance capture measurement error, distributed i.i.d N(0, σ^2), u_{it} is a non-negative error term measuring inefficiency. β_i is a vector of random coefficients, and α is a non-random intercept. Distribution of v_{it} needs to be specified to complete the model; in Bayesian context, it is generally assumed that v_{it} follow an exponential distribution with a parameter θ[18] specified as below.

$$f(u_{it}) = \theta \exp(-\theta u_{it}). \qquad (5.7)$$

Further, the probability distribution of random coefficient of the production function β_i is assumed to follow a multivariate normal distribution with the mean vector $\bar{\beta}$ and positive-definite covariance matrix **Ω**.

$$\beta_i \sim N(\bar{\beta}, \Omega) \qquad (5.8)$$

Given the specification, u is drawn from an exponential distribution with parameter θ, while the prior mean of θ is $q = -\ln r^*$; the Gibbs sampler for an exponential distribution model of Tsionas (2002) draws β_i and (a,b) from the conditional normal distribution, σ and θ from the conditional gamma distribution, Ω from the conditional Wishart distribution while u_{it} is drawn from the conditional truncated normal distribution. Further, it is assumed that $\beta_i/\bar{\beta}, \Omega$ are independent, and u_{it} as well as v_{it} are independent of X_{it}. Hence, it becomes a hierarchical model, with two-levels of latent variables that are β_i and u_{it}. At first, β_i varies across firms which indicates that each firm has its own specific set of production functions drawn from distribution (5.8) to consider the heterogeneity across firms. At the second level, each firm has production shock which is accounted by its inefficiency level u_{it} drawn from distribution (5.7) with parameter θ. It is important to note that intercept remains fixed as it is not possible to keep both measurement error and a random intercept. The Bayesian estimation of model (5.6) works in the following three steps.

Step 1: Specifying the prior distribution of parameters in the model.

The Bayesian framework requires prior information in the form of parameter distribution which can be obtained from previous studies. Most often, the prior distribution for α and β is specified as flat, which means imposing no prior information on means value of parameters. Following Tsionas (2002), the prior of the model can be specified as:

$$\alpha_{i,}\, \beta_i \sim N[(a,b), \Omega\,], i = 1, \ldots. N; \;\; (a,b) \sim N[(0,0), W] \qquad (5.9)$$

[18] Alternative distributions such as truncated and gamma are also possible which are computationally more demanding, while the exponential distribution is most commonly used in the Bayesian framework.

While Ω ~ Inverted Wishart; θ ~ two-parameter gamma; and σ ~ inverted gamma type distribution.

Combining the conditional probability distribution of all parameters into a joint density function and marginalising over u, the likelihood of the joint model in equation (5.6) can be expressed as:

$$L = NTln\theta + \left(\frac{\theta^2}{2}\right)\sum_{t=1}^{t}\sum_{i=1}^{N} W_{it} + \sum_{t=1}^{t}\sum_{i=1}^{N}\left[ln \quad \left.\frac{-\varepsilon_{it} - \theta W_{it}}{W_{it}^{1/2}}\right) + \theta\varepsilon_{it}\right] \qquad (5.10)$$

Where $\varepsilon_{it} \equiv E_{it} - \alpha - X'_{it}\bar{\beta}$; $W_{it} \equiv \sigma^2 + X'_{it}\Omega X_{it}$; $\varphi(.)$ denotes the standard normal cumulative distribution function, and X is a matrix of explanatory variables (Tsionas, 2002). And finally, energy efficiency can be obtained from the following equation.

$$efficienc \quad = \exp(-\hat{u}) \qquad (5.11)$$

5.3.3: Second stage regression and hypothesis testing

Bayesian SFA can also incorporate the inefficiency effect (factor explaining the estimated inefficiency) in the mean function of inefficiency. Following Koop et al. (1997), Bayesian SFA with inefficiency effect has been conducted. Since there are lots of parameters to estimate in the model, the sampler does not converge and has higher autocorrelation. The trace plot shows that the sample does not mix well and fails to converge. Hence, truncated regression analysis has been taken for estimating the impact of crucial factors on the energy efficiency. It accommodates the true underlying process of efficiency score estimation. The bootstrap technique has been used to build an empirical data generating process for correct finite sample bias in the standard error and confidence interval (Simar & Wilson, 2000). Energy efficiency score from the Bayesian model has been used as the dependent variable in the regression analysis. A set of dummies and continuous explanatory variables has been used, as discussed in the introduction section.

Further, non-parametric hypothesis tests have been done to know whether any statistical difference exists between certified and non-certified firms, and innovative and non-innovative ones. For this purpose, three dummy indicators have been taken (ISO 14001 certification, R&D expenditure, and patent application). Furthermore, taking the above three indicators as treatment, propensity score matching (PSM) method has been used to know the average treatment effect on treated (ATT) on the energy efficiency score. PSM is generally used to know the ATT, by matching the treated and control group. Matching, in this case, has been done on the basis of the potential determinant of the above treatment dummy indicators (age, size, profitability, import intensity, royalties & technical fee, etc.). Propensity score has been estimated through the logit model and then matched between treated and control group by using the nearest-neighbour and kernel matching method.

5.3.4: Data and variable

Company-level data for the analysis is sourced from PROWESS database managed by the Centre for Monitoring Indian Economy. The database consists of audited data from the companies' annual balance sheets. Data on Indian iron and steel industry is taken according to the classification provided by national industrial classification 2008. Four input variables—capital, labour, energy, and materials—and a single output have been used for the so-called KLEM (capital–labour–energy–material) production function. Labour is taken as wages and salaries as expenses in the absence of data in the physical term, energy as expenditure on power and fuel, and materials as raw material expenditure. Gross fixed assets is used to estimate capital stock and net sale value for output used in the analysis. All variables are given in monetary terms and adjusted to account for the price level following Balakrishnan et al. (2000). After cleaning the data and accounting for missing data, finally 82 firms have been taken which operate across the Indian states. Out of the total market shares of the iron and steel industry in India, the sample firms share 72 per cent of market share.

Four indicators of innovation have been utilised. The first is an input-based indicator (R&D expenditure), while the second is an output-based indicator (patent application). The patent application data for each firm has been extracted from the Indian Patent Office. The third and fourth are embodied and disembodied technology proxied by royalties & technical fee and import of capital goods data respectively. Since the iron and steel industry is not a high-tech industry, few firms have incurred R&D expenditure. Also, firms expend a very small amount of their turnover on R&D, hence the presence of R&D activity has been taken as a binary variable. Similarly, a binary variable has been considered for patent application count, and royalties & technical fee data. Patent dummy indicates the presence of innovation (product or process), while royalties & technical fee dummy shows whether firms purchase technical know-how. Therefore, in such case, the dummy indicator is supposed to provide a better proxy for innovative firms. In the case of Indian iron and steel industry, it is dominated by the private sector. Hence, only size and age have been taken as control variables. Description of variables has been given in Table 5.1 and descriptive statistics in Table 5.2.

Table 5.1: Variable Description

Variables	Definition	Symbol
Output	Net Sale	lnY
Capital	Gross fixed asset	lnK
Labour	Wages and salaries expenses	lnL
Energy	Fuel expenditure	lnE
Materials	Material expenditure	lnM
ISO 14001 certification dummy	Dummy indicator takes value 1 if firms have ISO 14001 certification	ISO_D
R & D expenditure dummy	Dummy indicator takes value 1 if firms undertake R & D expenditure	RD_D
Patent application dummy	Whether firms have applied for any patent	PAT_D
Disembodied technology dummy	Dummy indicator takes value 1 if firms incurred Royalties and technological fees otherwise 0	DISEMBD_D
Process dummy	Binary variable assign 1 for BOF/OF, 0 for EAF/IF	Proc_D
Age of the firms	Number of years from the incorporation of the firm	AGE
Size of the firms	Log of average total asset	SIZE
Embodied technology	Imports of capital (machinery and equipment) goods divided by sales	EMBD

Source: Author's calculation (2020)

Table 5.2: Descriptive statistics

Variable	Observation	Mean	Std. Dev.	Min	Max
LnE	1230	14.339	1.950	8.047	19.557
LnK	1230	16.886	2.080	12.52	22.50
LnM	1230	16.612	1.632	7.569	20.934
LnY	1230	17.417	1.648	11.926	21.922
LnL	1230	17.639	2.090	11.71	24.211
ISO_D	1230	0.4146	0.492	0	1
AGE	1230	29.024	15.64	2	110
RD_D	1230	0.2048	0.407	0	1
DISEMBD_D	1230	0.170	0.167	0	1
EMBD	1230	0.0091	0.028	0	0.292
SIZE	1230	8.3529	2.053	0	13.95
PAT_D	1230	0.0837	0.277	0	1
Proc_D	1230	0.4756	0.499	0	1

Source: Author's calculation (2020)

5.4: Results and Discussion

The energy efficiency estimation follows the microeconomics concept of input distance function as derived in the methodology section. The selected time period is relatively long, and there may be changes in the efficiency level over the sample period. Hence, it is quite pertinent to exploit the time dynamics of energy efficiency. A total of 1,00,000 iterations have been run with a burn-in of first 10,000 iterations to avoid the effect of initial values. Convergence property of simulation has been analysed through the dynamic trace plot and autocorrelation of coefficients as suggested by Griffin and Steel (2004, 2007). All models performed well, and a proper mix of the sample was evident.

5.4.1: Energy efficiency estimate

In a nutshell, classical SFA has been compared with Bayesian SFA model to gain insight into robustness and sensitivity of different estimation methods. Later, efficiency estimates of these models have been compared. For this purpose, drawing on Battese and Coelli (1992), the time-decay SFA model has been estimated. The results of posterior estimates have been given in Table 5.3. Looking at the statistical significance of the variable, classical SFA has less number of significant coefficient. On the contrary, Bayesian SFA has mostly significant coefficients with lower MCMC error. Hence, the classical model remains inadequate to utilise the in-hand information efficiently.

There is some similarity between both models, as most coefficients are of similar sign and are reasonably close. The difference may be probably owing to simulation and prior information provided in the Bayesian model. Nevertheless, there are considerable differences between the Bayesian and the classical model concerning the magnitude of the σ^2 (variance of the model) and the θ. The differences reflect the treatment of observation and nature of heterogeneity in the data. The differences in the value of θ depict important insights for the estimation of efficiency in the SFA. The value of σ^2 of the basic Bayesian SFA model is 0.08 whilst it is 0.64 under the standard SFA. Meanwhile, θ of the basic Bayesian SFA is 7.24 while it is 12.36 in the classical SFA. Given the higher value of θ in the classical SFA than the Bayesian one, it shows a higher probability of near-perfect efficiency in case of the classical SFA model than in the Bayesian SFA models (Tsionas, 2002). Therefore, the efficiency estimates from the Battese and Coelli (1992) model is higher than those of Bayesian models and it seems to overestimate the efficiency level. After considering both the estimation procedures, it seems more sensible to adopt a Bayesian framework for energy efficiency estimation in this case.

Having a better performance of Bayesian SFA, it is further possible to improve the model. Hence, in this chapter, three Bayesian SFA models have been estimated and compared for best fit. Firstly, basic model discussed in the methodology section has been estimated; then further augmented with t-distribution of the error term in the basic model, and finally a time-varying efficiency (TVE) model. All models have been compared by Deviance Information Criteria (DIC) given in Table 5.4, and the higher value of DIC is desirable.

Table 5.3: Bayesian and Classical SFA estimation

	Basic Model		T-distribution		Time-varying		Classical SFA	
node	Mean	MC error	mean	MC error	mean	MC error	mean	Robust Stand. Error
Constant	5.339	0.0019	4.23	0.014	3.992	0.01	4.547[a]	23.12
LnK	-0.782	0.0042	-0.831	0.003	-0.762	0.003	0.215[a]	0.610
LnM	-3.433	0.0060	-3.034	0.005	-3.468	0.02	-1.025	0.383
LnY	4.396 [a]	0.0021	3.339 [a]	0.007	3.325 [a]	0.021	1.791[a]	1.317
LnL	0.024	0.0002	-0.076	0.003	-0.657	0.004	-0.481 [a]	1.066
LnK_Sq	0.047	0.0002	0.087	0.001	0.323	0.001	-0.054 [a]	0.057
LnM_Sq	-0.240 [a]	0.0004	-0.287	0.002	-0.442	0.003	-0.074 [a]	0.054
LnY_Sq	-0.315	0.0002	-0.587	0.001	-0.545	0.007	-0.242	0.130
LnL_Sq	0.028	0.0005	0.058 [a]	0.001	0.051	0.001	0.006 [a]	0.031
LnK* LnM	-0.048	0.0006	-0.124	0.003	-0.429	0.001	-0.005 [a]	0.101
LnK* LnY	0.091	0.0004	0.168	0.001	0.345 [a]	0.001	0.086 [a]	0.115
LnK* LnL	-0.082 [a]	0.0005	-0.069	0.001	-0.399	0.001	0.024 [a]	0.103
LnM* LnY	0.512	0.0006	0.817	0.0004	0.874	0.01	0.275 [a]	0.163
LnM* LnL	0.132	0.0010	0.284 [a]	0.001	0.317 [a]	0.003	-0.075	0.03
LnY* LnL	-0.103	0.0003	-0.196	0.001	-0.0358	0.004	0.069 [a]	0.122
Proc_D	-0.374	0.0003	-0.43	0.002	-0.631	0.001	-0.686	0.243
sigmasq	0.081	0.0003	0.089	0.0002	0.087	0.647	2.64	0.781
θ	7.24	0.0001	6.65	0.0003	6.87	0.0011	12.36	0.144
Eta					0.054	0.001	-0.002	0.003

Note: “a” denote statistical insignificance at 5 percent level. Eta is the coefficient of time trend

Source: Author’s calculation (2020)

The model with t-distribution of error term has higher DIC value against the basic model. Hence, it shows that using t-distribution of error term better fits the model than using the basic model with the normal distribution of error. Furthermore, keeping the t-distribution of the error term and allowing the efficiency to vary over time has been incorporated in the TVE model. The value of DIC in the TVE model is higher than both the former models, hence it is a more appropriate model as per the DIC criterion. Therefore, TVE model has been selected for the final analysis. It is interesting to look at the time-varying nature of energy efficiency. A flexible form of TVE model has been specified, and the positive coefficient of *eta* shows increasing inefficiency over time. Hence, the Indian iron and steel firms in the sample experience decrease in average energy efficiency because of the expansion of technological gap rather than the decrease in absolute energy efficiency.

Contrary to this, the coefficient of eta in the classical SFA turns out to be statistically insignificant and of a different sign. The coefficient of Process Dummy is also statistically significant across all models and has a negative sign. It reflects lower energy consumption of the BOF process as compared to the EAF/IF process. This may be due to the fact that the BOF process is adopted to produce a primary product (DRI or crude steel) through an integrated process, while the EAF/IF process is used to produce the final product as per the requirement (also to enhance quality), thus requiring more energy. Though scrap-based EAF/IF process requires less energy, however, Indian firms mostly use DRI as backward linkage to the EAF/IF process to produce different final products such as wire, TMT bar, hot/cold rolled steel (GOI, 2020). These firms mostly use electrical energy which is relatively costlier than other sources of energy such as coal and gas, thus incurring a higher fuel cost.

Table 5.4: DIC criteria for Bayesian SFA model

	Dbar	Dhat	pD	DIC
Basic model	683.244	-268.968	963.683	1628.39
T-distribution of error model	578.183	-538.475	1316.67	1684.49
TVE Model	1133.25	70.158	1133.09	2196.52

DIC: Deviance Information criteria used for better model fitting

Source: Author's calculation (2020)

There are 82 firms under analysis, and there may be considerable variation in the energy efficiency levels across firms. Hence, to show the distribution of energy efficiency across firms, box plots of average energy efficiency from classical and Bayesian SFA are presented in Figure 5.1. Boxplot provides a quick view of distribution over four quantiles. The box inside the plot shows the inter-quantile range and the line inside the box shows the median of the energy efficiency score.

The vertical axis shows the scale of average energy efficiency, with energy efficiency score scaled between 0 to 1. Figure 5.1 shows a lower limit of 0 (fully inefficient) while a maximum average score of around 0.8 and 0.75 for classical and Bayesian SFA respectively. Both plots show more concentration of energy efficiency score in the lower and middle quantiles. Hence, a higher number of firms lie between 0 to 0.40 over the efficiency score scale of 0 to 1. . While, as per Bayesian SFA, relatively highly energy-efficient firms have 25 per cent further potential to enhance their energy efficiency.[19] The boxplot shows that classical SFA overestimates the efficiency score over a margin of 5 per cent. Relying on the estimates given by TVM of Bayesian SFA, there is enormous energy efficiency gap across the firms. The median energy efficiency of TVE Bayesian SFA and classical SFA is around 0.40 and 0.42 while that of the mean level is 0.39 and 0.43 respectively.

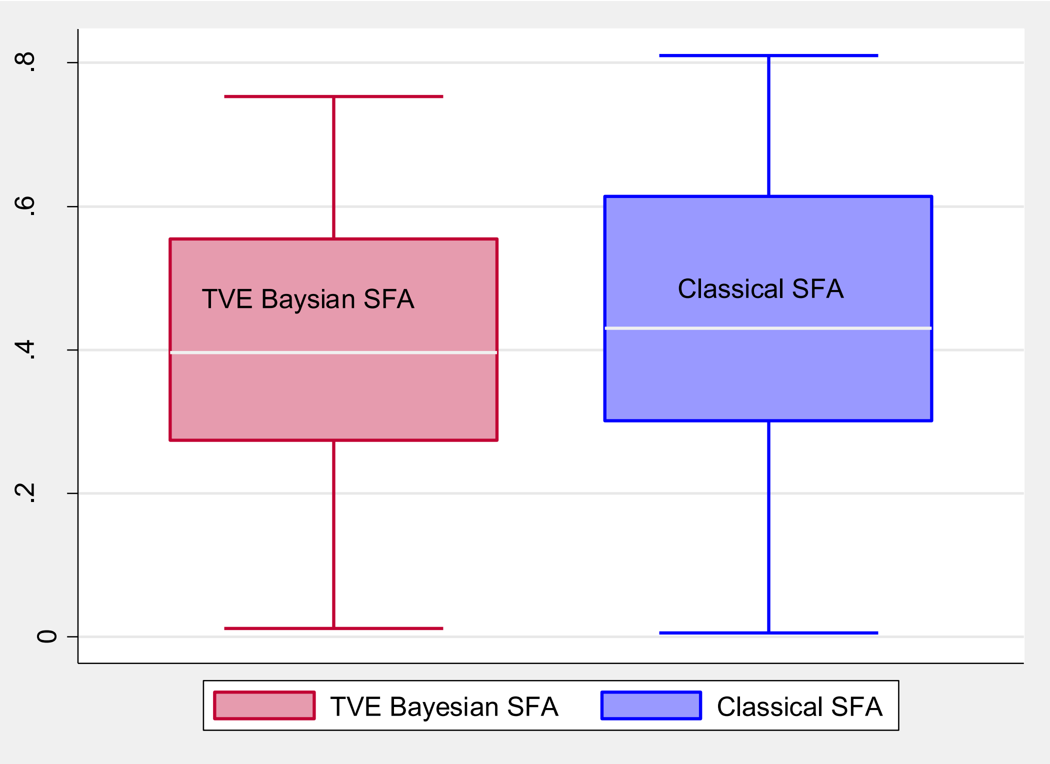

Figure 5.1: Box Plot of average energy efficiency
Source: Author's calculation (2020)

Iron and steel industry consumes a massive amount of energy which can be minimised by an average of 60 per cent. Vast energy saving opportunities exist for developing countries firms which can be harnessed through technology transfer and adopting best practices. Average energy efficiency plot over the sample period has been given in Figure 5.2. The plot depicts a slight increment in the energy efficiency gap across firms in the sample as there is a declining trend of average energy efficiency. It essentially means a decrease in relative measure of energy efficiency while it may be the case that absolute energy efficiency has increased for some firms. The plot shows that throughout 2003 to 2009, energy efficiency remains stagnant around 0.43,

[19] In the Bayesian SFA, mean energy efficiency shows mean taken out of considered iteration.

while after 2009, it starts decreasing slowly. The results have very serious policy implications for the iron and steel industry. Most of the Indian iron and steel industry firms require 6.9 Gcal/t against the world average of 4.5Gcal/t (CSE, 2016).

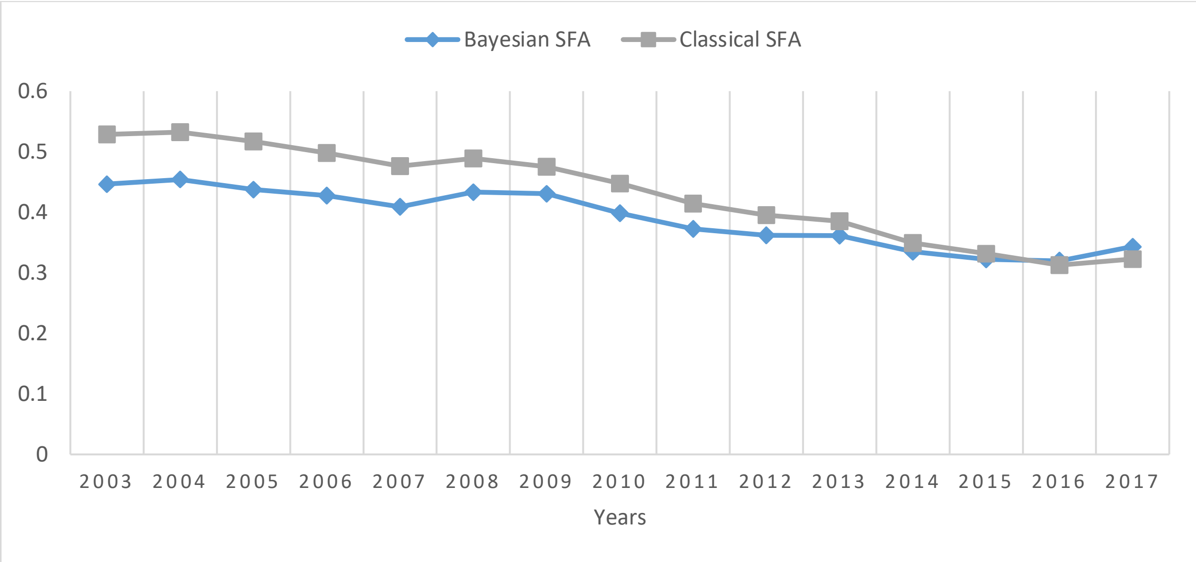

Figure 5.2: Plot of average energy efficiency over 2003 to 2017

Source: Author's calculation (2020)

5.4.2: Second stage analysis

After getting reliable estimates of energy efficiency, influence of crucial factors have been investigated that drive the energy efficiency levels. There is a set of theoretical and empirical literature that shows that firm's heterogeneity is crucial in explaining the firm's performance. At the firm-level, heterogeneity across firms in terms of experience, scale of operation and ownership remains essential in explaining the differences in energy efficiency (Haider et al., 2019). Innovation-efficiency nexus has been tested based on NRBV advanced by Hart (1995). They advocated that firms should build innovative capability to gain sustainable competitiveness over the long term. Particularly, firms need to pursue eco-friendly strategies to sustain over the long term rather than to look at short-term benefits. So, the NRBV visualises integrated link among a firm's resources (financial and physical resources) and sustainable competitiveness. Firm's general innovative capability results in higher energy efficiency, which is an indicator of sustainability and competitiveness. Higher energy efficiency firms will significantly reduce energy cost, which is a major component in the total cost of iron and steel production.

Primarily innovative and managerial capacity of firms enhance technical efficiency and overall productivity. Hence, energy efficiency estimated from TVE model of Bayesian SFA has been used as a dependent variable. ISO 14001, an EMS, is used as a proxy for better energy and environmental management while four different indicators of innovative capacity have been considered. The hypothesis is that there is a significant positive relationship between energy efficiency and ISO 14001 certification. Hence, these indicators are supposed to be positively associated with the energy efficiency score. As the iron and steel industry is one of the energy-intensive sectors, innovation and technical know-how will enable firms to use energy efficiently during the production process. Firms' heterogeneity has been captured by the size and age of firms and used as control variables. There is a high correlation between R&D expenditure and patent application variables; hence it is used separately in the analysis.

Firstly, regression model has been estimated without control variables and then checked the results after including control variables. The estimated coefficient from truncated regression has been given in Table 5.5. Certification turns out to be statistically insignificant with a negative sign in all the models. Hence, the result is unambiguous regarding the same, while it has been expected to have a positive impact on energy efficiency. In case of R&D and patent dummy, the coefficient is positive and significant in both models, while the magnitude of the coefficient is less in the model with control. The result is consistent and stable: R&D and patent application stimulate energy efficiency of firms as they enable firms to successfully assimilate advanced technology into the production process. Disembodied technology has a significant positive impact on energy efficiency, while embodied technology does not have any significant impact. The results are stable across the models.

Therefore, it indicates that technical know-how flows from advanced firms through technical license purchase are essential for efficiently utilising energy inputs. Regression results show the uneven impact of different channels of innovative capability on the energy efficiency level. Hence, on the whole, a firm's innovative capability carries a profound impact on energy utilisation efficiency and facilitates firms to dynamically improve their production process. The coefficient of age is negative and significant in all the models, which show that younger firms are more energy-efficient than older firms. Size of the firm carries a positive coefficient while it is statistically significant at 10 per cent level of significance. The magnitude of the coefficient is low and not highly significant. Hence, it suggests that the effect of size is neutralised in the second stage. This may be due to the scale of production (size) being adjusted in the translog production function.

Table 5.5: Truncated regression on energy efficiency score

Variables	Without control (Model 1)		With control (Model 2)	
Constant	0.165 (0.01)	0.763 (0.03)	0.604 (0.03)	0.396 (0.04)
ISO_D	-0.048[a] (0.16)	-0.049 [a] (0.12)	-0.030 [a] (0.32)	-0.026 [a] (0.36)
RD_D	0.191 (0.02)		0.184 (0.04)	
PAT_D		0.143 (0.01)		0.115 (0.02)
DISEMBD_D	0.062 (0.04)	0.043 [a] (0.08)	0.093 (0.03)	0.103 (0.00)
EMBD	-0.560 [a] (0.46)	-0.076 [a] (0.34)	-0.061 [a] (0.26)	0.156 [a] (0.29)
AGE			-0.002 (0.02)	-0.001 (0.01)
SIZE			-0.009 [a] (0.07)	-0.003 [a] (0.09)

Note: a denote statistical insignificance at 5 percent level.
P-value is given in parenthesis
Source: Author's calculation (2020)

5.4.3: Robustness test

The regression results are further confirmed by non-parametric tests conducted to know the statistical differences between the energy efficiency of certified and non-certified firms, and innovative and non-innovative firms. The results of three non-parametric tests for the equality of distribution, rank and median level have been given in Table 5.6. The results show that the differences in energy efficiency exist only for innovative and non-innovative firms; while in the case of certified and non-certified firms, no statistical difference exists in this case of equality of distribution, rank and median level. The energy efficiency of innovative firms is higher than non-innovative firms and differs in terms of distribution, ranking and median level, while the energy efficiency of certified firms remained in line with regression results. The results from all three tests are in line with that of regression analysis and thus validate the truncated regression results.

Table 5.6: Non-parametric test for equality of energy efficiency between two groups

Kolmogorov-Smirnov test for equality of distribution			Kruskal-Wallis Rank equality test		Equality of Median test	
Variables	D-value	P-value	chi-squared	P-value	Pearson chi-square	P-value
ISO_D	0.063	0.28	0.47	0.42	0.003	0.93
RD_D	0.323	0.01	19.41	0.01	23.21	0.01
PAT_D	0.421	0.03	3.73	0.05	6.32	0.03

Source: Author's calculation (2020)

In order to reveal the average difference in energy efficiency, PSM estimator has been conducted to estimates ATT. It shows the average difference in energy efficiency level between treated and control firms. Taking certified and innovative firms as a treated group, a control group of firms are matched using the PSM based on other similar characteristics of the treated group. The results have been given in Table 5.7. As in the case of certified firms, the difference is not statistically significant, while the magnitude of ATT is negative. Hence, certified firms have lower energy efficiency (by 1 per cent) on an average. On the contrary, innovative firms have a positive impact on energy efficiency. Firms with R&D expenditure have higher energy efficiency ranging from 0.05 to 0.07, which is statistically significant, while firms that file patent application have only around 0.03 higher energy efficiency as compared to firms without any patent application. It is only significant in the case of nearest-neighbour; matching the magnitude of the difference is nevertheless the same.

Table 5.7: Average Treatment effect by propensity score matching

Variables	Matching method	n. treat.	n. contr.	ATT	Bootstrapped Std. Err.	t-value
ISO_D	Kernel Matching	510	716	-0.021	0.014	-1.31
	Nearest Neighbour Matching	510	318	-0.027	0.019	-1.17
RD_D	Kernel Matching	252	950	0.059	0.019	1.90
	Nearest Neighbour Matching	252	166	0.071	0.028	3.09
PAT_D	Kernel Matching	103	73	0.041	0.039	1.21
	Nearest Neighbour Matching	103	1122	0.028	0.022	1.04

Source: Author's calculation (2020)

Nearest-neighbour matching provides estimates of ATT based on the matching of control group firm in the neighbour. Kernel matching matches similar control firms within a radius of propensity value of 0.1. The value of ATT are almost similar for both kernel, and nearest-neighbour matching method, and this shows the robustness of results. The magnitude of the difference is not very high, but taking it as a real impact of treatment on the outcome, it can be a considerable difference. The lower differences in energy efficiency between innovative and non-innovative firms may be due to two reasons. Firstly, very few number of firms have undertaken R&D activities and filled any patent application, and secondly, the scale of R&D activities are not such that they can produce a relatively higher difference in energy efficiency level.

5.4.4: Discussion on the results

At the first stage, the estimation of the energy efficiency level provides energy-saving potential with a given level of output and using current production technology. Median energy efficiency is 0.40 and this indicates that half of the sample firms lie between 0 to 40 per cent of the energy efficiency score. Therefore, these firms can save their energy input by at least 60 per cent in order to become fully efficient. Bayesian SFA provides a comprehensive measure of energy efficiency. The energy efficiency score is lower than that of classical SFA. The results are in-line with the specific energy consumption (SEC) trend of the average Indian firm. It can be documented by examining the SEC of Steel Authority of India Limited (SAIL), taken from the annual reports over the period 2003 to 2018.[20] The time series plot of SEC, given in Figure 5.3, shows an almost stagnating trend, with a meagre decline in SEC. The energy intensity of SAIL is decreasing (i.e., its absolute energy efficiency is increasing).

Certification does pay for business firms, even though it may fails to achieve the intended target, recent trends support its overwhelming adoption across the world. Indian firms are also found to have adopted ISO 14001 standard due to peer pressure. The energy efficiency gap across firms widens over the years and seems far away from the GBP. The second stage result fails to show any significant impact of ISO 14001 on energy efficiency as compared to other firms. EMS is not found to be very effective to enhance energy efficiency; hence, even though firms are adopting the ISO 14001 standard, there is a lack of innovative capacity building and technical know-how. India’s R&D investment in the steel sector is very limited in absolute and

[20] SAIL is one of the leading Indian state-owned steel companies, located in eastern part of the country. It has five integrated steel plants, most of which have ISO 14001 certification. SEC is given as per data provided by the Ministry of Steel annual reports, and it is averaged across all the plants.

relative terms. It ranges between 0.05–0.5 per cent of turnover as against 1–3 per cent in the case of foreign steel companies (GOI, 2019). EMS must be complemented by innovative capability for achieving higher energy efficiency. The result indicates that better energy efficiency would require dynamic innovative capability through different technological channels.

Figure 5.3: Energy intensity in Giga calories per tonne of steel production
Source: Author's calculation (2020)

Therefore, Indian firms need to adopt a *techno-managerial approach* to come up with a superior production process and assimilate advanced technology. It will enables firms to cope up with low-quality material and coal by providing customised solutions. R&D and patenting activities invoke an efficient production process that will propel firms into tapping the huge energy-saving potential. Integrating EETs with better managerial efficacy may speed up the diffusion of technical know-how through knowledge exchange. Further, it should generally assimilate into managerial practices with higher quality skilled labour. A technically skilled employee is crucial for implementing standard energy and eco-friendly saving processes. Both certified and non-certified firms need to introduce organisational reforms in the system and invest in building local absorptive capacity (R&D expenditure). Further, Indian firms need to collaborate with developed countries for EETs transfer through clean development mechanism and other similar measures. Disembodied technology acquired by firms (mainly from foreign firms) provides excellent impetus to enhance energy efficiency.

The adoption of ISO 14001 may also be intended for signalling a green identity among stakeholders without necessarily putting in serious efforts to outperform non-certified firms. Though the number of ISO 14001 certifications issued has increased among Indian firms, its real objective of environmental improvements may be undermined. The level of energy efficiency, on an average, is quite low though firms have been ISO 14001 certified. This result is in line with the findings of Shetty and Kumar (2017), who did not find any significant relationship between EMS and environmental performance for a sample of Indian firms. Business motives and market pressure may undermine the actual target to reduce environmental pollution. Even though a wide variety of cost-effective EETs are available, they have a lower payback period. Certain exogenous factors such as lower energy prices, managerial negligence and organisational barriers may cause unleashing of such an opportunity (Acharya and Sadath, 2017).

Given the uncertainty in the fuel prices and international competition, the industry should cut the per-unit energy cost. Firms can gain completive advantage to invest their resources and enhance technical capability in eco-friendly operations. Moreover, the findings have significant policy implications for business managers, policymakers, and regulators since it provides the empirical evidence on the importance of R&D investment in improving energy efficiency and reducing carbon emissions .

5.5: Concluding Remarks

The energy-intensive industry not only forms the industrial base of a country but also produces a large chunk of pollution. Enhancing the energy utilisation efficiency is one of the crucial and cost-effective policy options for sustainable development. Different EETs can be employed to reduce energy use in the production process. This study quantifies the energy efficiency level and respective energy saving potential, using firm-level data of the Indian iron and steel industry. Bayesian SFA has been applied with its classical counterpart. Classical SFA model remains insufficient to utilise the in-hand information while Bayesian SFA performs far better. Particularly, the TVE model with t-distribution of error is seen to better fit the model. The results show that Indian iron and steel firms have experienced a stagnant and slightly increase in energy efficiency gap over the sample period. While there is more concentration of energy efficiency score in the lower and middle quantiles, the majority of the firms lie between 0 to 40 per cent of efficiency level. Around half of the sample firms can reduce their energy consumption by at least 60 per cent. Over the period of 2003 to 2009, energy efficiency remained stagnant at around 0.43 while after 2009, it started decreasing slowly. The results have serious policy implications in terms of tapping the huge energy saving potential for the iron and steel industry. This is in line with the trend of energy intensity of SAIL, which has seen as almost stagnating level of energy intensity with reference to GBP.

Using a second-stage analysis, this chapter documents that building innovative capability and technical know-how enables firms to achieve higher energy efficiency. Technology transfer needs to be accelerated from best energy efficient firms of advanced countries to developing countries firms to reduce the energy efficiency gap. The findings support the arguments of NRBV that firms that invest in building innovative capacity for eco-friendly operation results in competitive advantage through better energy and environmental performance. In the case of voluntary measures, ISO 14001 certified firms have not shown higher energy efficiency levels than their counterparts. Hence, EMS adoption in the Indian iron and steel industry needs an effective implementation through adoption of EETs and structural transformation for efficient use of energy resources. Technological innovation appears to be a crucial solution for better utilisation of scarce resources. It can be instrumental for enhancing energy efficiency level. Size and age of the firm also matters for firm's energy efficiency. Younger firms have higher energy efficiency, which also indicates the importance of the use of the latest and advanced vintage of capital. While the larger size firms have relatively higher energy efficiency, small and medium scale firms need to coordinate and require proper policy support to enhance their energy efficiency.

Indian iron and steel companies are heterogeneous in terms of the resources and capabilities based on their local conditions. The government should integrate the regulatory policies with market-driven measures through institutional reforms and lower transaction costs. Moreover, the ESCO model of energy efficiency investment should be strengthened to foster commercialisation and adoption of EETs. Our study takes a broader view on the level of energy efficiency by considering the aspect of heterogeneity. Hence, it is strictly not comparable to those studies which assume homogenous production technology across firms and estimated energy efficiency. Similarly, this chapter is not comparable with DEA-based efficiency estimates as it is non-parametric and does not incorporate measurement error. However, the study has some limitations related to sample data. Firstly, the focus has only been on the Indian iron and steel industry, hence the results cannot be strictly generalised to other countries' firms. Secondly, the analysis is only restricted to listed firms. Therefore, the interpretation of results should take cognisance of this, and a more extensive data set may be required to rigorously link innovative capability to energy efficiency.

Chapter 6
Conclusion

6.1: Introduction

The industrial sector consumes massive amount of energy and resources and churns out enormous pollution. Among the industrial sectors, energy-intensive industries have considerable share in total industrial energy demand, mainly in coal and electricity. Carbon dioxide (CO_2) emission, oxide of sulphur (SOx), oxide of nitrogen (NOx) and particulate of matter (PM) are major gas generated during production process. It poses serious health concerns particularly to the local population. Hence, it is of prime importance to switch to clean fuel while at the same time, energy use needs to be reduced. Various policy actions have been taken globally to enhance clean energy production and innovation and diffusion of clean technology, advocating to limit greenhouse gas (GHG) emissions cost-effectively.

Recent research shows that a wide range of innovative technology solution has potential for reducing GHG emissions. These solutions pertain to renewable energy, fuel-switching, energy efficiency and waste to energy. Energy efficiency emerges as one of the cost-effective ways to reduce GHG emissions. Over the years, different energy-efficient technologies (EETs) have been advanced to improve energy efficiency. Such technologies maximise energy services during combustion, conserve any wastage of energy. Hence, globally energy efficiency has been increasing particularly in developing countries, to achieve sustainable development. Developing countries lagged to employ such technology and have lower energy efficiency as compared to developed countries. It is seen that developing countries prioritise economic growth without proper preservation of environment. It damages their eco-system as the burden exceeds the reproductive capacity of eco-system. To pursue sustainable development, it requires focusing on energy saving through eco-friendly technology. This will necessitate the wide-spread diffusion of cost-effective EETs.

Iron and steel production is characterised by a complex production system that requires a lot of energy and materials and generates a large quantity of pollution. In the iron and steel industry fuel expenditure has 20-40 per cent share in total production cost (Kanchan, 2013). It is also pertinent for firms' cost-cutting strategy. There are certain organisational and financial barriers which barricade the investment in innovative technology for energy conservation. Hence, firms are supposed to follow at least the best-performing peer firms and adopt such best practices to improve operational efficiency with energy efficiency. On the global level, the iron and steel industry need to recognise global warming challenges and quest for reducing GHG emission. World Steel Association (WSA) asserted that substantial CO_2 emission reductions will need technology transfer, collaboration and breakthrough technologies. Historically it has been seen that on average energy intensity has been reduced by 61 per cent since 1960 globally (WSA, 2019).

India is the second largest iron and steel producer in the world. It has diverse industrial resources for the production of different varieties of products. The national steel policy (NSP) of 2017 has set an ambitious target to boost steel production, technological up-gradation, quality production, and ensuring global competitiveness. It also aims to achieve better environmental performance through energy-saving and pollution control technology. It has set the target to achieve CO_2 emission of 2.2 – 2.4 tonnes per tonnes of crude steel (TCS) in blast furnace-basic oxygen furnace route and 2.6 – 2.7 tonnes per TCS in direct reduced iron route by the terminal year of 2030 (GOI, 2017). This target is far from the current global best practice (GBP) of 1.8 tonnes per TCS (WSA, 2019).

The status of EMS in the iron and steel industry is not very satisfactory and confined to the convenient energy-saving measures like waste heat recovery (WHR) and slag utilisation that gives direct economic benefits (GOI, 2019). Bureau of Energy Efficiency (BEE), the Ministry of Power has initiated a number of energy efficiency schemes. It has achieved considerable success in wide-spread adoption of energy-efficient LED bulb for lighting. In commercial buildings, different energy conservation techniques have been adopted. At the same time, rating and labelling of appliances provoke consumer awareness on energy efficiency and promote energy-saving from such appliances. In the Industrial sector, Perform, Achieve and Trade (PAT) has been implemented loosely. Target energy reduction was not restricted and in-line with a usual trend that may not trigger long-term investment in EETs. It requires lots of improvement like keeping lower transaction cost, lucid target goals, creating a functional trading market and improve the audit standard (Bhandari & Shrimali, 2018).

A vast amount of literature has emerged that measures energy efficiency and quantifies energy-saving potential. Changes in energy intensity (a traditional measure) over time has been analysed and identified different driving factors at end-use or sub-sectorial level. Primarily decomposition analysis has been conducted to decompose energy intensity into structural changes effect, activity effect and intensity effect. Though the industry is progressing towards higher efficiency and productivity, some barriers result in energy efficiency gap. From an economic perspective, the study has investigated the underlying energy efficiency through production function. It is based on total factor productivity (TFP) framework. These studies showed that TFP based energy efficiency could capture the underlying structure of the production function and provide a better estimate than energy intensity.

There is extensive literature on energy efficiency analysis in the case of the developed country. They have more stringent laws regarding the environmental issues and implemented several energy efficiency programmes while little attention has been paid to developing countries. Few studies have to date examined the issue of energy efficiency in the case of the Indian manufacturing sector. Especially in the iron and steel industry, no detailed study exists on energy efficiency analysis from an economic point of view. Therefore, there is a need to undertake a comprehensive study to evaluate the energy efficiency performance of the iron and steel sector of India and benchmark firms in terms of relative efficiency. With this background the main objective of this study is to:

(a) To quantify the technical and energy efficiency performance of the iron and steel industry at the state level.

(b) To quantify the technological and managerial gap in energy efficiency of iron and steel industry in India across different regions.

(c) To find out the influencing factors of adoption of EMS and assess indicators of energy and environmental performance.

(d) To quantify energy efficiency at firm-level and investigate the role of innovative capability on energy efficiency performance.

6.2: Findings

6.2.1: Chapter 2

This chapter estimates the energy efficiency of Indian iron and steel industry by using regional level data over the period of 2004-05 to 2013-14. TFP based measure of energy efficiency has been considered. Production function has been estimated through radial and non-radial variant of data envelopment analysis (DEA) and identifies the relative position of each state in term of energy efficiency. Data has been extracted from the Annual Survey of Industry (ASI) and after cleaning the data, 19 states have been retained in the sample. Four input and single output variables have been considered. Primarily, energy intensity has been calculated to get a first-hand impression of energy efficiency. It shows a declining trend over the period, but it does not decrease much for some states like Bihar, Jharkhand, Gujarat and Uttarakhand. Slack-based measure (SBM) of energy efficiency is employed to get a more comprehensive energy efficiency measure along with radial measure (BCC model) of energy efficiency. SBM of energy efficiency shows an overall 8 per cent of energy-saving potential without reducing output level. Further, scale efficiency has been estimated, which shows the overall average level of scale efficiency was 0.91. It shows scale inefficiency also contributed to total energy inefficiency. Therefore, the scale of operation needs to be adjusted to enhance energy efficiency and to implement standard energy-saving techniques. Hence, it requires decisive policy initiatives to proliferate energy efficiency program through the market base and regulatory mechanism to tap vast energy-saving potential.

It should be noted that energy efficiency score from DEA gives relative efficiency (comparing with firms on efficiency frontier). It is based on the best technology employed across states. At the international level, Global best practice (GBP) is an energy intensity of 3.91 Giga calorie per tonne of crude steel (Gcal/tcs) while in India, it is 6.55 Gcal/tcs on average, 3.57 Gcal/tcs in the U.S. and 5.54 Gcal/tcs in China (Hasanbeigi et al., 2014). India became the second largest producer of crude steel but is still lagging behind in the energy intensity level in comparison with the U.S. and China. Though there are certain constraints like low-quality iron ore and coal, lack of proper policy incentive and lax regulatory limit. GBP in terms of energy efficiency will provide a way to reduce energy consumption level. One critical issue behind the nascent investment in energy-efficient technologies (EETs) is low energy price and lack of technological know-how. It is also the fallout of perceived risk and longer paybacks despite benefits outweigh the costs of investment. Hence, iron and steel industry requires policy support to undertake massive investment in EETs and foreign technology. Japan is leading in this area to develop cost-effective EETs with the lowest energy consumption per TCS. These commercialised EETs need to spillover to other countries (Sugiyama et al., 2019). From the point of view of the life cycle of steel products, the utilisation of by-products, recycling, energy and water consumption are crucial factors to be managed efficiently.

6.2.2: Chapter 3

This chapter explores the magnitude of regional differences in energy efficiency by incorporating it into the production function. Indian iron and steel firms operate under state regulation, different climatic conditions and external economies of scale. Hence, there may be a regional-level technological gap in energy efficiency. This chapter uses firm-level data and incorporates regional grouping to measure firm-level energy efficiency and the regional technological gap simultaneously. Meta- and group- frontier analysis combined with SBM of DEA has been applied. Firm-level data is extracted from the Prowess database of Centre for Monitoring Indian Economy (CMIE), which sources data from the audited balance sheet of Indian companies.

Based on the geographical area of operation, it is categorised into four regions. Then energy inefficiency is decomposed into the technological gap and managerial inefficiency. The results depict huge energy efficiency gap across firms. While looking at the regional differences, each region differs in terms of technological gap. The northern region is relatively more efficient under group frontier, but it has the largest technological gap with reference to meta-frontier. South and West regions have relatively similar performance under meta-frontier, but they have differences in energy efficiency under the group frontier, while the eastern region performs moderately well as compared to other regions. Nevertheless, it has a huge difference from both frontiers. The results show that the significant energy efficiency improvement opportunities available across regions need to be tapped through technological advancement and energy management scheme.

Recent literature has attributed within-region energy inefficiency to the managerial front while technological differences might account for cross-region difference. Relatively lower energy efficiency with regard to meta-frontier shows that greater weight should be given to EETs spillovers in order to narrow down the technological gap. The above results guide towards some crucial policy implications. Energy-saving potential varies significantly across firms and contingent on the technological and managerial gap. Therefore, energy efficiency enhancement programme at the national level should consider regional heterogeneity. There should be cross-regional coordination and diffusion of EETs for better penetration of different energy efficiency programme. It is essential for the northern and eastern region to follow best practices and adopt target reduction in-line with advance technology. This should be assisted by the better material quality and related technical know-how gain at managerial and operational level personnel. The standard energy management system needs to be adopted across regions to reduce the regional heterogeneity. At the firm-level, some standard certification scheme like ISO 14001, 50001 is a better cost-effective option to enhance energy and environmental performance.

The regional technology gap may be due to differences in external economies of scale accruing to firms which effect the technology of energy utilisation. However, several other factors may also influence regional inequality: natural resource endowment, regional geographical characteristic, and resource endowment. Hence, improving cross-region energy efficiency, coordination and cooperation among the states should be encouraged actively. Since regional governments have significant autonomy, they should set their energy saving targets by considering potentials and situation of different industry. This study focuses on the iron and steel industry, which shows vast energy-saving potential. But the situation may differ according to the nature of the industry; hence, an action plan for energy efficiency improvement should be taken into account. EETs and better managerial practices can be successfully implemented.

6.2.3: Chapter 4

Several organisational theories explain firms' behaviour on the environmental practices take off. Firm's adoption of an environmental management system (EMS) can be seen from the different magnifying glass of organisation theory. The firms' legitimacy may be susceptible to civil society if the firm does not account for its environmental impact. Hence, different EMS have been adopted by firms to maintain their green identity. In this regard, ISO 14001 certification has emerged as an important EMS and has been widely adopted across the world. It is a relevant inquiry about whether EMS uptake, among Indian firms, has resulted in concrete environmental improvements. However, there is a dearth of research in this area as Indian firms vacillate to reveal environmental-related data (Kumar & Shetty, 2018). Therefore, this chapter estimates motivating factors that leads to ISO 14000 series adoption among Indian firms with limited insight into its effectiveness through thematic content analysis. It is a preliminary step to understand the behaviour of firms to adopt an EMS. It adds to on-going research into the success and implementation of EMS in India.

For this purpose, plant-level data has been sourced from ASI for the year 2014-15. The logit model has been estimated as our dependent variable (adoption of ISO 14000 series) is a binary variable. The logit regression confirms the influence of firm-level heterogeneity in adopting an

EMS. Firm characteristic, size, age and ownership do matter for decision to adopt an EMS. In the case of size, large and medium firms are more likely to be certified than small firms. Similarly, old firms have higher propensity to be certified. Further, ownership of the firm is statistically significant and influence firms' behaviour on environmental practices. The result shows that private firms are less likely to adopt an EMS as compared to public sector firms. Public sectors and government-owned firms are more visible and seem more responsible than the private sector.

The results indicate that Indian private firms have less inclination toward EMS and may undermine environmental issues. Exporting activity across firms does not assert any influence on the likelihood of EMS adoption. Therefore, the role of demand-side pressure from international customers to adopt green practices is absent in Indian iron and steel. Further, energy intensity does not have a strong influence on EMS adoption. The results show that firms that lie above-average energy intensity are more likely to adopt an EMS. State-level environmental regulation is not able to steer the adoption of EMS. Regulatory pressure may be one of the key variables that influence EMS adoption, but in India, it is operating under a weak institutional set-up. Therefore, the government needs to push-up the voluntary adoption of EMS and enable better corporate policy formulation to enhance environmental sustainability.

Comparative analysis of four leading Indian firms (TATA Steel, JSW Steel, SAIL, and Jindal Steel and Power) and a South Korean firm (Posco) has been done. Some crucial efficiency parameter showed that top Indian firms are far from GBP. In the case of energy and CO_2 emission intensity, TATA has the lowest value of 5.77 Gcal/tcs and 2.26 tonnes/tcs respectively, outperforming other Indian firms. While for other emissions, no proper reporting has been seen and they are far from Poscos' level. Indian firms do not bother about control end of pipe pollution with innovative solutions as Posco is doing. There is an average effluent discharge of 1.75 m3/tcs from Indian integrated plant. TATA has reported achieving near ZLD in 2015-16 while SAIL has proposed the plan for ZLD at different facilities. Hence, recycling and reusing of waste and water are very crucial practices to enhance sustainable production. Indian firms use millions of tonnes of surface water while having only a recycling rate of 30 per cent. Hence, Indian firms need excellent technical and financial support for implanting eco-friendly technology.

6.2.4: Chapter 5

This chapter deals with energy efficiency assessment at firm-level using a Bayesian stochastic frontier analysis (BSFA) to capture firm-level heterogeneity. At the next step, the role of different channel of innovations and EMS on energy efficiency has been explored. The purpose of adopting BSFA is to incorporate in-hand prior information and the random coefficient. Hence, it is supposed to provide a comprehensive measure of energy efficiency. There are 82 firms under analysis for the year 2003-04 to 2016-17 for which data has been consolidated from Prowess. Different versions of BSFA have been estimated to better fit the model with a classical SFA model.

The results from BSFA show a relatively stagnating trend of energy efficiency over the sample period. While there is more concentration of energy efficiency in the lower and middle quantiles and most of the firms lie between 0 to 40 per cent of efficiency level. Half of the sample firms can reduce their energy consumption by at least 60 per cent. BSFA better fits the model than classical counterpart as it has a lower standard error. It has also provided a confidence interval of efficiency score which shows that energy efficiency score is within the margin. Among three BSFA models, a time-varying model with t-distribution best fits the model.

In a second-stage analysis, regression analysis has been performed to analyse the driving factors of energy efficiency. The result documents that building innovative capability through R&D activity, patent application and disembodied technology enable firms to achieve higher energy efficiency, while embodied technology does not have any significant impact on energy efficiency. R&D activities stimulate absorptive capacity and technical know-how of advance technology. It is crucial for firms to adopt innovative measures and acquire technical know-how for enhancing energy efficiency. EETs need to be transferred from advanced countries to developing countries firms to reduce the energy efficiency gap. Further, there is no influence of EMS (ISO 14001) adoption on energy efficiency. Hence, certified and non-certified firms have similar energy efficiency distribution. Size and age also matter for firms' energy efficiency. Younger firms tend to be relatively energy efficient than older firms. It may be owing to the latest and advanced vintage of capital installed by younger firms. Larger-sized firms have relatively higher energy efficiency.

The findings substantiate the arguments that building innovative capacity for eco-friendly operation results in competitive advantage through better energy and environmental performance. It can be seen as firms' long-term strategy to gain sustainable competition. Moreover, EMS adoption necessitates an effective implementation and structural transformation not just to keep emission under the regulatory limit but to reduce to the lowest possible level. Given that energy is a major production input, efficient utilisation of energy resources should be of prime importance in reducing emission and effluent. Technological innovation appears to be a crucial solution for better utilisation of scarce resources. It can be instrumental in enhancing energy efficiency level.

6.3: Policy Implications

From the policy perspective, this thesis provides valuable insights for designing a nuanced energy efficiency programme. Policymakers need to bridge the regional technological gap across India to better manage the efficiency improvement programme. At the regional level, state governments are highly recommended to infuse the awareness and viability of EETs through active coordination with other states and energy service companies (ESCO). Further, technical and financial constraint primarily faced by small and medium enterprises needs to be resolved though customised technological innovation and concessional finance.

While having a substantial potential for energy saving at firm-level, recent energy efficiency programme is recommended to re-evaluate the targeted reduction of energy intensity. In a weak regulatory institutional set-up, market-driven adoption of EMS should be promoted. In this regard, a business model like ESCO should be promoted to resolve the firm-level barrier. It will help to reduce the risk associated with investment in EETs. Finally, R&D activities need to accelerate across, which assist firms to adopt GBP. Absence of transparency and clarity at the policy level and operational anomalies may jeopardise energy efficiency investments. Moreover, current energy efficiency policy requires proper monitoring and assessment to avoid any suboptimal outcomes.

6.4: Limitations

This study has taken a broader view of the level of energy efficiency by considering heterogeneity. It is strictly not comparable to other countries as it is based on the local condition of the Indian economy and climatic condition. The firm-level sample from Prowess database is restricted to listed firms that have audited balance sheet. Due to unavailability of data regarding CO_2 emission, only energy use efficiency has been examined. The main limitation of the thesis is that only technical and energy efficiency have been estimated. The other measure of efficiency, such as allocative, cost or profit efficiency, may extend the thesis. But it has not been estimated because of non-availability of consistent input and cost data. Key interest variable of the analysis is energy input (aggregate energy input) that provides different energy services during the production process (heating, electricity and feedstock). Disaggregate energy inputs may be better to be combined with a process-level analysis that map specific energy input with process one to one. Though, it can provide more detail on the energy efficiency potential of each process involved in iron and steel making, it may not account for managerial-level heterogeneity.

This thesis aims at measuring energy efficiency empirically, which is based on firm-level production function. Hence, it is out of scope of the thesis to examine the thermal efficiency by taking the different process into account. Further energy input data is taken in monetary unit rather than generally preferable physical unit due to non-availability of consistent data in physical unit. However, the monetary unit of energy data accounts for quality differences in energy source, which is absent in physical unit. For example, higher-quality coal may be relatively costlier, so it will reflect in expenditure on coal consumption. Hence, monetary energy input data will be reliable for measuring energy efficiency (Patterson, 1996). The thesis work can be extended further to analyse the effect of various barriers and constraints at the regional and organisational level to achieve higher energy efficiency. More detailed plant-level data may reveal greater insight on energy-saving potential. It may also allow to rigorously link innovative capability and other such potential driving factors to energy efficiency.

6.5: Conclusion

This thesis has estimated the energy efficiency of Indian iron and steel industry by estimating the production frontier using state and firm level data. At firm-level, energy-saving potential varies between 40 to 60 per cent, ranging from 10-30 per cent at state-level. The thesis finds huge technological gap in energy utilisation across the regions ranging from 40 to 50 per cent. South and west region have a lower technological gap as compared to the north and East region. Hence, firms should adopt a techno-managerial approach to improve its energy efficiency. The decision to adopt an EMS is contingent on firm's resources and its characteristics like size, age and ownership. The comparative analysis has shown that top Indian firms are far from GBP and perform not better than average Indian firms. There is a lack of proper water and waste management and shown inefficient utilisation of waste gas and energy. Several commercially viable conservation measures need to be put in practice to internally recycle and reuse such by-products. Further, the underlying innovative capability of the firms remains a crucial element in improving its position for efficient utilisation of energy input. Hence, allocation for R&D expenditure and technical know-how purchase needs to promote. Finally, voluntary adoption of EMS should be effectively assimilated into the daily operation of business to seriously minimise its environmental impact. It should be supplemented by employing quality technical and human resources.

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Appendix I

Energy intensity of Indian iron and steel sector

year	2004 - 05	2005 - 06	2006 - 07	2007 - 08	2008 - 09	2009 - 10	2010 - 11	2011 - 12	2012 - 13	2013 - 14	Average
AP	0.100	0.083	0.081	0.084	0.079	0.074	0.085	0.062	0.079	0.062	0.079
AS	0.061	0.091	0.052	0.097	0.084	0.056	0.039	0.044	0.083	0.078	0.068
BI	0.190	0.154	0.222	0.160	0.176	0.168	0.121	0.147	0.122	0.070	0.153
CT	0.112	0.110	0.084	0.087	0.084	0.071	0.059	0.056	0.069	0.057	0.079
GU	0.123	0.115	0.118	0.137	0.175	0.081	0.103	0.132	0.116	0.060	0.116
HA	0.034	0.052	0.033	0.043	0.051	0.046	0.043	0.042	0.047	0.037	0.043
HM	0.101	0.065	0.094	0.095	0.080	0.091	0.076	0.087	0.077	0.070	0.084
JH	0.082	0.096	0.144	0.063	0.209	0.179	0.145	0.198	0.162	0.319	0.160
KA	0.073	0.062	0.046	0.052	0.033	0.054	0.048	0.052	0.038	0.038	0.049
KE	0.184	0.146	0.165	0.131	0.095	0.118	0.091	0.098	0.089	0.059	0.118
MP	0.073	0.055	0.051	0.048	0.053	0.053	0.055	0.049	0.042	0.053	0.053
MA	0.079	0.071	0.076	0.075	0.082	0.083	0.069	0.070	0.071	0.068	0.074
OR	0.154	0.193	0.117	0.107	0.086	0.081	0.069	0.063	0.069	0.061	0.100
PU	0.076	0.104	0.092	0.078	0.073	0.075	0.074	0.073	0.065	0.078	0.079
RA	0.087	0.100	0.094	0.084	0.077	0.071	0.055	0.056	0.072	0.039	0.074
TN	0.084	0.084	0.063	0.106	0.067	0.056	0.056	0.039	0.119	0.070	0.075
UK	0.194	0.186	0.137	0.121	0.098	0.121	0.116	0.109	0.103	0.107	0.129
UP	0.098	0.093	0.070	0.072	0.065	0.076	0.071	0.061	0.050	0.052	0.071
WB	0.084	0.087	0.066	0.069	0.071	0.076	0.065	0.073	0.084	0.049	0.072
All India	0.093	0.094	0.088	0.089	0.096	0.083	0.077	0.076	0.083	0.064	0.084

Note: All India is national level energy intensity, last column is state average over whole period

Appendix II

State-wise Firm Distribution

Name	Number of ISO certified firms	Total number of firms	Madhya Pradesh	6	30
Assam	1	12	Maharashtra	24	102
Bihar	0	13	Meghalaya	1	14
Chhattisgarh	31	102	Odisha	20	87
Goa	3	4	Punjab	5	37
Gujarat	2	67	Rajasthan	7	49
Haryana	8	39	Tamil Nadu	11	44
Himachal Pradesh	2	9	Telangana	4	19
Jammu and Kashmir	1	6	Uttar Pradesh	9	51
Jharkhand	19	40	Uttrakhand	1	8
Karnataka	11	35	West Bengal	26	98
Kerala	0	9	Total	199	907

Source: Author calculation (2019)

Appendix III

Correlation analysis of variables

Variables	ISO14	size_s	size_m	size_l	age	export	Owner	EI_1	EI_2	capint
ISO14	1									
size_s	-0.169	1								
size_m	0.044	-0.155	1							
size_l	0.173	0.748	0.540	1						
age	0.123	0.034	0.038	0.054	1					
export	0.076	-0.114	0.049	0.130	0.019	1				
Owner	0.075	0.110	0.123	-0.176	-0.072	-0.113	1			
EI	-0.011	0.080	0.044	-0.098	-0.010	0.018	0.049	1		
ei_l	-0.031	0.033	0.075	-0.078	-0.015	0.012	-0.094	0.773	1	
capint	0.030	0.140	-0.049	0.152	-0.015	-0.002	-0.123	0.009	0.019	1
Regulation	0.259	-0.118	0.079	0.154	0.099	0.186	-0.234	0.017	0.04	0.124

Source: Author calculation (2019)

Benchmarking: An International Journal

Benchmarking energy use of iron and steel industry: a data envelopment analysis

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Benchmarking energy use of iron and steel industry: a data envelopment analysis

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Abstract

Purpose – The purpose of this paper is to benchmark the energy use of Indian iron and steel industry. For this purpose, the authors have estimated a production frontier to know the best performing states. Further, the energy-saving targets are estimated to lie below the benchmark level for those states. Panel data for this purpose are extracted from the Annual Survey of Industry (an official database from the government of India) for 19 major steel-producing states over the period from 2004–2005 to 2013–2014.

Design/methodology/approach – The authors employed a radial and non-radial (slack-based measure) variant of the data envelopment analysis (DEA) to estimate the production frontier. Particularly, slack-based measures (SBMs) developed by Tone (2001) are used to get a more comprehensive measure of energy efficiency along with technical efficiency. Variable returns to scale technology is specified to accommodate market imperfection and heterogeneity across states. Four inputs (capital, labour, energy and material) and a single output are conceptualised for the production process to accommodate input substitution. The relative position of each state in terms of the level of energy efficiency is then identified.

Findings – The authors started by examining energy-output ratio. The average level of energy intensity shows declining trends over the period of time. States like Bihar, Jharkhand, Gujarat and Uttarakhand remain stagnant in the energy intensity level. SBM of energy efficiency shows an overall average energy saving potential of 8 per cent without reducing average output level. Considerable heterogeneity exists among states in terms of the energy efficiency scores. Further, the authors calculated scale efficiency (SE) which shows the overall average level of SE is 0.91; hence, the scale of operation is not optimal and needs to adjusted to enhance energy efficiency.

Originality/value – The authors demonstrate the empirical application of DEA with SBM to energy use performance. This is the first study that benchmarks Indian states in terms of the consumption of energy input to produce iron and steel by applying DEA.

Keywords Benchmarking, Iron and steel industry, DEA, Energy efficiency

Paper type Research paper

1. Introduction

The environmental impacts of the industrial sector have become an increasingly important topic of public debate. World industry contributes about 37 per cent of the global greenhouse gas emissions (GHG), of which over 80 per cent is from energy use (Price *et al.*, 2006). Iron and steel industry, which is one of the most energy-intensive industrial sub-sectors, contributes about 7 per cent of total anthropogenic CO_2 emissions (Kim and Worrell, 2002). The energy intensity of industrial sector has steadily declined in most countries since the oil price shocks of the 1970s (Dasgupta and Roy, 2017). A wide range of technologies has the potential for reducing GHG emissions, of which energy efficiency is one of the most cost-effective ways to achieve it. Two different definitions of energy efficiency are found in the literature. First, according to an engineering point of view which measures lowest possible energy consumption through theoretical thermodynamic law or globally best available technology (BAT) and then compares with actual energy consumption. Second from an economic point of view, which measures energy efficiency from real-world best practice, through benchmarking with the current level of technology. Energy efficiency from an economic point of view is important because it is very difficult to realise whole energy efficiency measured theoretically from an engineering point of view. This is primarily due to factors beyond the control of the firm. There are in fact certain barriers that

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cause the non-realisation of full benefit from energy efficient technology. Although energy efficient technology outweighs the cost associated with it, the presence of economic and organisational barriers results in "energy efficiency gap" (Hochman and Timilsina, 2017). Therefore, an economic analysis of energy use efficiency and energy saving potential can help to quantify the magnitude of barriers.

Globalisation and international competitiveness have directed the emerging economies to adopt an efficient production system including the energy efficiency. More importantly, the increased energy consumption has resulted in the voluminous quantities of environmental hazards[1], and thereby questioned the quality and sustainability of the ecological and environmental system. In addition, increased energy consumption has also resulted in national energy security concerns. It becomes quite imperative to make an introspection of energy use across full income continuum from less developed countries to developed countries. With the issues of energy accessibility, high energy prices, global warming and environmental sustainability, economies both individually and in collaboration are exercising some market-oriented and regulatory mechanisms among which improving their energy efficiency level by employing energy-efficient technology is one of the cost-effective options[2]. Energy demand has increased more than double during the last decade and proved to be an important impute for the growth of the Indian economy (Nain *et al.*, 2017). But the story has some other side, where people are facing the major challenge of climate change and global warming.

Most of the crude steel/steel produced in India is by Integrated Steel Plants (ISPs) using Direct Reducing Iron (DRI) – Electric Arc Furnace (EAF) process. Most industrial processes use at least 50 per cent more than the theoretical minimum energy requirement determined by the laws of thermodynamics, suggesting a large potential for energy-efficiency improvement and GHG emission mitigation (IEA, 2006). Iron and steel industry in India is covered under the Environment Protection Act as well as Environment Protection Rules and Regulations enacted by the Ministry of Environment and Forest. They are monitored by Central/State Pollution Control Boards. The above facts depict the importance of Indian iron and steel sector for the GHG mitigation concern and environment management. This sector is also important for the infrastructural development and future growth of the economy. Given the fact that Indian iron and steel industry lacks behind other developing countries like China in terms of energy efficiency, energy efficiency improvement is the key factor in the improvement in the industry's overall performance. For enhancing energy efficiency, the government of India has enacted energy conservation act 2002 and establish the Bureau of Energy Efficiency hereafter BEE in 2002. Different industrial energy efficiency schemes were devised to gain efficiency in energy consumption. Against this backdrop, this study makes attempt to examine the energy efficiency performance of Indian iron and steel industry. Hence, it will analyse whether industrial energy efficiency scheme leads to any significant improvement in the energy efficiency. This will help in designing a better industrial energy efficiency programme. Particularly, at the regional level, it will help energy inefficient states to imitate energy efficient states.

The rest of the sections are arranged as follow. Section 2 provides some overview of India iron and steel industry, while Section 3 documents related literature review. Section 4 provides methods and data used in the studies, Section 5 includes results and discussion and, finally, Section 6 concludes.

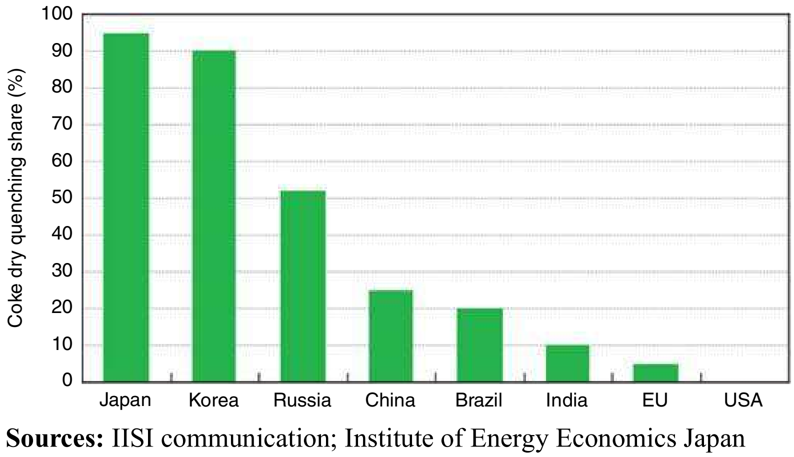
2. Current scenario of iron and steel industry in India

During post-liberalisation, with the help of the private sector, India emerged as the 3rd largest producer of crude steel in the world in 2015, as per the ranking released by the WSA (2015). The private sector accounted for 91 per cent of total production for the sale of pig iron in the country in 2014–2015. India is the world's largest producer of sponge iron with a host of coal-based units. Coal base system dominated this sector, accounting for around 90 per cent of total sponge iron in the country. The steel industry in India consists of relatively efficient private sector steel plants, alongside less efficient public steel plants and a significant number of mini blast furnaces that cannot reach the energy efficiency levels of larger plants due to their small scale.

Indian iron and steel production involves highly energy-intensive processes which consume 21 per cent of the total industrial energy consumption. Emerging need of iron and steel during near future for urbanisation and infrastructure energy need may increase from current 46 million tonne oil equivalent (Mtoe) to around 200 Mtoe over the period to 2040 (IEA, 2015). The sector contributes about 6.2 per cent of the GHG emissions. There is a huge potential in improving energy efficiency in the Iron and Steel Industry irrespective of limitations in the availability and quality of iron ore and coking coal. As compared to globally BAT benchmark of 16.4 gigajoules per ton crude steel (GJ/tcs), energy consumption in major steel plants in India was 27.3 GJ/tcs in 2009 (Krishnan *et al.*, 2012). Cooking and non-cooking coal is the major energy input. There is some recent advancement in the energy efficient technology like coke dry quenching (CDQ) and Pulverised coal injection used in a blast furnace. CDQ is used to improve the quality of the coke and decreases the coke consumption in the blast furnace by about 2 per cent. This saving amounts to 0.6 GJ/t coke. Japan and Korea are the leading countries in CDQ installation mainly on account of government initiative and energy conservation policy, as given in Figure 1. CDQ can be applied and retrofitted at new and existing plants. Asian countries widely apply CDQ, while India is lacking behind it due to lower energy price (Coal and electricity price). Moreover, it is not applied in the USA and Canada and the use rate is below 5 per cent in Europe. (IEA, 2007).

3. Literature review

Literature on energy efficiency analysis can be broadly classified into two parts, first, literature based on the partial factor framework (takes only energy consumption into account), while second, literature based on total factor productivity based on production frontier. The partial factor framework is used in the literature to find out the driving factor of the energy intensity changes at energy end-use or sub-sectoral level over the period of time and attempts to make an energy efficiency performance index. These literature works have analysed the contribution of scale, intensity and structural effect at the sub-sectoral level and end-use energy consumption (Paul and Bhattacharya, 2004; Das and Paul, 2014; Xu *et al.*, 2014; Tandon and Ahmed, 2016). These scholars have mainly



Sources: IISI communication; Institute of Energy Economics Japan (IEEJ) (2006)

Figure 1.
Application of coke dry quenching in iron and steel plant

taken help of the structural and the index decomposition analysis (IDA)[3] to estimate the effect of these changes on energy or carbon emission changes over time. Structural and the IDA does not take all factors of production into consideration and lack a comprehensive analysis of energy efficiency. Countries, like New Zealand, Canada and USA, etc., have applied the IDA technique to track the energy use trend over the period of time.

Second, classification based on production frontiers which used the concepts of the production function. There are two main approaches to estimate production frontier: first is data envelopment analysis (DEA), while second is stochastic frontier analysis (SFA). DEA is a flexible and non-parametric approach easily modified to apply in energy and environmental evaluation and the examination of energy efficiency achievements across various energy consuming units in an economy or across the economies at large. It is a widely applied benchmarking technique for assessing relative performance in the energy use at the sectoral or economy level and quantifying energy saving potential with current technology (Wei, 2001; Zhou and Ang, 2008; Zhou *et al.*, 2008; Hu and Wang, 2006; Mukherjee, 2008; Zhang *et al.*, 2011).

DEA is a popular technique for a comparative analysis of energy efficiency and policy designing. Recently, DEA has been applied in characterizing different production system and energy use performance. Mardani *et al.* (2017) applied the DEA methodology for the energy efficiency where the feasibility of the production function is either virtually absent or very hard to frame. Applying a slack-based measure of DEA, Chen and Jia (2017) found that except certain developed regions, the environmental efficiency of China's industry was low, varied across regions and did not show any signs of improvement over the study period 2008–2012. Li and Tao (2017) provided an illustrious review of various methodologies and policies used in the energy efficiency performance of high energy consuming industries. Moon and Min (2017) pointed out the sensitivity of overall energy efficiency to the pure energy efficiency (PEE) of the manufacturing firms in Korea. Zhu *et al.* (2017) highlighted the better performance of natural resource utilisation in mainland China at the cost of huge natural resource consumption. Though, however, a heterogeneity is observed at the regional level, Liu and Lin (2018) documented the evidence of a ladder-like distribution of energy efficiency of the inter-provincial China's transport sector, with eastern region found to be more efficient, and followed by central and western regions.

On the contrary, SFA, a purely statistical method, is also used to estimate efficiency frontier. SFA is a parametric approach to efficiency analysis which imposes a parametric form of the production function. Feijoo *et al.* (2002) employed a Cobb-Douglas SFA model to examine the energy efficiency of Spanish industry. Buck and Young (2007) while making a cross-sectional energy efficiency analysis of Canadian commercial buildings also made the use of SFA. Boyd (2008) suggested the use of SFA technique to examine plant-level energy use efficiency. Recently, Zhou *et al.* (2012) employed the parametric frontier approach in order to measure the economy-wide energy efficiency position in case of a sample of OECD countries. Lin *et al.* (2011) evaluated China's steel industry energy efficiency with that of Japan as a baseline, and found more than 200 million ton coal equivalent energy saving, which was expected to become fully energy efficient in 2020. Lin and Moubarak (2014) estimated the energy saving potential in China's paper industry under various scenarios using the cointegration and associated stability tests, and the study found energy price, industry structure, profit margin and technology affecting the energy intensity negatively. Kong *et al.* (2013) described the role of energy audit and method for estimating baseline energy consumption, using paper mill data of Guangdong province, China. The study shows 967.8 terajoules of energy saving potential from nine energy saving opportunities. The energy and environmental efficiency of other industries also was analysed like in transport and gas industry using the benchmarking technique (Goncharuk, 2008, 2009). Castro and

Frazzon (2017) reviewing the benchmarking of best practices and classifying academic literature into DEA non-DEA studies found that DEA is more a flexible and accommodated advance model. Apart from energy and environmental performance, DEA has been applied in estimating the technical efficiency and productivity of different service providing industry like telecom operators, integrated water management, and (Gilsa *et al.*, 2017; Storto, 2014; Nigam *et al.*, 2012). DEA can also be applied in cost and allocative efficiency analysis (Sarkar, 2017).

Though India is facing the problem of energy security and accessibility, energy efficiency evaluation has not been conducted very exhaustively. Some earlier studies like Srivastava (1997), Nag and Parikh (2000) and Bhattacharya and Paul (2001) analyse the energy and carbon emissions trend and deriving factor, and documented some measures of energy use and energy efficiency, using economy and sectoral level data. Schumacher and Sathaye (1999) made a heuristic evaluation of India's paper industry in terms of productivity and energy efficiency perspective for the period from 1973–1974 to 1993–1994. Mukherjee (2008) made use of DEA technique for an interstate analysis of energy efficiency of the aggregate manufacturing sector. The study further found a passive role of relative energy prices in improving the efficiency standards, the large share of manufacturing output leading to lower energy efficiency, high-quality labour force affecting efficiency positively and the poor execution of power sector reforms resulting in no improvements in energy efficiency.

Gielen and Taylor (2009) found that industrial sector is heterogeneous as far as efficiency standards are concerned. In order to achieve a low carbon growth along with improved efficiency, the study suggested complementarity between energy efficiency measures and low carbon growth measures. Mandal and Madheswaran (2011) analysed the energy efficiency of Indian cement industry by applying DEA. The author reported the existence of a considerable potential for energy saving, varying across the firms. Sahu and Narayanan (2013) evaluated the nature of the relationship between labour and energy intensity in the case of paper industry of Indian manufacturing. Using the unit-level data, the authors documented an inverted U-shaped relationship between the two, implying the substitutability between the two-factor inputs. Dasgupta and Roy (2017) examined the energy intensity trends in case of seven highly energy-intensive industries and aggregate manufacturing in India. Energy demand is found to be augmented by activity growth much heavily. Reddy and Ray (2011) analysed the energy intensity of five energy intensive sectors of India and found that the energy intensity of iron and steel industry decreased ranging from 5.17 per cent by alloy steel to almost 60 per cent by ferroalloys over the period 1991–2005 but still remains higher compared to developed countries. In the context of India, very less number of studies are found which systematically analysed the efficiency level of industrial energy consumption.

Studies that analysed the energy efficiency of the aggregate manufacturing sector may suffer from aggregation bias as energy consumption differs significantly across industries. On the other hand, some studies analysed energy efficiency specific industry like paper and cement industry. Further, most of the studies are based on a partial factor framework that takes only energy output ratio as an indicator of energy efficiency and do not use a benchmark to estimate relative performance in the energy use. The underlying energy efficiency might not be captured due to not considering input substitution, and hence leading to the misspecification of production function (Mukherjee, 2008). To overcome the above limitation, this study analysed the energy efficiency of iron and steel industry which is one of the most energy-intensive industries. To the best of our knowledge, not any study conducted so far has analysed the energy efficiency of Indian iron and steel industry using the production theoretic approach. Contrary to other studies, the present paper uses a panel of 19 major steel producing Indian states over the period from 2004–2005 to 2013–2014. We employed a total-factor productivity framework that takes factor substitution and production function into account. Further relative technical and energy efficiency is estimated through a well-established function theoretic approach and benchmarking technique that is DEA. We have conceived four factors of production and a single output (desirable output) consolidated from an official database: the annual survey of industries (ASI), to conduct the analysis. In the absence of data of undesirable output (carbon emission from energy consumption), we focussed on energy use only but it has implication for environmental quality. Since data of carbon emission (undesirable output) are derived from energy input, the minimisation of energy consumption leads to a reduction in carbon emission. Therefore, we can get a reliable energy efficiency score in the absence of undesirable output data. We employed slack-based measure (SBM) advanced by Tone (2001) to get a comprehensive measure of energy efficiency along with the radial measure of efficiency. Further, regional level results depict considerable energy efficiency variation among states and higher energy efficiency improvement opportunities for states like Gujarat, Andhra Pradesh, Orissa and Tamil Nadu.

4. Methodology and data

In the non-parametric approach, Charnes *et al.* (1978) henceforth (CCR) were the first to propose DEA method to evaluate the efficiency of decision-making units (DMUs). CCR model assumes an input orientation and constant returns to scale. In this model, technical efficiency is obtained as the ratio of minimum (optimal) achievable input bundle to the actual input bundle in an input-oriented measure of efficiency[4]. Subsequently, Banker *et al.* (1984) henceforth (BCC) developed an efficiency measure based on variable returns to scale (VRS) called as BCC model. This method is actually based on linear programming which creates a piecewise linear best practice frontier based on the observed input-output data. Based on above two models, various modifications and refinements were made and a different version of DEA appeared in the literature.

As it is very flexible, DEA is a widely applied and well-established method of energy and environmental evaluation. DEA is recognised in the literature as a powerful method that is more suitable for performance measurement than traditional, econometric methods such as regression analysis and simple ratio analysis (Castro and Frazzon, 2017; Mardani *et al.*, 2017). Owing to its flexible nature, DEA has been widely applied in energy and environmental evaluations[5], and in the current study, we also applied it in order to arrive at a normative measure of energy efficiency instead of a descriptive measure as given by energy intensity. For an overall view of the methodology applied in the study, a flowchart is given, as shown in Figure 2. Flowchart of the applied method shows that two variants of DEA (radian and non-radial measures of technical efficiency) were applied initially and subsequently, the corresponding energy efficiency scores were calculated to arrive at the energy saving target for inefficient states and identify benchmark states. We proceeded further to differentiate between PEE and scale efficiency (SE).

4.1 Radial measure of efficiency

We use two variants of DEA, radial and non-radial adjustment. Radial measures use only proportional reduction in all inputs, while non-radial measures use a non-proportional reduction in all inputs. We have used input-oriented BCC variant of DEA for a radial measure of technical efficiency and then derive radial energy efficiency. Let us start with some notational system to formally define the model. Suppose that a typical firm produces a single output y by employing m inputs $x = (x_1, x_2, \ldots, x_m)$. Let there be n numbers of firms $(j = 1, 2, \ldots, n)$ to be evaluated, y_j be the output and x_j be the input bundle of the jth firms. We can now specify production possibility set:

$$p(x) = \{(x, y) \in R : x \text{ can produce } y\}, \tag{1}$$

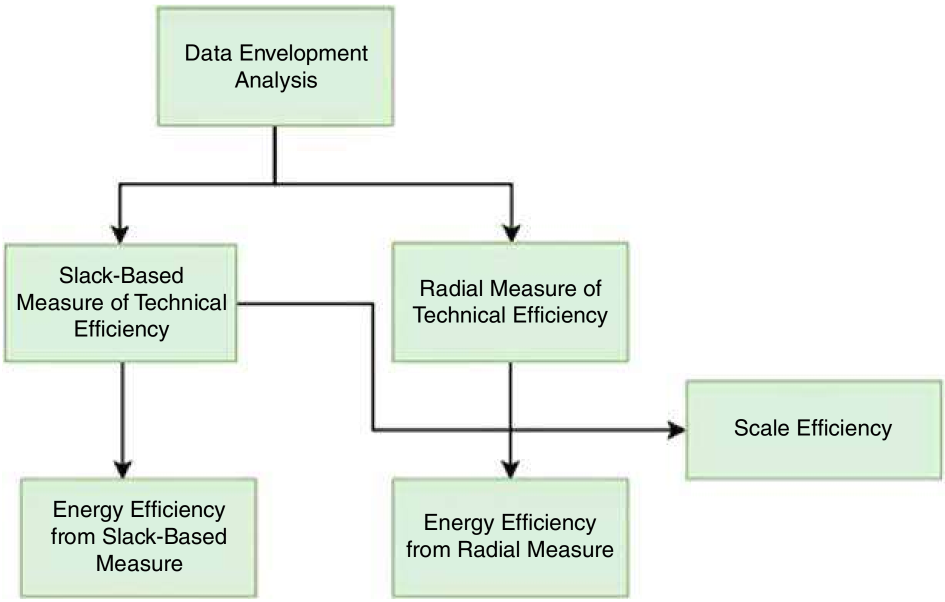


Figure 2.
Flowchart of method

T includes all the feasible input and output vector assumed to satisfy the typical neoclassical regularity condition of a production function like a closed and bounded set. Given the observed input-output combinations with free disposability assumption, an input-oriented BCC efficiency measure minimises all inputs in equal proportion to arrive at the optimal input bundle. The efficiency of a particular DMU with the input-output bundle (x_0,y_0) can be estimated through following BCC model:

$$\theta^* = \min \theta, \tag{2a}$$

Subjected to:

$$\sum_{j=1}^{n} x_{ij}\lambda_j \leqslant \theta x_{i0}, \tag{2b}$$

$$\sum_{j=1}^{n} y_j\lambda_j \geqslant \theta y_0, \tag{2c}$$

$$\sum_{j=1}^{n} \lambda_j = 1, \tag{2d}$$

$$\lambda_j \geqslant 0,\ j = 1, 2, \ldots, n,$$

where x and y are the vectors of inputs and outputs, respectively. i is an index of inputs (capital, labour, material and energy); j is an index of firms under consideration. λ is a scalar by which all the inputs of an inefficient firm are reduced in order to reach at the frontier point. θ measures the technical efficiency of the firms through proportionate reduction in all the inputs.

The BCC model specified above has the objective to reduce all inputs by the same proportion to the largest possible extent in firms. While keeping output level at least what is being actually produced, ensured by (2c), constraint (2d) implies that the technology exhibits VRS. The value of θ lies between 0 and 1, and an efficient firm will assign the value of $\theta^* = 1$, meaning that no proportional reduction in inputs is feasible, whereas inefficient firms will have $\theta^* < 1$. Note that the radial measure of efficiency does not take slacks into accounts with a particular input; if slacks exist, further reduction in that input is feasible. Therefore, a radial measure of efficiency has a low discriminatory power. In order to calculate the efficiency of a particular input (say energy), minimum energy requirement will be proportional reduction plus some slacks associated with this particular input. Here, slacks are calculated residually and then energy efficiency becomes the ratio of minimum energy requirement to actual energy use. We call this measure of energy efficiency as BCC energy efficiency denoted by γ^*. If no slack exists with respect to energy input, then $\gamma^* = \theta^*$. But the problem arises here is that it does not deal directly with inputs and output slacks and hence, not able to gauge the whole aspect of inefficiency (Tone, 2001).

4.2 SBM of efficiency

In order to overcome the problem of radial measure of efficiency, recent studies apply some variant of the non-radial measure of efficiency. The SBM is the most popular non-radial approach with desirable features. It directly takes input and output slacks into account and provides more comprehensive efficiency measurement. We applied SBM developed by Tone (2001) which can be viewed as a product of input and output inefficiency. Therefore, it has a higher discriminatory power and is suitable for energy efficiency analysis.

A graphical illustration given in Figure 3 depicts the advantage of the SBM model over traditional radial measures of efficiency. The SBM finds the furthest point on the efficiency frontier through maximising the amount of slack in the objective function. It is assumed that the isoquant curve Q is constructed from the combinations of energy and non-energy inputs that produce the same quantity of output. Points that lie on the isoquant curve are technically efficient but points above the isoquant curve are inefficient due to the fact that they employ extra inputs to produce the same quantity of output, for example, point "a". As per the radial measures of efficiency, energy efficiency score of the firm at the point "a" is given by distance measurement (od/oa). On the other hand, SBM projects the reduction in the energy inputs to point "b", the "furthest point" on the efficient frontier. Energy efficiency score of the firm at the point "a" is given by distance measurement (bk/ak).

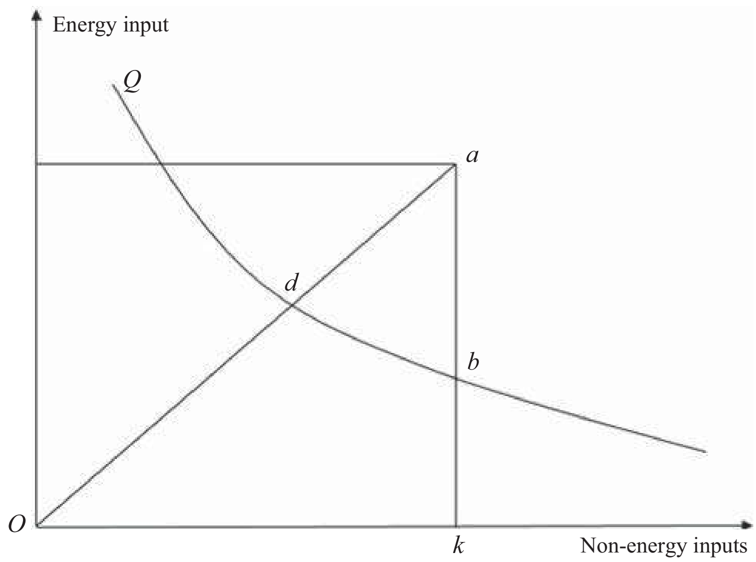


Figure 3.
Graphical Illustration of radial versus SBM of energy efficiency

We called this as SBM energy efficiency. Based on production possibility test:

$$\text{Minimise } \rho = \frac{1-(1/m)\sum_{i=1}^{m} s_i^-/x_{i0}}{1+(1/s)\sum_{r=1}^{s} s_r^+/y_{r0}}. \tag{3a}$$

Subject to:

$$x_0 = x\lambda + s^-, \tag{3b}$$

$$y_0 = y\lambda - s^+, \tag{3c}$$

$$\lambda \geqslant 0,\ \ s^- \geqslant 0,\ \ s^+ \geqslant 0.$$

Above fractional can easily be transformed into an equivalent linear programme through the Charnes-Cooper transformation used in the CCR model (see Charnes *et al.*, 1978).

Let t be a scalar term ($t > 0$), and multiply t to both the denominator and the nominator in (3a); this will not cause any change in ρ. t will be adjusted such that denominator becomes 1. Then the denominator term will move to the list of constraint. Then the model becomes:

$$\text{Minimise } \tau = t - \frac{1}{m}\sum_{i=1}^{m} ts_i^-/x_{i0}. \tag{4a}$$

Subject to:

$$1 = t + \frac{1}{s}\sum_{r=1}^{s} ts_r^+/y_{r0}, \tag{4b}$$

$$x_0 = x\lambda + s^-, \tag{4c}$$

$$y_0 = y\lambda - s^+, \tag{4d}$$

$$\lambda \geqslant 0,\ \ s^- \geqslant 0,\ \ s^+ \geqslant 0,\ \ t \geqslant 0.$$

The model given above becomes a nonlinear programming problem due to the presence of the nonlinear term ts_r^+ $(r = 1, \ldots, s)$. However, it can be easily transferred into a linear programming as follow.

The first term is defined as:

$$S^- = ts^-,\ \ S^+ = ts^+,\ \ \text{and } \Lambda = t\lambda,$$

$$\text{Minimise } \tau = t - \frac{1}{m}\sum_{i=1}^{m} S_i^-/x_{i0}. \tag{5a}$$

Subject:

$$1 = t + \frac{1}{s}\sum_{r=1}^{s} S_r^+/y_{r0}, \tag{5b}$$

$$tx_0 = X\Lambda + s^-, \tag{5c}$$

$$ty_0 = Y\Lambda - s^+, \tag{5d}$$

$$\Lambda \geqslant 0,\ S^- \geqslant 0,\ S^+ \geqslant 0,\ \ t \geqslant 0.$$

If an optimal solution of linear programming be:

$$\tau^*,\ \ t^*,\ \ \Lambda^*,\ S^{-*},\ S^{+*}.$$

Then it can provide an optimal solution of SBM as follows:

$$\rho^* = \tau^*,\ \lambda^* = \Lambda^*/t^*,\ s^{-*} = S^{-*}/t^*\ s^{+*} = S^{+*}/t^*.$$

Through the optimal solution of above parameter, it can be easily determined whether a firm is being efficient or not. We can calculate energy efficiency measure as follows:

$$\text{Energy efficiency} = \frac{\text{TEI}}{\text{AEI}} = \frac{(\text{AEI} - \text{ES})}{\text{AEI}} = 1 - \frac{\text{ES}}{\text{AEI}}, \tag{6}$$

where TEI is the target energy input; AEI the actual energy input; and ES the energy slack. Energy slack is calculated from the model (5a)–(5d), after that we estimated the energy efficiency level of each state under study. The hallmark of the SBM model lies in its method to calculate the efficiency of any specific input, for example, energy efficiency in this study. Hu and Wang (2006) and Zhou and Ang (2008) applied similar method, where they derived the energy efficiency index in the total factor productivity framework. Following Zhang and Choi (2013), we have applied SBM to derive energy efficiency in case of Indian iron and steel sector.

By imposing a restriction of $\lambda = 1$, we can get an estimate of energy efficiency under VRS technology as described in BCC model. This energy efficiency score is called as PEE score. Following Wei *et al.* (2011), total energy efficiency is decomposed into two components: PEE and SE:

$$\text{Energy efficiency} = \text{pure energy efficiency} \times \text{scale efficiency}. \tag{7}$$

If SE equals to 1, it means that the firm is operating under an optimal scale size. It can also verify whether energy inefficiency stems from inefficiency in the scale of operation and management, sub-optimal scale, or both (Wei *et al.*, 2011).

4.3 Data consolidation

State level data are extracted from the ASI for the period from 2004–2005 to 2013–2014 based on the national industrial classification of 2004 and 2008 (Basic Iron and Steel, Code-271 and 241). This analysis covers 19 major states which account for more than 95 per cent of total Iron and Steel produced in India. We use four input variables and a single output variable for the analysis. Input variable includes: labour, capital, energy and materials measured as total persons engaged, fixed capital, fuel consumption and expenditure on materials, respectively. The gross value of output is taken as an output variable. Following Mukherjee (2008), in order to investigate the energy efficiency performance of a "typical firm" in a state, all variables are divided by the total number of factories in the state. All variables are used in real terms by deflating with respective price index using the base year of 2004–2005[6]; since no data were available for state-level price index, national level price index is used for all variables except labour as it is measured in numbers.

It is justifiable to the extent that these inputs are often be purchased in the national market and are relatively more mobile; nevertheless, it is an imperfect measure[7]. Descriptive statistics and correlation matrix of the variable used in this study are provided in Table I. Descriptive statistics show that maximum variation exists for labour inputs and lowest variation for energy inputs. There also exists a difference between mean and median which shows considerable heterogeneity in the distribution of the variation. Further, the correlation matrix shows relatively a high correlation among variables. All input variables highly correlate with output.

5. Results and discussion

DEA estimates production frontier and provides the underlying technical and energy efficiency of the states over the period of time. Our main focus is on energy efficiency which is derived from the technical efficiency model. The energy-saving targets for states lie below the benchmark level. Different sources of energy utilised in the production of iron and steel vary significantly across countries. Coal and electricity (purchased and generated) are major components of energy consumption in the Indian iron and steel sector. Due to the unavailability of data regarding different sources of energy and energy use in physical unit, the monetary measure of energy (fuel expenditure) is considered. Preliminary, we examine differences in energy intensity across the region, a simple measure of energy efficiency calculated as the ratio of fuel consumption to gross output. The average level of energy intensity at the national level is 0.08 over the period of study. This means that producing INR1 worth of iron and steel product requires INR0.08 worth of energy expenditure. Over the period of study, the industry experienced a meagre decline in energy intensity from 0.09 to 0.06 at the national level. Figure 4 shows the energy intensity trend of four major iron and steel producing states; Chhattisgarh, Orissa, Gujarat and Jharkhand. Gujarat and Jharkhand are most energy-intensive states. We also calculated energy intensity for all states, which is given in Table AI for all years.

BCC variant of DEA method with VRS is employed to get a precise estimated of production frontier to accommodate market imperfection and observable heterogeneity. We first estimated radial measures of technical efficiency, as shown in Table II. BCC model shows a maximum proportional reduction in all inputs while keeping output level not less than what is being actually produced. The overall average level of technical efficiency of the states during the study period was 0.970, which implies that it would be feasible to reduce all the inputs proportionally by 3 per cent and still able produce same level of output. Jharkhand, Haryana and Assam show 100 per cent technical efficiency throughout the years. States like Gujarat and Andhra Pradesh can reduce even more than average level, up to 7 per cent, while Orissa can reduce 9 per cent of all the inputs with the same level of output.

	Fixed capital	Labour	Energy use	Materials	Gross output
Mean	35.85	119.30	4.99	30.74	60.68
Median	15.25	77.492	3.88	27.66	49.92
Maximum	284.13	453.06	26.17	102.7	202.24
Minimum	0.587	14.179	0.125	0.774	1.37
SD	50.72	101.17	4.366	19.73	41.84
Correlation matrix					
Fixed capital	1				
Labour	0.720	1			
Energy use	0.558	0.736	1		
Materials	0.557	0.508	0.504	1	
Gross output	0.759	0.739	0.703	0.880	1

Table I. Descriptive statistics and correlation matrix

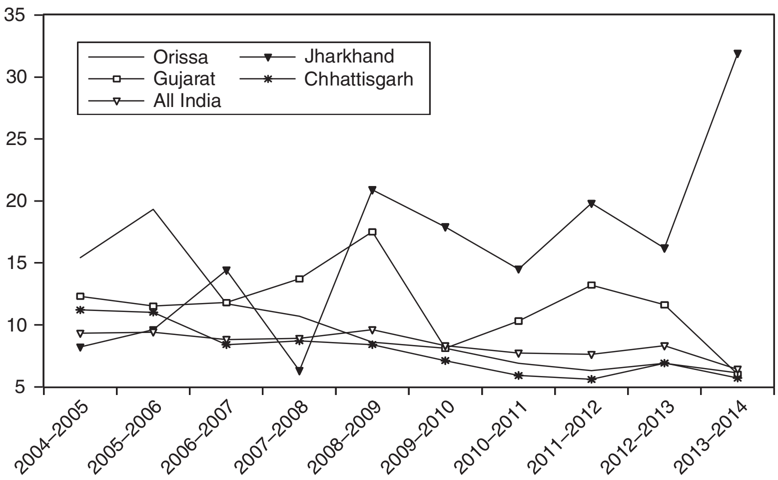


Figure 4.
Energy intensity in Indian rupee (per cent)

States	2004–2005	2005–2006	2006–2007	2007–2008	2008–2009	2009–2010	2010–2011	2011–2012	2012–2013	2013–2014	Average
AP	0.895	0.856	0.933	0.935	0.938	0.988	0.907	0.906	1.000	1.000	0.936
AS	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
BI	1.000	1.000	1.000	1.000	1.000	1.000	0.916	1.000	1.000	1.000	0.992
CT	1.000	0.930	1.000	0.859	1.000	1.000	0.970	0.891	0.967	0.828	0.945
GU	1.000	0.915	0.967	0.989	0.932	1.000	0.927	0.880	0.765	1.000	0.938
HA	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
HM	1.000	1.000	0.963	1.000	1.000	1.000	0.847	0.866	1.000	1.000	0.968
JH	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
KA	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.903	0.990
KE	1.000	0.907	1.000	0.894	1.000	0.958	1.000	1.000	0.954	1.000	0.971
MP	0.939	1.000	1.000	1.000	1.000	1.000	1.000	0.992	1.000	1.000	0.993
MA	1.000	1.000	1.000	1.000	1.000	0.930	0.902	0.873	0.937	0.864	0.951
OR	0.810	0.792	0.902	0.689	1.000	1.000	1.000	1.000	1.000	1.000	0.919
PU	1.000	0.885	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.988
RA	0.969	0.859	1.000	1.000	0.955	1.000	1.000	1.000	0.917	1.000	0.970
TN	1.000	0.909	0.874	0.866	0.993	1.000	1.000	1.000	0.994	0.830	0.947
UK	1.000	1.000	1.000	1.000	0.989	0.918	0.940	0.923	0.922	1.000	0.969
UP	0.976	0.950	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.993
WB	0.879	0.923	1.000	0.908	1.000	1.000	1.000	1.000	0.969	1.000	0.968
Average	0.972	0.943	0.981	0.955	0.990	0.989	0.969	0.965	0.970	0.970	0.970

Notes: AP, Andhra Pradesh; AS, Assam; BI, Bihar; CT, Chattisgarh; GA, Goa; GU, Gujarat; HA, Haryana; HM, Himachal Pradesh; JH, Jharkhand; KA, Karnataka; KE, Kerala; MP, Madhya Pradesh; MA, Maharashtra; OR, Orissa; PU, Punjab; RA, Rajasthan; TN, Tamil Nadu; UP, Uttar Pradesh; WB, West Bengal

Table II.
BCC technical efficiency score

Given the fact that energy is a key input in the production of iron and steel, benchmarking the energy use and identifying the relatively inefficient states provide key insights to policy maker to imitate best practices. Here, the underlying energy efficiency from BCC model is calculated as the ratio of minimal energy input to actual energy input. This accommodates possible substitution and technical change in the production process. A minimal level of energy input is calculated as actual energy input minus proportional reduction in energy input and adjusted for slack in energy input. The estimated energy efficiency score of BCC model is given in Table III. The overall average level of energy efficiency of the states during the study period was 0.923, which implies that it would be feasible to reduce energy

States	2004–2005	2005–2006	2006–2007	2007–2008	2008–2009	2009–2010	2010–2011	2011–2012	2012–2013	2013–2014	Average
AP	0.783	0.856	0.933	0.872	0.938	0.988	0.878	0.906	1.000	1.000	0.915
AS	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
BI	1.000	1.000	1.000	1.000	1.000	1.000	0.583	1.000	1.000	1.000	0.958
CT	1.000	0.704	1.000	0.859	1.000	1.000	0.970	0.891	0.967	0.828	0.922
GU	1.000	0.616	0.512	0.545	0.480	1.000	0.507	0.497	0.448	1.000	0.661
HA	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
HM	1.000	1.000	0.912	1.000	1.000	1.000	0.709	0.866	1.000	1.000	0.949
JH	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
KA	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.182	0.918
KE	0.998	0.468	1.000	0.860	1.000	0.615	1.000	1.000	0.922	1.000	0.886
MP	0.939	1.000	1.000	1.000	1.000	1.000	1.000	0.992	1.000	1.000	0.993
MA	1.000	1.000	1.000	1.000	1.000	0.930	0.886	0.610	0.843	0.782	0.905
OR	0.525	0.494	0.902	0.605	1.000	1.000	1.000	1.000	1.000	1.000	0.853
PU	1.000	0.643	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.964
RA	0.925	0.837	1.000	1.000	0.955	1.000	1.000	1.000	0.917	1.000	0.963
TN	1.000	0.892	0.874	0.721	0.993	1.000	1.000	1.000	0.456	0.803	0.874
UK	1.000	1.000	1.000	1.000	0.722	0.631	0.551	0.905	0.873	1.000	0.868
UP	0.469	0.950	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.942
WB	0.879	0.777	1.000	0.908	1.000	1.000	1.000	1.000	0.969	1.000	0.953
Average	0.927	0.925	0.927	0.923	0.918	0.919	0.922	0.923	0.923	0.923	0.923

Table III. BCC energy efficiency score

inputs by 8 per cent without the additional requirement of any other inputs and still able produce same level of output. One thing to be noted here is that the states which show 100 per cent technical efficiency by definition will have no slacks and not be energy efficient. States like Gujarat, Orissa and Uttarakhand show a vast potential for more than proportional reduction in energy consumption. On the other hand, states like Tamil Nadu, Kerala and Andhra Pradesh can also reduce even more than the average level of 8 per cent with the same level of output.

As noted in Section 3, SBM method is a relatively advanced model and provides a more comprehensive measure of inefficiency as it directly takes slacks into account. It has more discriminatory power, hence it provides an efficiency score less than that of radial measures of efficiency. SBM technical efficiency is given in Table IV. The overall average level of technical efficiency of the states during the study period was 0.921 that is less than radial measure of efficiency, which implies that it would be feasible to reduce inputs (not proportionally) up to 8 per cent and still able produce the same level of output. Technical efficiency score is low for most of the states and also a considerable variation in the average performance is noticed across states. Under SBM method, Jharkhand, Haryana and Assam show 100 per cent technical efficiency throughout the years. On the other hand, a considerable decline is noted in technical efficiency score for other states like Tamil Nadu, Orissa, Chhattisgarh, Andhra Pradesh and Gujarat as compared with radial measures. These states have greater potential to improve the technical efficiency under the assumption of non-radial adjustment in input reduction. This shows that each input should be adjusted in different proportion to arrive at a benchmark level.

Finally, we estimated the SBM of energy efficiency score which finds the maximum possible reduction in energy input. The estimated energy efficiency is based on minimal energy that can be used to produce the current level of output. Results of SBM of energy efficiency show the relative performance of the states in terms of energy use. The energy efficiency score provides a target to achieve minimal energy use given by benchmark states. Considering complementarity among inputs, this measure is a more relevant measure of energy efficiency in the total factor productivity framework. The results of SBM energy

States	2004–2005	2005–2006	2006–2007	2007–2008	2008–2009	2009–2010	2010–2011	2011–2012	2012–2013	2013–2014	Average
AP	0.822	0.742	0.816	0.826	0.859	0.867	0.778	0.587	1.000	1.000	0.830
AS	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
BI	1.000	1.000	1.000	1.000	1.000	1.000	0.715	1.000	1.000	1.000	0.972
CT	1.000	0.830	1.000	0.800	1.000	1.000	0.839	0.710	0.790	0.707	0.868
GU	1.000	0.769	0.802	0.816	0.706	1.000	0.686	0.513	0.486	1.000	0.778
HA	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
HM	1.000	1.000	0.923	1.000	1.000	1.000	0.756	0.766	1.000	1.000	0.944
JH	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
KA	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.542	0.954
KE	0.951	0.600	1.000	0.807	1.000	0.851	1.000	1.000	0.893	1.000	0.910
MP	0.807	1.000	1.000	1.000	1.000	1.000	1.000	0.844	1.000	1.000	0.965
MA	1.000	1.000	1.000	1.000	1.000	0.837	0.747	0.750	0.797	0.721	0.885
OR	0.642	0.568	0.596	0.558	1.000	1.000	1.000	1.000	1.000	1.000	0.836
PU	1.000	0.707	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.971
RA	0.946	0.795	1.000	1.000	0.890	1.000	1.000	1.000	0.887	1.000	0.952
TN	1.000	0.788	0.768	0.675	0.961	1.000	1.000	1.000	0.729	0.659	0.858
UK	1.000	1.000	1.000	1.000	0.894	0.817	0.765	0.736	0.870	1.000	0.908
UP	0.833	0.776	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.961
WB	0.740	0.789	1.000	0.796	1.000	1.000	1.000	1.000	0.818	1.000	0.914
Average	0.934	0.861	0.942	0.909	0.964	0.967	0.910	0.890	0.909	0.928	0.921

Table IV. SBM technical energy efficiency score

efficiency score are given in Table V. Overall average level of energy efficiency is 0.922, which is exactly same as estimated through BCC model. Nevertheless, SBM energy efficiency score differs from that of BCC at the individual state level. It shows the highest average possible reduction of 37 per cent of energy input from the average level of consumption in case of Gujarat, while in case of Andhra Pradesh, Orissa, Tamil Nadu, Kerala, Maharashtra and Chhattisgarh, it ranges from 22 to 16 per cent. States like Bihar,

States	2004–2005	2005–2006	2006–2007	2007–2008	2008–2009	2009–2010	2010–2011	2011–2012	2012–2013	2013–2014	Average
AP	0.694	0.713	0.588	0.656	0.937	1.000	0.652	0.640	1.000	1.000	0.788
AS	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
BI	1.000	1.000	1.000	1.000	1.000	1.000	0.545	1.000	1.000	1.000	0.955
CT	1.000	0.648	1.000	0.620	1.000	1.000	0.985	0.735	0.687	0.801	0.848
GU	1.000	0.509	0.377	0.589	0.468	1.000	0.497	0.407	0.477	1.000	0.632
HA	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
HM	1.000	1.000	0.904	1.000	1.000	1.000	0.648	0.663	1.000	1.000	0.922
JH	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
KA	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.162	0.916
KE	0.980	0.449	1.000	0.497	1.000	0.583	1.000	1.000	0.921	1.000	0.843
MP	0.659	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.966
MA	1.000	1.000	1.000	1.000	1.000	0.715	0.695	0.579	0.659	0.643	0.829
OR	0.506	0.439	0.401	0.605	1.000	1.000	1.000	1.000	1.000	1.000	0.795
PU	1.000	0.626	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.963
RA	0.949	0.658	1.000	1.000	1.000	1.000	1.000	1.000	0.910	1.000	0.952
TN	1.000	0.843	0.723	0.564	1.000	1.000	1.000	1.000	0.454	0.773	0.836
UK	1.000	1.000	1.000	1.000	0.786	0.657	0.460	0.516	0.645	1.000	0.806
UP	0.428	0.779	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.921
WB	0.680	0.740	1.000	0.740	1.000	1.000	1.000	1.000	0.767	1.000	0.893
Average	0.922	0.922	0.921	0.922	0.922	0.922	0.922	0.922	0.922	0.922	0.922

Table V. SBM energy efficiency score

Punjab, Madhya Pradesh and Rajasthan are close to efficiency frontier; therefore, a less scope exists for improvements in energy efficiency level. State average energy efficiency score over the year remains stagnating over the period. In some states, it increases very marginally because the adaptation rate of energy saving technology is very low. This shows the poor implementation of industrial energy efficiency programme initiated by BEE, India.

Based on technological specification regarding returns to scale, we calculated the SE of energy consumption. This is the ratio of energy efficiency score under the constant return to scale to variable return to scale. The result of SE is given in Table VI. As on 2013–2014, average SE was 0.89, while pure energy efficiency was 0.92; this shows that total energy inefficiency is relatively more due to scale inefficiency. However, pure energy inefficiency also contributes to some extent that leads to lower total energy efficiency.

5.1 Discussion

The results of both BCC slack adjusted radial measure and SBM of energy efficiency show 8 per cent reduction of energy on an average level. Comparing our SBM of energy efficiency with traditional energy efficiency indicator that is energy intensity shows that lower energy-intensive states like Assam, Haryana, Rajasthan and Punjab also have a higher level of energy efficiency. But the case is different for states like Bihar and Jharkhand that have higher energy efficiency score and also have a higher level of energy intensity. This particular contrary result shows the weakness of traditional energy efficiency indicator. Overall, energy intensity has declined by 31 per cent over the period of study. The rate of decline in energy intensity level is very low as compared to other energy-intensive industry. Thus, iron and steel industry needs special attention from standpoint of energy efficiency to achieve cleaner and sustainable production. We estimated kernel density estimates of the average energy efficiency level over the period of study, which is given Figure 5. The plot of kernel density function shows that considerable variation exists among states which are further visualised through box plot. Box plot of average energy efficiency score is given in Figure 6 which shows most of the states lie below the mean level of energy efficiency.

States	2004–2005	2005–2006	2006–2007	2007–2008	2008–2009	2009–2010	2010–2011	2011–2012	2012–2013	2013–2014	Average
AP	1.000	1.000	1.000	1.000	0.993	1.000	0.943	0.995	1.000	0.819	0.975
AS	0.750	0.789	0.885	0.493	0.899	1.000	1.000	0.896	0.600	0.665	0.798
BI	0.411	0.419	0.401	0.631	0.410	1.000	0.840	0.452	1.000	1.000	0.656
CT	1.000	1.000	1.000	0.992	1.000	1.000	0.885	0.958	1.000	1.000	0.983
GU	1.000	1.000	0.917	0.798	0.841	1.000	0.985	0.728	0.909	1.000	0.918
HA	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
HM	0.752	1.000	0.868	1.000	1.000	1.000	0.879	1.000	1.000	0.745	0.924
JH	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.269	0.745	0.901
KA	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.758	1.000	0.960	0.972
KE	0.618	0.986	1.000	0.729	0.847	1.000	0.600	1.000	0.875	0.945	0.860
MP	0.941	1.000	1.000	1.000	1.000	1.000	1.000	0.990	1.000	1.000	0.993
MA	0.447	0.781	0.723	1.000	1.000	1.000	0.970	0.969	1.000	1.000	0.889
OR	1.000	1.000	0.987	0.966	1.000	1.000	0.802	0.622	0.624	0.829	0.883
PU	1.000	0.995	1.000	1.000	1.000	1.000	0.735	0.948	1.000	0.664	0.934
RA	0.920	0.978	1.000	1.000	0.946	1.000	1.000	1.000	0.776	1.000	0.962
TN	1.000	0.999	0.948	0.799	0.969	0.960	1.000	1.000	0.844	0.961	0.948
UK	1.000	1.000	1.000	1.000	1.000	0.992	0.978	1.000	0.828	0.603	0.940
UP	0.947	0.893	1.000	0.729	1.000	0.971	1.000	1.000	1.000	1.000	0.954
WB	1.000	1.000	0.954	0.985	1.000	1.000	1.000	0.539	0.774	1.000	0.925
Average	0.883	0.939	0.931	0.901	0.942	0.996	0.927	0.887	0.868	0.891	0.917

Table VI. Scale efficiency of Iron and steel sector

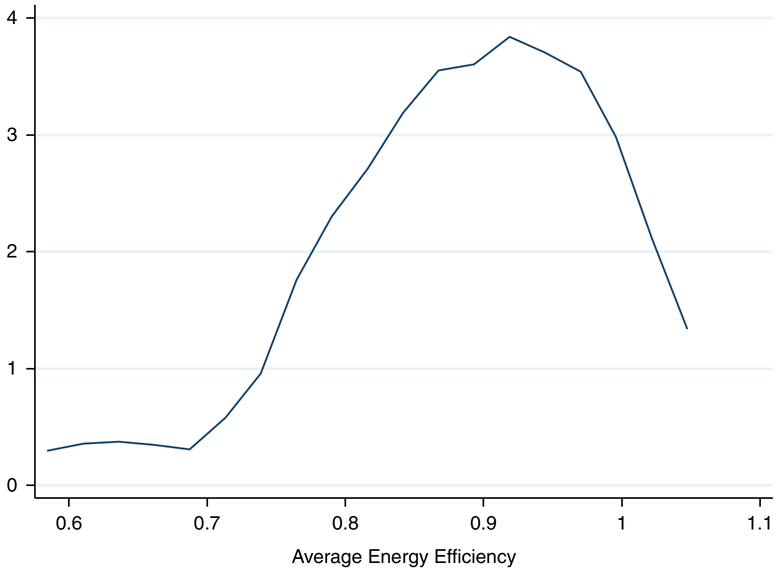


Figure 5.
Kernel density plot of average energy efficiency

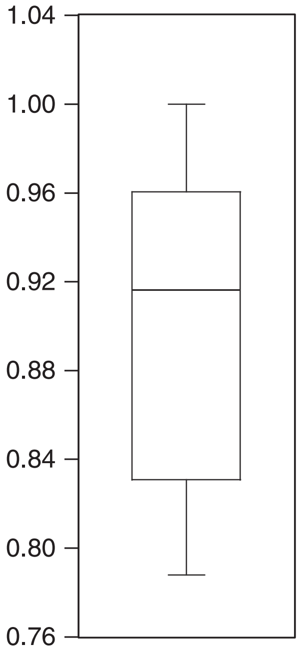


Figure 6.
Box plot of average energy efficiency

The variation in the energy efficiency level across states mainly depends upon the technology used, the final product (crude steel, Ferroalloy and sponge iron, etc.), the raw material used and type of fuel (coal or gas). One of the reason for less energy efficient states is mismatch of type of fuel used and raw material employed in the production process, particularly a large amount of available fine iron ore remains unsuitable for Indian plants (Ministry of Steel, GOI, 2011). Other main reason is that the large-scale production of coal-based DRI carried out in some state Andhra Pradesh, Karnataka, Orissa and Chhattisgarh remains energy inefficient. There are some Natural Gas based DRI productions in these states which are energy efficient but remain stagnant due the scarcity of natural gas (Ministry of Steel, GOI, 2011). Coal-dominated production states need special attention due to low-quality coal and technological obsolescence. EAF route of producing steel through steel scrap requires less energy as it is required only to melt the scrap and hence its production needs to be enhanced to achieve higher energy efficiency. Some advanced energy-efficient technologies, such as oxygen-assisted melting and oxygen-fuel burner, may enhance energy efficiency but are not employed due to financial and organisational constraint. On the other hand, some advanced technologies like Sinter cooler – waste heat recovery and CDQ are adopted in some large-scale plants in Jharkhand and West Bengal (GOI, 2014). But these technologies need to be employed in all the large-scale plants through regulatory and market incentive. Government has to put specific regulation and create financial incentive to invest in energy efficient technology. The Green Rating Project (GRP) of centre for science and environment is an independent programme that rates environmental and resources efficiency of major plants in a specific sector after a rigorous process of data collection and verification. GRP rating of iron and steel sector shows the very poor performance of large ISP mainly located in Orissa and Chhattisgarh, among which Steel Authority of India, a public sector company is worth mentioning. Ispat industries limited located in Maharashtra and Essar steel limited, Hazira, Gujarat got the first and second rank, respectively. These plants run on the gas module which is one of the largest and most efficient in the country. The blast furnace has advanced technologies like pulverised coal injection and top pressure recovery turbine (Stained steel, Centre for Science and Environment, nd). The small and medium enterprises engaged in steel re-rolling dominantly in Punjab, Haryana and Rajasthan region achieved some level of energy efficiency by government initiatives (Ministry of steel, 2014). Therefore, condition in which firm operates and state government intervene results in differences in energy efficiency level. Orissa, Chhattisgarh and Jharkhand (iron ore-rich states) are the leading states in terms of plant, production and investment. Poor transport facility (especially for raw materials and fuel) is another factor that hinders other states to invest in the large integrated plant.

It should be noted that energy efficiency score from DEA gives relative efficiency (comparing with firms on efficiency frontier) which is based on technology being currently employed. As compared to globally BAT benchmark of 16.4 gigajoules per tonne of crude steel (GJ/tcs), energy consumption in major steel plants in India was 27.3 GJ/tcs, while it was 14.90 GJ/tcs in the USA and 23.11 GJ/tcs in China (Hasanbeigi *et al.*, 2014). India is the third largest producer of crude steel but still lagging behind in the energy intensity level in comparison with USA and China. Therefore, global best technology in terms of energy efficiency will provide a way to reduce energy consumption level despite low-quality iron ore and coal. One critical issue behind low investment rate in energy-efficient technology is the presence of barriers (like economic and organisational barriers). These barriers lead to underinvestment in energy efficient technology despite benefits outweigh the cost of investment. In the Indian case, some policy initiatives have been taken recently as Perform Achieve and Trade programme in 2012, to reduce specific energy consumption in eight energy-intensive industries. The first phase of the programme (2012–2015) was quite successful which saved energy around 8.67 Mtoe. There are different energy efficiency programmes launched under BEE which should be used to incentivise firms. But special policy is needed for iron and steel sector because it needs huge investment and foreign technology.

There is a dire need of regional level policy in order to provide adequate incentive to firms for investment in energy efficient technology. This will help in enhancing technical and cost efficiency also. Only Kerala and Andhra Pradesh have some mandates for energy-saving target for several industries operating through energy management centre. Therefore, creating a state-level action plan and audit system is a most needed step and should be well adopted by all the states (Sarkar *et al.*, 2016). This study recommends sector-specific policy stance and negotiation with industry to deliver a quality institutional and regulatory mechanism.

6. Concluding remarks

There is growing concern about global warming and GHG mitigation, addressing through international negotiation. Different policy options are being implemented like carbon trading and environmental regulation in order to move in desired and conductive directions. Adherence to the past trends of steady improvement in energy efficiency remains as the most cost-effective option. Therefore, this study estimates the energy efficiency level of Indian iron and steel sector by using regional level data over the period from 2004–2005 to 2013–2014. We employed the radial and non-radial variant of DEA to estimated energy-saving potential and identified the relative position of each state in term of the level of energy efficiency. We started by examining a simple indicator of energy efficiency that is energy to output ratio. It shows declined trends over the period of time but for some states like Bihar, Jharkhand, Gujarat and Uttarakhand; it does not decrease much. The main aim of the study is to estimate energy efficiency level in the total factor productivity framework and uncover energy saving potential for different states. SBM of energy efficiency is employed to get a more comprehensive measure of energy efficiency along with the radial measure (BCC model) of energy efficiency. SBM of energy efficiency shows overall average energy saving potential of 8 per cent without reducing output level. Further, we also calculated SE which shows the overall average level of SE was 0.91, which shows scale inefficiency also contributed to total energy inefficiency. Therefore, the optimal scale of operation should be devised to implement standard energy efficiency programme. Finally, this study recommends policy initiative to propagate energy efficiency programme through the market base and regulatory mechanism in order to tap vast energy saving potential.

Notes

1. World industries constitute for about 37 per cent of total global greenhouse gas emissions, of which over 80 per cent is from the energy use (Price *et al.*, 2006).
2. Energy efficiency has become cost-effective policy option for mitigating climate change and having vast untapped potential for energy saving (Worrell *et al.*, 2008).
3. A detailed account of IDA has been provided in Ang and Zhang (2000).
4. Technical efficiency can also be measured upon an output orientation which is the ratio of the actual level of output to maximum (optimal) achievable level of output.
5. For more details on application of DEA in energy and environmental evaluations, refer to Mardani *et al.* (2017).
6. Fixed capital, fuel consumption, expenditure on materials and Gross value of output are deflated by wholesale price index (WPI) of machinery and machine tools, WPI of fuel and power, weighted WPI of non-food primary article and WPI of iron and steel.
7. Same measure is adopted by Mukherjee (2008) for whole manufacturing industries.

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Appendix

Year	2004–2005	2005–2006	2006–2007	2007–2008	2008–2009	2009–2010	2010–2011	2011–2012	2012–2013	2013–2014	Average
AP	0.100	0.083	0.081	0.084	0.079	0.074	0.085	0.062	0.079	0.062	0.079
AS	0.061	0.091	0.052	0.097	0.084	0.056	0.039	0.044	0.083	0.078	0.068
BI	0.190	0.154	0.222	0.160	0.176	0.168	0.121	0.147	0.122	0.070	0.153
CT	0.112	0.110	0.084	0.087	0.084	0.071	0.059	0.056	0.069	0.057	0.079
GU	0.123	0.115	0.118	0.137	0.175	0.081	0.103	0.132	0.116	0.060	0.116
HA	0.034	0.052	0.033	0.043	0.051	0.046	0.043	0.042	0.047	0.037	0.043
HM	0.101	0.065	0.094	0.095	0.080	0.091	0.076	0.087	0.077	0.070	0.084
JH	0.082	0.096	0.144	0.063	0.209	0.179	0.145	0.198	0.162	0.319	0.160
KA	0.073	0.062	0.046	0.052	0.033	0.054	0.048	0.052	0.038	0.038	0.049
KE	0.184	0.146	0.165	0.131	0.095	0.118	0.091	0.098	0.089	0.059	0.118
MP	0.073	0.055	0.051	0.048	0.053	0.053	0.055	0.049	0.042	0.053	0.053
MA	0.079	0.071	0.076	0.075	0.082	0.083	0.069	0.070	0.071	0.068	0.074
OR	0.154	0.193	0.117	0.107	0.086	0.081	0.069	0.063	0.069	0.061	0.100
PU	0.076	0.104	0.092	0.078	0.073	0.075	0.074	0.073	0.065	0.078	0.079
RA	0.087	0.100	0.094	0.084	0.077	0.071	0.055	0.056	0.072	0.039	0.074
TN	0.084	0.084	0.063	0.106	0.067	0.056	0.056	0.039	0.119	0.070	0.075
UK	0.194	0.186	0.137	0.121	0.098	0.121	0.116	0.109	0.103	0.107	0.129
UP	0.098	0.093	0.070	0.072	0.065	0.076	0.071	0.061	0.050	0.052	0.071
WB	0.084	0.087	0.066	0.069	0.071	0.076	0.065	0.073	0.084	0.049	0.072
All India	0.093	0.094	0.088	0.089	0.096	0.083	0.077	0.076	0.083	0.064	0.084

Notes: All India is national level energy intensity. Last column is state average over whole period

Table AI.
Energy intensity of Indian iron and steel sector

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Reducing the energy consumption of Indian iron and steel industry through enhancing energy efficiency: Role of regional coordination

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This article aims at estimating the energy efficiency of the iron and steel industry in production theoretic approach. Taking a regional perspective, we have done a meta-frontier analysis combined with the slack-based measure of data envelopment analysis (DEA). The results depict huge energy efficiency gap exists across four regions. The northern region is the best performer under group frontier than meta-frontier DEA. South and west regions are relatively well-performed under meta-frontier than group frontier while the eastern region performs moderately well under both frontiers. The results show the significant energy efficiency improvement opportunities available across regions can be realised through technological advancement and energy management.

1 | INTRODUCTION

Improvement in energy efficiency become inevitable to combat the issues of climate change, carbon dioxide (CO_2) emission reduction and energy security. Energy efficiency becomes one of the critical factors in enhancing firm performance and environmental sustainability. Higher energy-efficient firms have low-cost production and provide a competitive advantage over inefficient energy firms (Prasad & Mishra, 2017). Energy efficiency provides one of the best solutions for reducing pollution from energy-intensive firms. Notwithstanding wide-ranging environmental regulations, lack of effective enforcement has demanded a market-based mechanism for cost-effective industrial pollution reduction (Kumar & Shetty, 2018). Therefore, the government has shifted the policy from command and control regulations to market-based policy in order to enhance energy efficiency and other environmental performance. The market-based mechanism is simple, effective and easy to compliance and leads to efficiency gain in management (Kumar & Shetty, 2018). Investment in energy-efficient technology (EET) outweighs the cost of investment hence financially profitable investment. However, the presence of economic and organisational barriers result in "energy efficiency gap" (Hochman & Timilsina, 2017). Therefore, an economic analysis of energy use efficiency can provide insight to the energy efficiency gap. Developing countries like India lacks behind developed countries in terms of energy-efficient production (Gielen & Taylor, 2009). Hence, there is a dire need to increase the participation of firms in the energy efficiency programme. Industrialised countries are leading in energy efficiency programme to enhance the energy efficiency, like the Energy Star system, ISO 50001 and Environmental management programme. These programmes are generally adopted in developed countries and unpopular in developing countries (Moon & Min, 2017).

Production of crude steel has been continued to increase in India, and become the third largest producer in the world in 2015 following the United States and China World Steel Association (2015) (WSA, n.d.). The speciality of Indian iron and steel industry lies in the hosting world largest production of coal-based sponge iron also known as direct reduced iron (DRI). Coal (cooking and non-cooking) is widely used in the production which accounts for around 90% of total sponge iron in the country (Reddy & Ray, 2011). Average energy cost of iron and steel production varies between 20 and 40% of total manufacturing cost hence it is one of the most energy-intensive sectors in the Indian economy. Most of the Indian iron and steel industry requires 6.9 Gcal/t against the world average of 4.5 Gcal/t (TERI, 2013). Hence, there is a need for comprehensive analysis of the energy-saving potential of the iron and steel industry. Different energy use reduction policy was enacted over time but does not account for the considerable regional heterogeneity which needs to be reduced to conserve energy requirement in the long-run. Since there is growing supply of iron and steel from developing countries like India it also has serious environmental consequences alongside the production and export. Hence, developing countries should consider these very issues which relate to sustainable development of a country. Since it is inevitable to reduce the production of iron and steel, energy efficiency improvement and pollution control programme will provide a better option to limit the environmental consequences. This study will provide an insight to implement energy efficiency programme which will assist in meeting the target reduction of carbon emission. Further, the role of the technological gap in energy utilisation has been shown in the analysis will be greater implication for adopting the EET across regions.

There is a limited number of studies which analyses the energy efficiency of the Indian industry. To the best of our knowledge, this is the first study which has done a meta-frontier analysis and incorporates regional heterogeneity in case of Indian economy. Indian economy is geographically very diverse across the region in terms of industrial development and resource endowment (Kumar, 2014). We have made several contributions to the literature on end-use energy efficiency analysis. Firstly, we have made a comprehensive analysis of energy efficiency with the objective of energy conservation along with output expansion using a unique firm-level data in a production theory approach. Since economic development with energy-saving is the primary concern of developing countries and needs a comprehensive analysis. Secondly, generally, research on energy efficiency analysis assumes similar production technology across regions and hence ignore possible regional heterogeneity may lead to biased energy efficiency estimation. Hence, we combined slack-based measure (SBM) of efficiency with meta-frontier analysis to derive an unbiased measure of energy efficiency.

Lastly, the technological gap ratio (TGR) and other indicators were derived to examing the regional heterogeneity and cause of energy inefficiency through the decomposition of the total energy inefficiency which is crucial for designing regional energy efficiency policy and long-term planning.

Rest of the sections are arranged as follows. Section 2 describes related literature and a brief methodology review. Section 3 introduced the method applied in this study and data sources while Section 4 provides empirical results and discussion. Finally, Section 5 draws the conclusion and policy implication.

2 | LITERATURE REVIEW

Energy intensity (energy-output ratio) is generally used as an indicator of energy efficiency takes only one input into account. It is used in the literature to find out the driving factor of the energy efficiency changes at energy end-use or sub-sectoral level over the period. It has certain limitation as it ignores possible substitution among factors of production and underlying technical productivity (Honma & Hu, 2009). There are two main approaches in economic literature to take accounts of these factors, first is data envelopment analysis (DEA) while second is stochastic frontier analysis to estimate efficiency. Scholars have investigated energy and environmental performance by using different variants of DEA like SBM, Directional distance function (DDF) and meta-frontier model (Wang, Zhao, Zhou, & Zhou, 2013; Zhang, Kong, & Yu, 2015; Zhou, Ang, & Poh, 2008). Recently, Zhou et al. (2012) have employed the parametric frontier approach in order to measure the economy-wide energy efficiency position in case of a sample of Organisation for Economic Co-operation and Development (OECD) countries.

DEA measure relative efficiency based on the linear programming method and easy to model the objective function for policy designing. Recently, DEA has been adopted for the different condition to better represent the real-world production system and energy utilisation performance (Mardani, Zavadskas, Streimikiene, Jusoh, & Khoshnoudi, 2017). The SMB was adopted by Chen and Jia (2017) to examine regional variation in the environmental efficiency of China's industry and found large variation across regions. Li and Tao (2017) describe the use of various DEA model to provide better policies implication for highly energy-intensive industries. Moon and Min (2017) find out the larger contribution of pure energy efficiency in increasing the overall energy efficiency in the energy-consuming manufacturing companies in South Korea. Zhu, Wu, Li, and Xiong (2017) emphasised the role of efficient utilisation of natural resource in mainland China. They document that a large amount of natural resource exploitation happens at the cost of environmental degradation, which varies across regions. Liu and Lin (2018) estimated the energy efficiency of China's transport sector, supports the distribution of energy efficiency as ladder-like distribution across the Chinese provinces, using regional categorisation, they show that level of energy efficiency higher in the eastern region followed by central and western regions. Zhang et al. (2015) construct ecological efficiency by combining SBM with meta-frontier in the context China region-level data. Dynamic DEA model applied by Lu and Lu (2018).

Most of the studies in the Indian case uses DEA for energy efficiency evaluation. Some notable studies are related to energy efficiency analyses reviewed here. Mukherjee (2008, 2010) used aggregate manufacturing sector data and conducted an inter-state analysis. Mandal and Madheswaran (2010, 2011) has conducted energy efficiency of the Indian cement industry using states and company level data. Dasgupta and Roy (2017) study the level of energy intensity across major energy-intensive firms and decomposition of energy intensity over the period. Recently, researcher has investigated the role of total factor productivity as a proxy of technological advancement in the reduction of energy intensity (Haider & Ganaie, 2017; Sahu & Sharma, 2016). Prasad and Mishra (2017) have taken managerial perspective and find out the linkage between ISO-14001 certification and carbon emission through panel regression of firm-level data of iron and steel industry. They found the statistically significant relationship and role of ISO certification in low-carbon emission growth. Bhat, Haider, and Kamaiah (2018) applied SBM and estimated feasible energy-saving of Indian pulp and paper industry using region-level data and found major energy efficiency gap among states. At state-level, Haider and Mishra (2019) show enormous energy efficiency gap across states and massive energy-saving potential in the iron and steel industry. There is a substantial research gap in conducting an energy efficiency analysis in the Iron and steel industry which consume a significant amount of industrial energy consumption.

3 | METHODOLOGY

3.1 | Energy efficiency based on group and meta-frontier

Efficiency measurement in the economic literature is generally defined with respect to some benchmark (relative efficiency) or ideal condition based on rational behaviour of the producer. Here energy efficiency is analysed in production theocratic framework where inputs (energy and non-energy inputs) used to produce a single output. In the non-parametric framework, Charnes et al. (2018) proposed DEA for performance evaluation of decision making units (DMUs). As it is very flexible, DEA has widely applied and well-established method in energy and environmental performance evaluation.[1]

The notion of meta-frontier was proposed by Hayami (1969) and Hayami and Ruttan (1971) based on the production technology heterogeneity faced by different DMUs. This incorporate heterogeneity with regard to region, type, scale and other inherent attributes. Therefore, DMUs under study should be divided into different groups according to the sources of technological heterogeneity. Then the production frontier for each group should be estimated separately using group frontier. Finally, a grand production frontier should be estimated by enveloping all the group frontiers called meta-frontier.

In order to measure the energy efficiency of Indian iron and steel producing firms incorporating technology heterogeneity, we suppose that there are $n = 1,\ldots, N$ number of firms (DMUs) and each firm uses $x \in R_+^m$ input vector to produce the output vector $y \in R_+^R$. In this study, four inputs viz., capital, labour, energy and material are taken with a single output variable. Then, production technology is estimated using the non-parametric method. Production units (firms) are divided into $h = 1,\ldots, H$ independent groups with N_h number of firms in hth group. Production units are assumed to face with the same production technologies in each group, and the technological gap in the production only exists among different groups.

The production technology set with input and output bundle of a particular group can be given by model (1):

$$T^{\text{group}} = \left\{ (x,y) : \sum_{n=1}^{N_h} \lambda_n^h x_{mn} \le x_m, m = 1,\ldots,M, \right.$$

$$\sum_{n=1}^{N} \lambda_n^h y_{rn} \ge y_r, r = 1,\ldots,R, \tag{1}$$

$$\lambda_n^h \ge 0, n = 1,\ldots,N. \}$$

where λ_n^h is a non-negative vector of scaling factor for constructing the production frontier using a convex combination of input and output. Model (1) is assumed to satisfy the regularity condition of the well-behaved production function, then the envelopment of group production technology will provide a frontier technology of a particular group h. The energy efficiency is estimated by applying SBM proposed by Tone (2001), we derived following equations from Tone (2001) and applied data of each group to estimate group frontier energy efficiency (GEE) of Indian iron and steel industry.

$$\rho^* = \min \frac{1-(1/M)\sum_{m=1}^{M} s_{m0}^x / x_{m0}}{1+(1/R)\sum_{r=1}^{R} s_{r0}^y / y_{r0}},$$

$$x_{m0} = \sum_{n=1}^{n_h} \lambda_n^h x_{mn} + s_{m0}^x, \tag{2}$$

$$y_{r0} = \sum_{n=1}^{N_h} \lambda_n^h y_{rn} - s_{r0}^y,$$

$$s_{m0}^x \ge 0, s_{r0}^y \ge 0, \lambda_n^h \ge 0,$$

where M index for inputs variable, $r = 1, 2,\ldots, R$ is index of outputs variable. s_{m0}^x is slack associated with the input vector while s_{r0}^y is slack associated with output vector. 0, DMU under evaluation for efficiency. Similarly, meta-frontier can be estimated by pooling the data on input and output of all firms across the country. We have used following Equation (3) to calculated energy efficiency derived from input-oriented SBM efficiency model (2).

$$\text{GEE} = \frac{\text{OEU}}{\text{AEU}} = \frac{\text{AEU-ES}}{\text{AEU}}, \tag{3}$$

where OEU: optimal energy use; AEU: actual energy use; ES: energy slacks. In SBM, the amount of reduction in energy input required to reach the production frontier is captured in associated slacks.

3.2 | Technological gap in energy use efficiency

Meta-frontier energy efficiency (MEE) provides the relative performance of firms with reference to national-wide technology while GEE score is based on relative performance within the group or the particular region. Therefore the gap between MEE and GEE need to be analysed. O'Donnell, Rao, and Battese (2008) show that the gap between meta efficiency and group efficiency as the TGR as a measure of the distance between MEE and GEE. Higher the TGR score lower the gap between group and meta-frontier and if TGR = 1 implies no gap exists between them. Hence TGR of nth firm in the hth group can be constructed as given in Equation (4) while average level of TGR of a particular group (h) can be as given in Equation (5):

$$\text{TGR}_n^h = \frac{\text{MEE}_n^h}{\text{GEE}_n^h}, \tag{4}$$

$$\mathrm{TGR}^h = \frac{\sum_{n=1}^{N_h} \mathrm{TGR}_n^h}{N^h}. \tag{5}$$

Since the energy efficiency from group frontier is a sub-set of meta-frontier based energy efficiency, MEE ≤ GEE will consistently hold. Hence, the score of TGR ranges between 0 and 1. If TGR getting closer to 1 means smaller the gap between group and meta-frontier and vice versa.

The firms within the same group suppose to have similar production technology. Thus, the inefficiency in energy use measured through group frontier in general sense can be viewed as managerial inefficiency rather purely technical factor. Whereas the gap between MEE and GEE score is considered as inefficiency due to technical factors. Hence total energy inefficiency can be decomposed into the technology gap inefficiency (TGI) and group managerial inefficiency (GMI) which is equals to meta-frontier energy inefficiency.

3.3 | Data and variable

Firm-level data for the analysis is collected from the electronic database *PROWESS* managed by the Centre for Monitoring Indian Economy. Data of Indian iron and steel industry is extracted as per classification provided by national industry classification 2008. We conceptualised four inputs; capital, labour, energy and materials and a single output of the production function. Labour is taken as wages and salaries expenses, energy as expenditure on power and fuel, and materials as raw material expenditure. Gross fixed asset as capital employed and net sale value for output used in the analysis. All variables are given in monetary term and adjusted to take account of the price level we converted variables in the real term following (Balakrishnan, Pushpangadan, & Babu, 2000). After cleaning the data to account for missing data we have ended up with 97 firms operate across four different regions. We followed the literature on the meta-frontier analysis of energy efficiency and form four regions very intuitively. Firms are geographically divided as per their office of operation. The number of firms and states assign under different regions are given in Table 1.[2]

The period of 2003–2004 to 2013–2014 is chosen for the analysis based on the changing structure of the India economy especially

TABLE 1 Division of states and region formation

Region	States	No. of firms
North	Delhi, Punjab, Haryana, Uttarakhand, Himachal Pradesh	22
South	Andhra Pradesh, Kerala, Tamil Nadu, Telangana	22
East	Chhattisgarh, Jharkhand, Odisha, West Bengal	27
West	Maharashtra, Gujarat, Goa	26

Note: States given in the above grouping have firms under analysis.

the policy mandate of government in terms of energy efficiency improvement. We have conceived four inputs and a single output (desirable output) in the absence of data of undesirable output (carbon emission from energy consumption).[3] Since data of carbon emission (undesirable output) is derived from energy input and hence minimization of energy consumption leads to a reduction in carbon emission (Haider & Bhat, 2018). Therefore, we can get a reflation on environmental policy implication through energy efficiency evaluation though it is better to characterised production function with the undesirable output.

4 | EMPIRICAL ANALYSIS AND DISCUSSION

4.1 | GEE and MEE

The energy efficiency of the firms under four different groups is measured through SMB variant of DEA proposed by Tone (2001). It shows the level of energy utilisation of a certain production unit. Higher magnitude means better energy utilisation and close to frontier technology. Table 2 shows average energy efficiency under group and meta-frontier from the year 2004 to 2016. The average level of energy efficiency under group frontier from 2004 to 2016 is 0.90, 0.64, 0.73 and 0.57 for the north, south, east and west regions. The northern region has the highest energy efficiency level, followed by east, south and west. Hence, energy efficiency difference is highest in the western region. Eastern region experiences the highest increase in energy efficiency from 0.55 to 0.86 over the period of 2004–2016. North and west have experienced very small changes while the southern region experienced a decline over the same period. The northern region has better infrastructure in terms of transport and closes to the capital region. Further, it is a relatively environmentally sensitive area and hence public awareness and regulatory pressure lead to better pollution control through energy efficiency improvement.

The small and medium enterprises engaged in steel re-rolling dominantly in the northern region has achieved some level of energy efficiency by government initiatives (GOI, 2014). While the eastern region is endowed with rich mineral and coal resources used in the production of iron and steel and historically very sound industrial (iron and steel) base. It has more of the large-scale integrated plant operated by the large corporate house in India and some government-owned plant. Better energy efficiency in the eastern region supports the role of industrial agglomeration in achieving higher energy efficiency (Otsuka, Goto, & Sueyoshi, 2014). The southern area is also moderate energy efficiency level may be due to the energy efficiency programme. Interestingly, west and south have more considerable energy efficiency variation across firms while north and east have relatively less variation across firms.

Similarly, meta-frontier is estimated based on the whole sample and takes the best energy-efficient units across the nation as benchmark which capture technological gap across different groups. The overall average energy efficiency under meta-frontier for north, south,

TABLE 2 Average energy efficiency under group and meta-frontier

	North		South		East		West	
	GEE	MEE	GEE	MEE	GEE	MEE	GEE	MEE
2004	0.938	0.466	0.739	0.477	0.558	0.362	0.656	0.472
2005	0.947	0.414	0.673	0.429	0.594	0.426	0.514	0.398
2006	0.925	0.354	0.544	0.438	0.704	0.358	0.455	0.322
2007	0.912	0.419	0.561	0.402	0.723	0.380	0.521	0.328
2008	0.929	0.410	0.646	0.420	0.659	0.788	0.507	0.340
2009	0.874	0.380	0.669	0.366	0.719	0.464	0.599	0.350
2010	0.917	0.508	0.617	0.433	0.736	0.522	0.585	0.517
2011	0.864	0.471	0.642	0.498	0.800	0.442	0.622	0.452
2012	0.873	0.457	0.666	0.531	0.920	0.550	0.499	0.427
2013	0.784	0.458	0.704	0.598	0.852	0.570	0.559	0.514
2014	0.905	0.473	0.610	0.575	0.828	0.529	0.587	0.518
2015	0.900	0.311	0.662	0.573	0.644	0.466	0.685	0.482
2016	0.957	0.440	0.689	0.575	0.865	0.426	0.636	0.510
Average	0.902	0.428	0.648	0.486	0.739	0.483	0.571	0.433

Abbreviations: GEE, group frontier energy efficiency; MEE, meta-frontier energy efficiency.

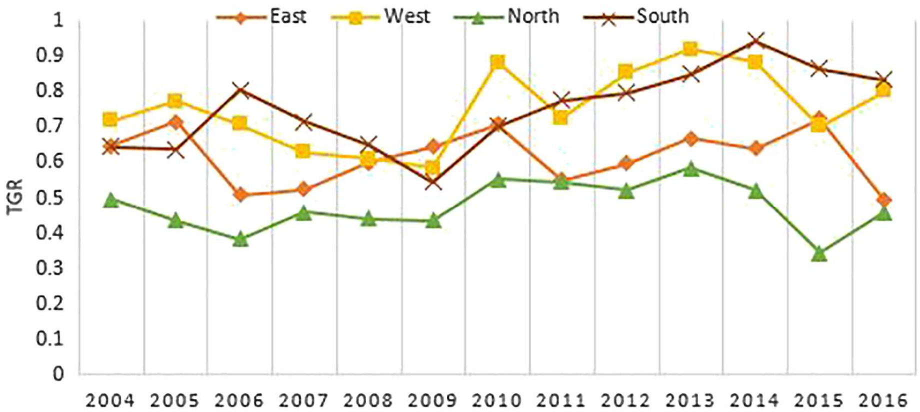

FIGURE 1 Technology gap ratio in the east, west, north and south

east and west are 0.42, 0.48, 0.48 and 0.43, respectively. As noted in the previous section, MEE will be lower than that of group frontier. East and south have increasing trend over time while the other two regions remain relatively stagnant. The northern region is the best performer under group frontier, but this is not the case when it comes to meta-frontier. This shows that it is not necessary that best within the group also perform well under meta-frontier because of the frontier is constructed here based on national-wide best technological employment.

4.2 | Technological gap ratio

In order to analyse the existence of the technological gap in energy efficiency across four groups, TGR of energy efficiency is calculated according to Equations 4 and 5. The graph of TGR over the sample period is given in Figure 1. Overall west and south have better technological advancement in terms of energy utilisation, thus having better TGR score. While east and north remain less efficient in employing national-wide technology and having a considerable technological gap in energy utilisation. This particular result is very interesting in the India context in designing regional energy efficiency policy. Where considerable heterogeneity exists across regions and demand for quick spillover of advanced technologies across the regions. Hence, the national-wide energy-efficient firms in the southern and western region should be imitated to reduce regional heterogeneity. Over a period of time, TGR increases for almost all four regions with some fluctuation in 2009–2010 and 2014–2015. There is no smooth increasing trend of TGR over time as in the case of the group and meta-frontier efficiency.

We further decompose energy inefficiency into parts: TGI and GMI, attributed to the technological gap inefficiency and managerial inefficiency. The overall average level of TGI and GMI is given in

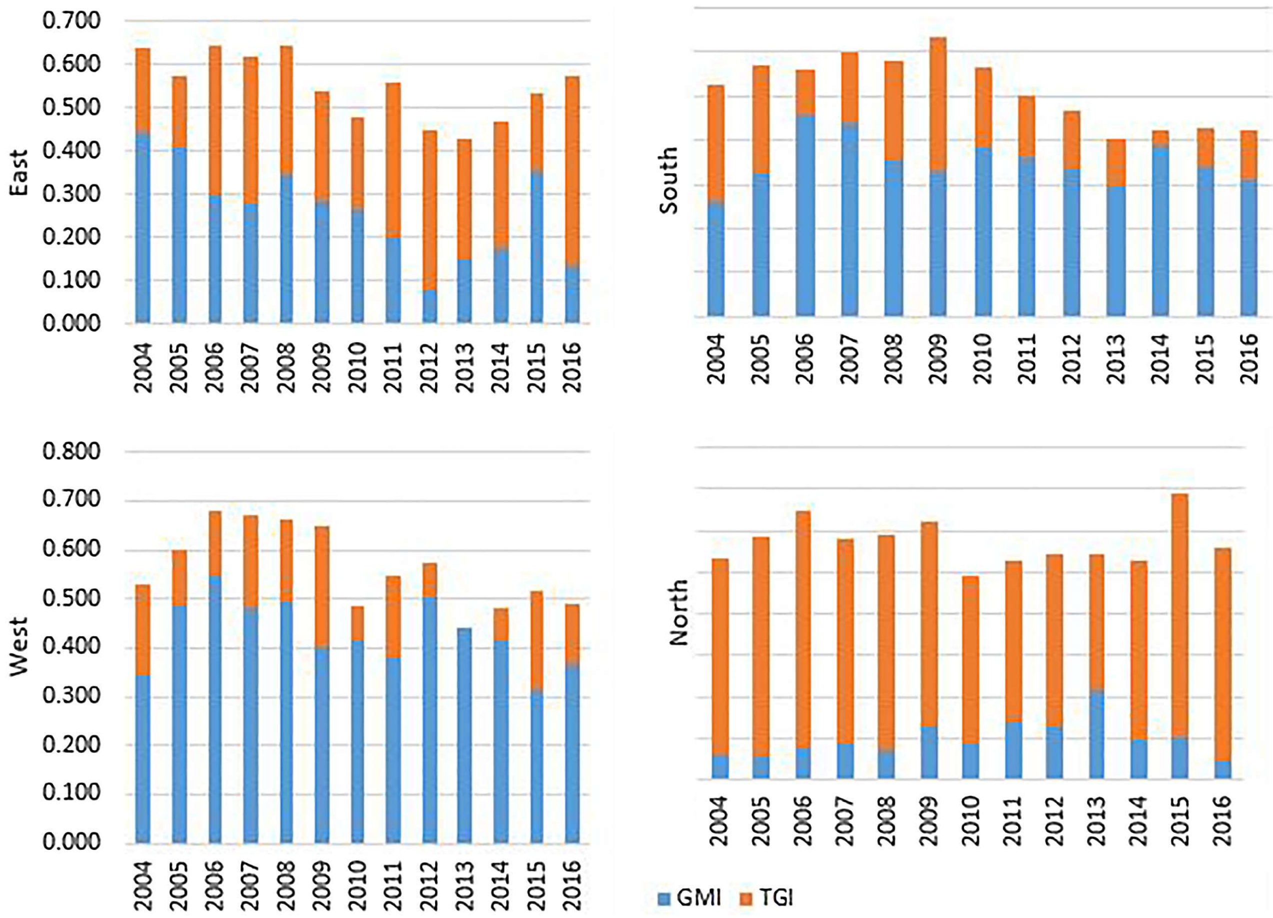

FIGURE 2 Decomposition of energy inefficiency in all four regions

Figure 2. In south and west, energy inefficiency is more caused by GMI, while for the north, it is heavily caused by TGI. Energy inefficiency in the eastern region is equally caused by both TGI and GMI. This result highlights the role of managerial efficiency in improving total energy efficiency in south and western region while more focus on technological advancement should be given in the northern region. Even though excellent opportunities available for energy efficiency measures, lower energy prices and negligence of energy-saving generally leads to ignorance of energy management (Acharya & Sadath, 2017). However, some commercially available technology for enhancing energy efficiency is employed at some large-scale integrated plant in Jharkhand and West Bengal (GOI, 2014).

Further, we tested that whether the energy efficiency across four regions significantly differs (statistically), the nonparametric test known as Kruskal–Wallis test was adopted. Here, we assumed that there is no difference among the energy efficiency of the four regions. The result shows that the test statistic of Kruskal–Wallis method is 36.17, which is much higher than the lower critical value at 1% significance. Thus, the null hypothesis of all four regions come from the same gross is not supported which means the energy efficiency level across all four regions (east, west, north and south) are really significantly different.

4.3 | Analysis of actual and potential energy intensity

Most of the time, in designing energy-saving target and energy efficiency improvement, most countries and regions take insights from the index of energy intensity (Honma & Hu, 2009). On the contrary, the estimation of energy efficiency applied in this case is based on relative efficiency in a total factor productivity framework. So there is the methodological difference between energy intensity indicator as energy efficiency (a single-factor based efficiency index) and energy efficiency from derived from total factor productivity framework. However, there are also some conceptual connent between these two types of indices. After the constraint of inputs is taken into account, the optimised combination of energy consumption under the group and meta-frontier is given by $\left(\mathrm{GEE}_n^h\right)e$ and $\left(\mathrm{MEE}_n^h\right)e$, respectively. Similarly, the optimal energy intensity under two frontiers can be calculated as $\left(\mathrm{GEE}_n^h\right)e/y$ and $\left(\mathrm{MEE}_n^h\right)e/y$, respectively. Figure 3 shows a comparison of national actual energy intensity and potential energy intensity during the span of 2004–2016 under the MEE model. The trend over time of actual energy intensity and potential energy intensity is mostly stable, but there is a significant gap between both where actual energy intensity is considerably higher than potential

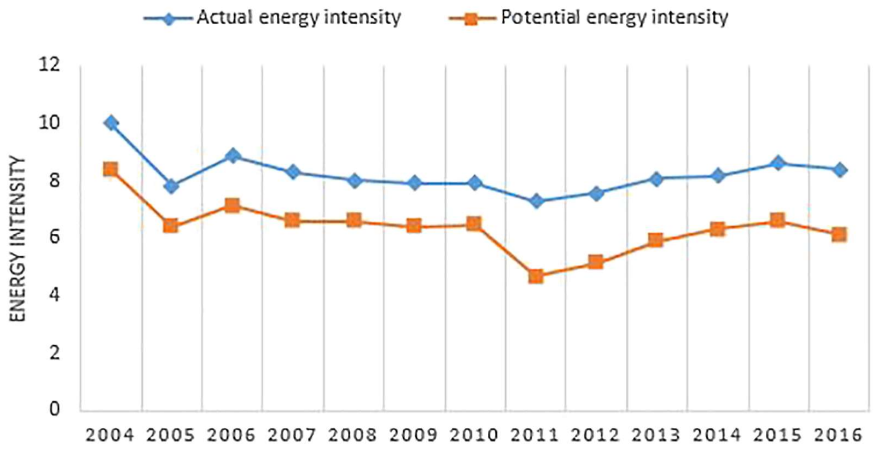

FIGURE 3 Comparison of actual energy intensity and potential energy intensity (in monetary unit and percent)

energy intensity. The obvious gap between actual energy intensity and potential energy intensity has been widening since 2011. This particular phenomenon verdict that substantial energy-saving potential is existent for India iron and steel industry. Overall energy intensity has been declined over the period of study. The rate of decline in energy intensity level is very low. Thus the iron and steel industry needs special attention from the standpoint of energy efficiency to achieve cleaner and sustainable production.

There is a need for massive investment in EET through specific market-based mechanism which can be channelised through some financial incentive to the private sector. Calculated the comparable energy intensity level of 14.90 GJ/tcs in the United States while it is 23.11 GJ/tcs in China in the year 2006. Nevertheless, India is at third position in the production of crude steel but having a significant gap in the energy intensity level as compared to the United States and China. Hence, there is an urgent need for technological spillover through the adoption of EET at large-scale in order to lower the energy efficiency gap. Unawareness and financial constraint at the organisational and managerial level lead to underinvestment in the EET (Nagesha & Balachandra, 2006). Government of India has taken certain policy action recently under the Bureau of Energy Efficiency (BEE, n.d.) as Perform, Achieve and Trade programme in 2012, but it lacks support from the regional government. Though two states, Maharashtra and Tamil Nadu, came forward and started setting their own goal of energy-saving from the industrial sector (GOI, 2018). Hence, coordination and energy efficiency scheme at the regional level is required in order to bridge the technological gap across regions and to achieve higher EET penetration rate. At the firm-level, long-term energy plan should be designed to become robust towards high energy cost and also enhance the overall performance. Further, they will be benefited from EET spillover across regions.

5 | CONCLUSION

Energy efficiency remains one of cost-effective option to reduce energy consumption and low-carbon growth at firm-level. Therefore, this article attempts to estimate energy efficiency in the production function and meta-frontier DEA approach. With the objective of sustainable development (energy conservation with economic growth), this study estimated the energy efficiency of Indian iron and steel industry using firm-level data.

Energy efficiency under group frontier shows maximum feasible energy-saving under existing technology with the improvements at the managerial level. While MEE provides information on potential energy-saving with reference to the nation-wide best technology. The result shows that the northern states have the highest level of energy efficiency, followed by east, south and west under group frontier. Eastern region has experienced the highest increase in energy efficiency from 0.55 to 0.86 over the period of 2004–2016. The average level of energy efficiency under meta-frontier is higher for the south and east region while that of lower for north and west region. This shows that it is not necessary that best within the group also perform well under the meta-frontier because of the meta-frontier is based on national-wide best technology production function. Better energy efficiency in the eastern region, where the iron and steel industry is dominant in the industrial sector supports the role of industrial agglomeration in achieving higher energy efficiency. Low TGR shows that west and south regions have better technological advancement needs to be spillover across north and east region. While energy inefficiency in the west and south are relatively more caused by GMI whereas north and east region are significantly caused by TGI. Hence, the overall results highlight the role of managerial efficiency in improving total energy efficiency in south and western region while more focus on technological advancement should be given in the northern region.

Some of the policy implication derived from the above results are summarised below. Energy efficiency varies significantly across four regions and states and the energy-saving target is also quite different. At the firm-level some standard certification scheme like ISO 14001, 50001 should be implemented to enhance energy and environmental performance. The magnitude of the technology gap across four regions is attributed to the technology of energy utilisation. Hence, for the mutual benefit among the states and regions, coordination and cooperation should be promoted actively in order to ensure that EET and better managerial practise can be successfully implemented.

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ENDNOTES

[1] For more detail on application of DEA in energy and environmental evaluation, Sueyoshi, Yuan, and Goto (2017) provide a literature survey.

[2] In group formation, Madhya Pradesh and Chhattisgarh comes under central region but no firms fall under Madhya Pradesh, and Chhattisgarh are close to eastern region and with similar industrial structure hence included in eastern region.

[3] In literature on energy efficiency measurement, most of studies that consider undesirable output that estimated by carbon emission from energy consumption. Hence, it may be not much difference when energy inputs already minimise which will automatically reduce carbon emission.

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ACADEMIC PAPER

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Corporate environmental responsibility, motivational factors, and effectiveness: A case of Indian iron and steel industry

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This study provides an understanding of motivational factors that lead to the adoption of an environmental management system (EMS) from the perspective of resource-based view theory. Further, the role of EMS has been examined to reduce energy intensity by estimating the average treatment effect. Therefore, different logistic regression has been estimated to find out major motivational factors. Results from the logit model validate the role of firm's size, age, and ownership in motivating firms to adopt an EMS whereas regulatory pressure does not influence the firm's adoption of EMS. Furthermore, negative average treatment effect shows the effectiveness of certification in reducing energy intensity. The comparative analysis of sustainability report indicates that TATA Steel outperforms in terms of carbon emission intensity as compared with Steel Authority of Indian Limited, Jindal power and steel limited, JSW Steel, and average Indian firms. Nonetheless, top Indian steel companies are far behind the global best practices in terms of energy, water, emission, and effluent performance indicators.

1 | INTRODUCTION

There has been an apparent massive increase in industrial pollution and its impact on society. It provokes the stringent policy mandate from government and businesses to integrate the environmental impact of industrial production. In recent years, there has been growing concern over the environmental impact of heavily polluting industries. Civil and institutional voices have been raised over the corporate environmental responsibility (CER) or in more general corporate social responsibility (Earnhart, Khanna, & Lyon, 2014; Nurunnabi, 2016). To fix the CER and combat environmental issues, advanced economies implemented environmental laws with strong enforcement. Although, the situation is different in emerging economies, which shows a lack of seriousness in the enforcement of environmental law due to weak institutional capacity (Berliner & Prakash, 2014; Blackman, 2012). To supplement regulatory laxity, alternative cost-effective options are proposed and promoted by regulatory institutions, which are self-governed and market oriented. Moreover, the modern business firm recognizes its CER and adopt voluntary environmental programs (VEPs) or environmental management system (hereafter EMS) to minimize its environmental impact strategically (Jayashree, Malarvizhi, Kasim, & Mayel, 2016; Zobel, 2016).

Among different EMS, ISO 14000 series has been gained more popularity and widely adopted in advanced economies and latter in emerging economies (Neumayer & Perkins, 2004; Oliveira, Oliveira, Ometto, Ferraudo, & Salgado, 2016; Qi et al., 2011) as it has several other benefits beyond better environmental performance and regulatory compliance. ISO 14000 series is an objective measure and based on third-party verification. It comprises a formal structure and continuous appraisal and identifies the different dimension of potential environmental performance improvement during the production process. The global trend of ISO is very uneven. European countries are leading to adopt ISO 14001, whereas Asia and the Pacific regions envisage the largest growth. China has the highest number (165,665) of ISO14001 certification, which is 23,901 for Japan, whereas India is lagged, having only 7,887 ISO14001 certifications in 2017 (ISO Survey, 2017). In the case of India, there is a shift in the trend since 2013 as can be seen from Figure 1. The number of certification grew from mere 111 in

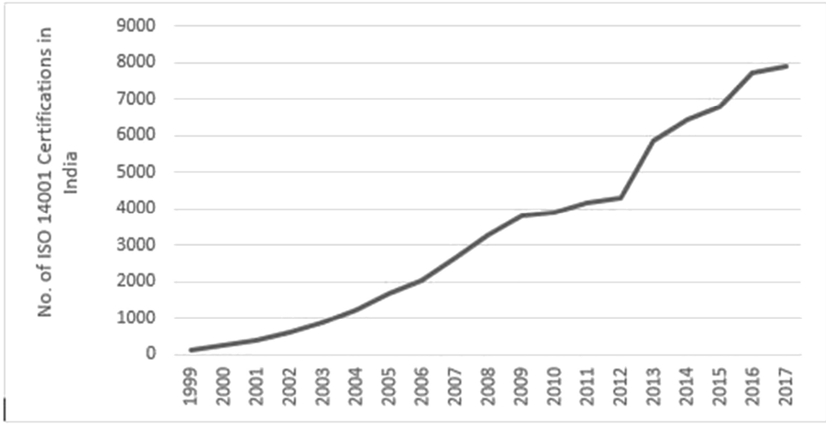

FIGURE 1 Trends ISO 14001 certifications in India

1999 to 4,286 in 2012 where it was drastically increasing to 7,887 in 2017. Hence, it documents that Indian companies are inclined to adopt ISO 14001 in recent years.

The motivation to adopt an EMS may typically depend on organizational behavior, motivations, and characteristics. Most of the previous studies examine the driving factors of EMS adoption either in the case of advanced economies by using cross-country data or in the case of emerging economies by using a growing body of literature available. Some recent studies have been conducted in the case of emerging economies using survey data and provide limited insight into the matter (Singh, Brueckner, & Padhy, 2014). Most of the recent studies use signaling, principal–agent, and legitimating theory to explain the firm's uptake of an EMS. They found a greater role of supply and demand side pressure of the market. While resource-based view (RBV) advocates a theoretical framework of the firm's performance based on the firm's internal resource and characteristics (physical and technical). RBV is well suited in our case of iron and steel firms where the production requires a very large amount of different resources like raw materials and energy inputs. Based on the RBV, major firm-level factors like age, size, and ownership have been examined. The size of the firm is used to proxy the internal capacity as large size firms have greater resources. The age of the firm indicates the level of experience as older firms have greater accumulated knowledge. Ownership represents firms' corporate policy; hence, it may highly influence firms' adoption of an EMS practice. Besides this, other firms' characteristics like export orientation (provides technical experiences with foreign customers) and energy intensity (energy per unit of output) have been analyzed. Reducing energy intensity may also motivate firms to adopt an EMS owing to higher energy price. Because iron and steel production is energy-intensive, and energy cost share is around 20–25% of the total cost, adoption of an EMS like ISO 14000 series should reduce the energy intensity through utilizing energy efficiency technology and better management practices. As energy efficiency is one of the key aspects in the companies' environmental objectives, an EMS may assist firms to save energy cost.

It is quite an interesting area of research to test whether recent EMS certification uptake among Indian firms has resulted in concrete environmental improvements. However, owing to the dearth of research in this area and very limited availability of data, there is very little evidence on it, as Indian firms vacillate in providing and reporting the environmental-related data (Kumar & Shetty, 2018). The study contributes to the growing literature on several grounds, first, this study has taken a larger plant-level dataset of a pollution-intensive sector (iron and steel) to provide insights to motivating factors that lead to EMS adoption. Second, this study analyzes the effectiveness of EMS in reducing energy intensity. As iron and steel production is highly energy-intensive, reducing energy consumption provides a competitive advantage to the firms. Hence, we tested whether an EMS adopted plant has lower energy intensity as compared with the non-EMS plant. Third, the role of the environmental regulation index at the state level is analyzed to check whether state-level differences in the regulation has any influence on EMS adoption. Furthermore, a comparative analysis of several environmental indicators of top steel-producing Indian companies has been done along with one foreign company (Posco steel) to provide a comparative view on the current environmental performance of Indian companies with respect to the best practices. Therefore, the study will provide a significant policy insight for firms to adopt an EMS like ISO 14001 in the pollution-intensive industry and reducing energy use. A better understanding of motivational factors will help policymakers to design effective policy to encourage firms to adopt an EMS. Hence, this will provide an in-depth insight of energy and environmental policies at the firms' level, which is crucial for pollution control and EMS adoption.

2 | OVERVIEW OF INDIAN IRON AND STEEL INDUSTRY

Iron and steel sector has a current capacity of 120 million tonnes (MT) whereas production stood at 101.4 MT in the year 2017 and contributes 2% of Indian gross domestic product (Firoz, 2014). The industry has experienced phenomenal growth of 8% per annum after the economic reform of 1991 and expect to produce 300 MT in the year 2030 (MOS, 2017). In the production of 1 tonne of crude steel (tcs), 3.5 to 5.0 tonnes of raw materials is required whereas the remaining part after production (2.5 to 4 tonnes) comes as either by-products, waste, and air and water discharge. On average, Indian steel plant generates 2.7 tonnes of CO_2 per tcs. If current growth rate prevails, there will be 800 MT of CO_2 emission in 2030, which will be 44% of India's current total CO_2 emission, and this obviously is not sustainable (Green Rating Project, n.d.). The Indian industrial sector has vast energy-saving potential from the current level, which can be achieved through the best available technology (Bhat, Haider, & Kamaiah, 2018; Haider & Bhat, 2018; Haider & Mishra, 2019). The status of VEPs in the iron and steel industry are not very satisfactory and confined to the environmental policy and ISO 14000 certification (Kumar & Shetty, 2018). Moreover, some of the firms adopted energy-saving measures like waste heat recovery (WHR) and slag utilization that gives direct economic benefits. An in-depth comparative analysis of top steel-producing companies has been done on several environmental indicators. This will provide a more lucid situation on the current environmental performance of the industry.

3 | LITERATURE REVIEW

3.1 | Theoretical insight on EMS adoption

There are several modern organizational theory in the context of a corporate management system, which hypothesize the motivation behind the firm's behavior on the environmental practices takeoff. The argument that lies at the heart of this literature is that firms use ISO 14001 or other VEPs to signal their eco-friendly practices and conciliate the pressures from a variety of institutions (Bae, Masud, & Kim, 2018; Jayashree et al., 2016). Firm's motivation for embracing an EMS can be attributed to relational, innovational, operational, and other business motives. Legitimacy theory argued for creating a legitimate image of the business among stakeholders. As firms operate under direct and indirect pressures from various stakeholders, VEPs may have the potential to build a reputation of the firm among them (Prasad, Mishra, & Kalro, 2017). Environmental practices are seen as a part of a strategic practice that will benefit firms in tangible and intangible forms. Hence, it justifies the rationality of adopting an EMS in the competitive world (Earnhart et al., 2014; Fikru, 2014b; Khanna, 2010). The RBV reflected the role of internal firm structure and capability and argued that better resource firms could efficiently allocate resources to acquire ISO 14001 certification (Jabbour, 2015). Taking the case of iron and steel firms, which is a resource-intensive production process, the present study uses RBV of adopting an EMS.

3.2 | Empirical literature

Early empirical studies examine the role of different output and input market factors on per capita diffusion of ISO 14001 standard across countries (Bae et al., 2018; Corbett & Kirsch, 2001; Potoski & Prakash, 2013; Prakash & Potoski, 2007). Most of the studies found that export orientation of firms and particularly country to which firms primarily export (advanced economies) influences the ISO 14001 adoption decision. A country that is highly inclined to ISO 14001 standards may seek similar standards from its trading firms. It is also envisaged that exporting to Japan and Europe, which have a higher number of ISO 14001 certifications, influences the certifications in exporting countries. Larger size firms and firms with prior experience of ISO 9000 standards are greatly inclined to adopt ISO 14001 (Fikru, 2014b). Several other factors like efficiency gain, enhancing corporate image, and getting international recognition also motivate firms to adopt ISO 14001 standard. Blackman (2012) shows that along with different motives of firms EMS certification, penalty within the last 3 years increases the probability of ISO 14001 certification.

Motivation to adopt the ISO certification remains unclear in emerging economies whereas bureaucratic regulation and enforcement, unionized labor force, granting of permits, and higher rates for emission charges are more effective in influencing such practice (Earnhart et al., 2014; Fikru, 2014b; Frondel, Krätschell, & Zwick, 2018; Iatridis & Kesidou, 2018). Hence, certified firms are in a privileged position as the target exceeds the legal requirements. Supply chain dynamics, foreign ownership, and foreign customers are also found to be significant factors that lead to ISO 14001 adoption (Dasgupta, 2000; Qadir & Gorman, 2008; Turaga & Gupta, 2018). There are mixed results in the empirical studies on the efficacy of ISO 14001 or other EMS programs in reducing pollution level from the firm (Ferrón Vílchez, 2017; Hazudin, Mohamad, Azer, Daud, & Paino, 2015; Heras-Saizarbitoria, Molina-Azorín, & Dick, 2011). Internal, market, and more custom pressures are the significant factors whereas external pressure from regulators and civil voices were insignificant in the Indian context (Singh, Jain, & Sharma, 2014, 2015). Shetty and Kumar (2017) did not find any significant relationship between VEPs and environmental performance for a sample of Indian polluting industry's firms. In the case of Indian small and medium enterprises, Singh, Brueckner, and Padhy (2015) found that ISO 14001 certification enables effective waste minimization whereas for Indian iron and steel companies, ISO 14001 adoption reduces carbon emission growth (Prasad & Mishra, 2017). Some recent studies indicate that adopting an EMS helps in reducing energy cost with better management practices. The recent literature has been pointing out different market pressure while little has been discussed on energy intensity. The focus of this study is a particular industry that is iron and steel, which is highly polluted and resource-intensive. Hence, it requires special attention to explore the factors that motivate the adoption of EMS.

4 | DATA AND METHOD

Because the study has been conducted on the sample of iron and steel producing plant particularly, we have collected the latest available data from the Annual Survey of Industry (ASI) for the year 2014–2015. ASI is the official industrial firm-level dataset of Indian government, which covers the whole country and is conducted on an annual basis[1]. Based on National Industrial classification (three-digit code 241), 1,210

[1]Because there is no across-year indentifier to make a panel data, we have used cross-section data of the latest availible data of the year 2014–2015.

plants were selected, but after cleaning and removing the plant with missing observation, we were left with the sample of 907 plant-level data for iron and steel industry. As compared with earlier studies, present study is based on a relatively larger sample on the firm's motivation on ISO 14001 takeoff. Data are given for whether a plant has IS0 14000 series certification, which also consists of ISO 14001 EMS standard, and 21% of firms have IS0 14000 series certification. The data cover plant operated across 22 Indian states and of different sizes. Geographical distribution of firms has been given in Table A1, which shows the distribution of the certified and total number of firms across states. There is an agglomeration of steel plant in the northern part of the country (Jharkhand, Chhattisgarh, and West Bengal); hence, it has the largest number of plants. Table 1 provides details of the data construction and variables' symbol used in the regression as well as the descriptive statistics. To get a more clear picture of the relationship, we have reported the correlation analysis among the variables in Table A2. The correlation of ISO 14000 series adoption is positive with age, export, private ownership, capital intensity, regulation, and large and medium-sized firms whereas it is negatively correlated with small size firms and both measures of energy intensity.

Firm-level data are not available in case of regulation, so the state-wise regulation index is used to test whether state-level differences in regulation resulted in differences in ISO 14000 series certification across firms. State-level environmental enforcement index has been taken from Lovo (2015). Energy intensity is measured as the ratio of energy consumption and gross output both in monetary term. One more indicator of energy intensity is used as a dummy variable based on the average energy intensity level. The above-average level is assigned value 0 and lower than average is assigned value 1. This will provide some insight, on an average level, whether the difference in energy intensity of firm assert some influence on the ISO 14000 takeoff. Around 76% of firms are wholly private owned; hence, it is important to test whether there is any difference in the ISO 14000 takeoff between public and private sectors. Further, some interaction dummy has been used to test the interaction of large and medium-size firms with ownership and export orientation. This will provide additional

TABLE 1 Variable Ddescription used in the regression analysis

Variable	Symbol	Measurement	Mean (standard deviation)
ISO 14000 Series certification (EMS)	ISO14	Do you have ISO 14000 certification? (Yes/No)	0.21 (.4140716)
Size	size_m for medium firms size_l for large firms	Dummy variable Classification based on number of employees Large ≥ >= 100 employees Medium ≥ >=20 and ≤ <=99 Small ≥ >=5 and ≤<=19 small is the reference category in all the analyses	Large = 0.7233 (0.45) Medium = 0.10 (0.15)
Export orientation	Export	Dummy variable Whether firm has exported in 2014–20-15	0.0981 (0.2976)
Age	Age	Years since the establishment of the plant	1997 (30.17)
Ownership	Owner	Dummy variable Classification Owd = 1 if wholly private otherwise 0 Public sector use as reference category	
Regulation	Regulation	State level environmental regulation index taken from	
Energy intensity	EI_1	Ratio of energy to output	0.11(11.11)
Energy intensity (Dummy variable)	EI_2	EI_1 = 1 for firms whose energy intensity is lower than average energy intensity Otherwise 0 Higher average energy intensity categories kept for reference	0.64(.4784)
Capital intensity	Capint	Ratio of fixed capital and output	0.720707(1.283)
Interaction of ownership and size	Own_m	Ownership * size_m	0.0893 (0.286)
Interaction of ownership and size	Own_l	Ownership * size_l	0.48952
Interaction of export and size	Export_m	Export * size_m	0.005(0.074)
Interaction of export and size	Export_l	Export * size_l	0.08820 (0.283)

Note:. All variables hasve been collected from the Annual Survey of Industry for the year 2014-–2015.

Abbreviations: EMS, environmental management system; ISO, International Organization for Standardization.

TABLE 2 Logistics Regression Results: ISO 14000 Certification (Yes/No) as Dependent Variable

Variables	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Size_m	1.070**	1.045**	1.049**	3.544**	1.112**	0.986*
Size_l	1.266***	1.265***	1.271***	2.556**	1.318***	1.199
Owner	−−0.863***	−−0.892***	−−0.893***	0.649	−−0.892***	−−0.923***
Age	0.013**	0.013**	0.013**	0.013**	0.013**	0.013***
EI_1	0.009					
EI_2		−−0.326*	−−0.327*	−−0.322*	−−0.328*	−−0.338
Export	0.448	0.455*	0.454*	0.470*	1.261	0.469*
Capint			−−0.010			
Own_m				−−2.907*		
Own_l				−−1.569		
Exm					−−1.054	
Exl					−−0.829	
Regulation						−−0.506
Log pseudolikelihood	−−414.537	−−413.651	−−413.641	−−411.240	−−413.435	−−396.154
Pseudo R^2	0.121	0.123	0.123	0.128	0.124	0.118

Abbreviation: ISO, International Organization for Standardization.

Notes: *, **** and * show the level of significance at the level of 1%, 5% and 10% level respectively.

*Significance at 10% level. **Significance at 5% level. ***Significance at 1% level.

insights from testing whether large and medium-sized private organizations are more likely to adopt an EMS as compared with other firms as it is expected that it may have a differential impact on the motivation of an EMS. Large and medium-size export-oriented firms are also more likely to adopt an EMS; hence, we have also included these interaction terms in the regression analysis.

To this end, the logit model of regression analysis has been applied as our dependent variable is binary. The logit model is generally applied when the dependent is binary through nonlinear regression, which follows the logistic distribution. Also, to check the robustness of the result, the probit model is applied, and results are almost similar; hence, we reported the logit model only[2]. The following logit model specification has been adopted, where, the *L* stands for the log of the odds ratio, which is not only linear in variables but also linear in the parameters. Z_i is the set of explanatory variables.

$$L_i = \ln\left(\frac{P_i}{1 - P_i}\right) = Z_i = \beta_1 + \beta_2 X_i.$$

For the casual effect of EMS adoption on the energy intensity level, average treatment effect (ATE) has been estimated. For this purpose, propensity score matching (PSM) has been applied to balance the treated and control group. PSM is based on the matching of EMS adopted firms, which is the treated group, with similar non-EMS firms, which is the control group. PSM has been conducted on the basis of firms' characteristics (age, size, and ownership), and after estimating the propensity through probit model, each EMS adopted firms has been matched with a non-EMS firm. Two matching procedure has been used: the nearest neighbor and kernel matching, and corresponding ATE has been calculated.

[2]This study has also performed the probit model. Both logit and probit models have provided the similar result. Due to the space brevity, results are not discussed here; one can get the results on request.

5 | RESULTS AND DISCUSSION

In the whole sample, 21% of the firms have certification whereas among large-size firms, 26% of the firms have the certification. Contrary to it, only 6% of the small size firms have the certification. Among the NIC five-digit classification, railway track-producing firms have a higher share of the certified firms followed by pig iron-producing firms. In the case of state-wise distribution, Goa, Karnataka, and Jharkhand, have the highest share of certified firms whereas Gujarat, Bihar, and Kerela have the lowest share of certified firms. Looking at ownership wise distribution, government enterprises have the largest share of the certified firms whereas the private sector has the lowest number of certified firms.

Table 2 shows the results of the logistic regression model, which consists of six different models using a different combination of motivational factors and indicators. Model 1 included major firm characteristic, whereas in model 2, the second measure of energy intensity (EI_2) has been introduced. Model 3 added capital intensity as an explanatory variable whereas Models 4 and 5 introduced an interaction term of size with export and ownership. Finally, the state-level regulatory index has been included in Model 6. Model 1 shows that large and medium-size firms are more likely to be certified as compared with small size firms. The positive likelihood of getting certified in case of both large and medium-sized firms is consistent in all other models and also supports the existing literature. The coefficient of export is insignificant in Model 1, whereas in another model, it turns to be significant at the 10% level. Hence, demand-side pressure seems very weak in the case of Indian iron and steel as its major demand comes from the domestic market. This is contrary to the existing studies, which strongly supported the role of pressure from importing countries' customer to adopt EMS. Although in case of energy intensity, EI_1, which is the ratio of energy to output, is not significant. Therefore, to explore further the role of energy intensity, we constructed a second measure of energy intensity, EI_2, as a dummy variable based on average energy intensity. The result from Models 2–6 consistently shows that having lower energy intensity of firms are less likely to get certified. However, the significance of the results is weak, as it is significant at the 10% level. The positive coefficient of age shows that old firms are more likely to be certified, owing to old firms that have more resources, whereas new firms are financially constrained (Haider et al., 2019). Therefore, higher age firms are more likely to adopt an EMS. The result is robust, as it is statistically significant across all models. Ownership of firms also plays an important role in shaping corporate management practices. Consequently, we have tested whether private firms are more likely to adopt an EMS. The results show that privately owned firms are less likely to adopt the EMS as compared with public sector firms. Public sector firms feel more pressure from the regulatory authority and more visible than the private sector. Hence, they are more likely to undertake environmental practices. On the other hand, private firms saw it as an extra burden under the weak regulatory scenario. Indian private firms do not feel great pressure from civil society and regulatory authority; hence, they do not take environmental practices seriously. Capital intensity turns out to be insignificant and does not influence EMS practices. Interaction of size with export and ownership also turns out to be insignificant except in case of interaction of ownership and medium-sized firms. Hence, medium-size private firms are more likely to adopt EMS with respect to large and small size private firms. Regulation index at the state level also does not influence the adoption of an EMS, which shows that firms do not feel regulatory pressure enough to voluntarily adopt an EMS.

We have tested the significance of an EMS for reducing energy intensity as compared with non-EMS adopting firms. Using EMS adopted firms as a treated group, we have calculated the ATE on treated using PSM, and the results are reported in Table 3. The results show that EMS adopted firms have lower energy intensity as compared with non-EMS firms by 6% to 8%. It is an important implication for firms to adopt EMS in order to utilize energy resource efficiently and reduce per unit energy consumption. Energy efficiency level of firms depends upon the technological and management approach toward energy use, whereas EMS like ISO 14001 continuously quests to reduce environmental impact along with cost-saving (energy cost also) through both means. For iron and steel industry, it is essential to reduce energy consumption (fossil fuel) to compete in the global market. Hence, firms with higher energy intensity can adopt an EMS like ISO 14001 certification as an effective managerial tool and benchmark their performance with best practices.

6 | COMPARATIVE ANALYSIS OF SELECTED INDICATORS

Most of the international organization has initiated and encouraged business firms to report their businesses' sustainability and impact on the environment. Most of the multinational companies, based on the transparency principle, report their sustainability dimension of operation and extend the involvement of different stakeholders across the world. In this regard, the Global Reporting Initiative has taken international initiative for business and other organizations to report their impact on climate change, labor, and human rights. It has several dimensions to environmental performance indicators.

We have done a comparative analysis of quantitative indicators, like energy and emission intensity, water use, and by-product management, of the report available from four Indian steel companies viz TATA steel, Steel Authority of Indian Limited (SAIL), JSW Steel, and Jindal power and steel limited. All four companies have a corporate environmental policy and show concern over the environmental impact of its operation. Along with these firms, the South Korean-based steel company, Posco Steel, has also been included in the analysis for benchmarking and reference purposes, which recently has opened a subsidiary in India, known as POSCO Maharashtra Steel.

We looked into the qualitative and quantitative aspects of the sustainability report of these companies. There is a difference in the number of indicators reported by companies, which show that

TABLE 3 Average treatment effect of ISO 14000 certification on energy intensity

Propensity score matching method	Treated firms	Control firms	Average treatment effect	Standard error	*t* - value
Nearest neighbour matching	199	708	−-0.062	0.19	−-3.26
Kernel Mmatching	199	485	−-0.074	0.17	−-3.64

Note:. Standard error has been calculated based on bootstrap of 1,000 replication

; *t*- value is higher than 2 (rule of thumb), which shows statistical significance of average treatment effect.

Abbreviation: ISO, International Organization for Standardization.

environmental disclosure practices differ across companies. The thematic analysis has been done on the performance analysis in terms of (a) specific energy consumption (SEC) and efficiency performance, (b) emission performance, (c) effluents and waste, and (d) water consumption and biodiversity.

6.1 | SEC and efficiency performance

Energy intensity is an important efficiency parameter for energy use. World Steel Association sustainability indicator has given the world average energy intensity of 4.77 giga calories per tonne of crude steel (Gcal/tcs) whereas the Indian average is 6.9 Gcal/tcs. It clearly shows the existence of a larger gap for SEC in most of the Indian plant. None of the considered companies has reached the world average and operates around an average Indian SEC. TATA performs well among them with 5.76 Gcal/tcs and near Posco's SEC of 5.22 Gcal/tcs as shown in Figure 2. Over the last 3 years, SECs of TATA and SAIL have been decreasing whereas JSW is increasing and became above the Indian average. Jindal that operates with electric arc furnace does not report its SEC. Indian firms are moving toward coal-based sponge iron production (an energy-inefficient production system), which requires on average 8.5–9 Gcal/tcs. Lower energy price induces firms to ignore the issue of energy conservation, which can employ commercially available energy-efficient technologies (EETs) and harness vast energy-saving potential. TATA has provided energy conservation and technology absorption-related detail, whereas SAIL that has described in one page with notably one plant (Rourkela) has operated with top recovery turbine generator (TRTG) and commissioning at other plants. JSW directly reported and highlighted the remarkable achievement of the 98.5% waste gas utilization and 71% WHR without describing details about the EETs employed and respected energy saving. Though these big companies are sending money on energy conservation measures, in comparison with its turnover, it is lower. Posco application of different EETs enables them to utilize most off-gases generated during the production processes, which is used for self-generation of electricity. "Energy recovery facilities such as CDQ, TRTGs, and LNG combined cycle power plants cover 63 percent of electricity use at Pohang and Gwangyang Works." Posco has been developing innovative technology for reducing air pollution by capturing CO_2 emission and other gases. The performance of Indian companies needs to be improved considerably in order to reach global best practice (hereafter GBP). In this regard, the government should promote and incentivize firms to self-generation of electricity through WHR and off-gas utilization.

6.2 | Emission performance

CO_2 emission is considered as major air pollutant beside other important emissions like Sulfur oxides (SOx), Nitrogen oxides (NOx), and dust. GBP around the world operate with 1.8 tonne CO_2 per tonne of crude steel (tCO_2/tcs) with the employment of different pollution control technology (Sustainable steel, n.d.). Posco engages with developing a different innovative method to minimize emission, for instance capturing CO_2 from off-gas and development of pulsating combustion technology. Similar is the case with energy intensity. Indian firms are far away from achieving GBP or Posco CO_2 emission intensity of 1.91 tCO_2/tcs, average Indian firms emit around 2.7 tCO_2/tcs, whereas TATA steel provides a national benchmark of 2.26 tCO_2/tcs as shown in Figure 3. Despite higher energy intensity, JSW has lower CO_2 emission intensity as compared with SAIL, which shows the importance of end of pipe technology for emission control. SOx, NOx, and dust emission are reported by TATA and JSW only, whereas SAIL only reports dust emission, stating that SOx and NOx are controlled and under the regulatory limit. NOx emission is provided by TATA and JSW, which is reaching around Posco level. In case of dust as emission, TATA steel (0.57 kg/tcs) performed better than JSW (1.2 kg/tcs) and SAIL (0.81 kg/tcs), but when compared with Posco (0.09 kg/tcs), there is a significant gap between Indian practices and GBP. Notably, SOx emissions are very high around 2.1 kg/tcs for JSW and 1.36 kg/tcs in case of TATA, which is more than double of Posco level of 0.56 kg/tcs. Taking Posco emission level as best practice, Indian leading steel producers are very far to GBP. The dominant share of coal as energy input and traditional

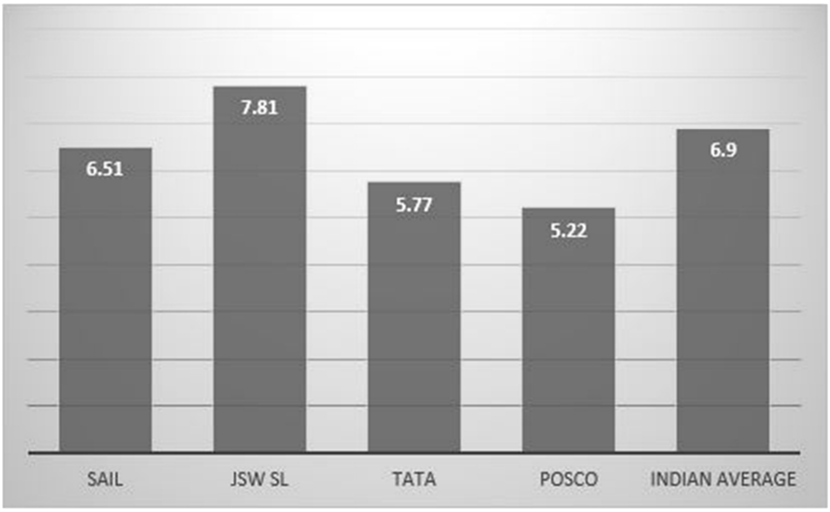

FIGURE 2 Specific energy Consumption (GCal/tcs) for the year 2015-16

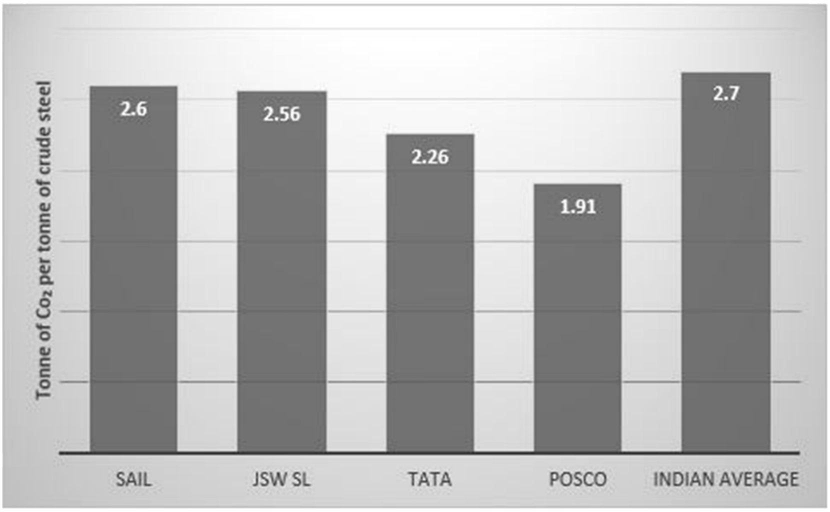

FIGURE 3 CO_2 emission intensity for the year 2015-16 (in t/tcs)

production method is primarily responsible for such scenario, but these companies are having vast resources and do not care about these issues and prefer not to use pollution control equipment. Local population has also been facing severe problem from heavy dust emissions like eye irritation and breathing problems.

6.3 | Effluents and waste management

Effluents are major water pollution discharges in the form of untreated effluents into surface water. Very less is mentioned about the effluents management whereas all companies acknowledge the need for zero liquid discharge (ZLD) and the importance of reuse and recycle. The average effluent discharged from Indian integrated plant is about 1.75 m^3/tcs. TATA has achieved near ZLD in 2015–2016 whereas SAIL has proposed the plan for ZLD at different facilities. As per the global practices, plants should not release wastewater at all. Examining the average solid waste generated, the reports show that every tonne of steel production churns out half a tonne of solid waste whereas the GBP is only 100 kg/tcs. Hence, the recycle and reuse of these waste have become crucial. Practically, these by-products can be utilized 100% as Posco does it around 98% of waste generation. Companies across the world use this waste to build roads and railway tracks.

6.4 | Water consumption and biodiversity

A general narrative has been asserted in the reports that "No negative impacts were observed on the water sources or the nearby water bodies because of operations" though a large amount of surface water has been withdrawing to produce millions of tonnes of steel with an only recycling rate of around 25%. On an average, specific water consumption of Indian steel plant is very high at 3.5 m^3/tcs, as mentioned in Figure 4. Even TATA and JSW are consuming more than the national average whereas SAIL is at the national average. This shows that top Indian steel companies remain inefficient in water consumption. Taking Posco for the benchmark, water consumption at 1.5 m^3/tcs, Indian industry can save more than half of the current consumption of water as it becomes crucial for sustainable development. However, little concern has been seen to improve water consumption efficiency. Freshwater intake of steel companies has seen decline marginally, but

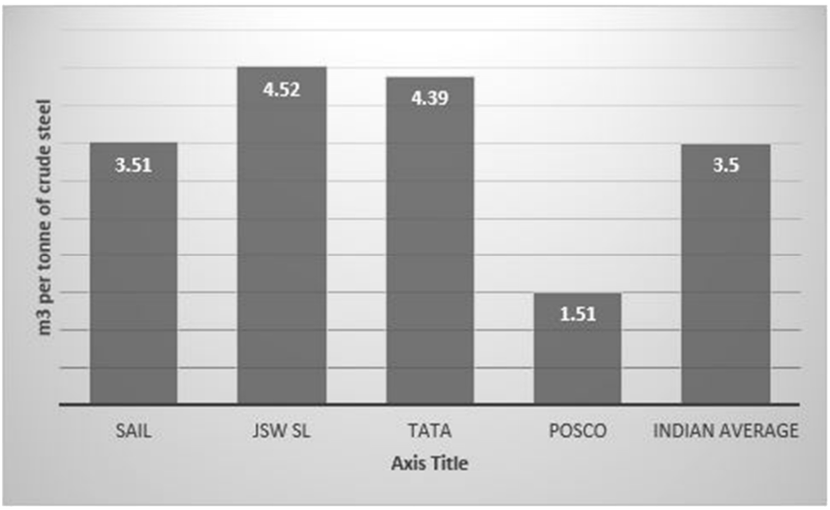

FIGURE 4 Specific Water Consumption for the year 2015-16 (in m3/tcs)

over the last 3 years, it remains substantially higher with regard to GBP. TATA and JSW have reported the water recycling rate of 23% and 30% (as percentage makeup water requirement), respectively. All companies have reported concern over biodiversity conservation and associated with an external organization to develop the biodiversity of the surrounding area. Tree plantation and ecological restoration steps have been taken by TATA and SAIL.

7 | CONCLUDING REMARK

VEPs are recognized as a potential supplement for the weak regulatory condition and more effective as they are flexible and self-regulated programs. Recently, there has been growing interest among firms to adopt EMS like ISO 14001 and other ISO 14000 series standard. Thus, this paper explores the role of different firm-level motivational factors that lead to the adoption of an EMS that is ISO 14000 series certification. We have estimated different logit model as our dependent variable (adoption of ISO 14000 series) that is a binary in nature. Results from the logit model validate the role of firm's size, age, and ownership in motivating firms to adopt an EMS. In case of size, large and medium-sized firms are more likely to be certified as compared with small size firms. Old firms are more likely to get EMS certification. Ownership of the firm may influence firms' behavior on environmental practices; the result shows that a private firm is less likely to adopt the EMS as compared with public sector firms. Public sectors and government-owned firms feel more pressure from the regulatory authority and more visible than the private sector. Furthermore result shows that greater than average level of energy intensity motivates firms to adopt an EMS. However, the significance of results is weak as it is significant at the 10% level whereas the energy output ratio is also not significant. None of the interaction of size with export and ownership influences the adoption of an EMS except the interaction of ownership and medium-sized firms. Hence, medium-size private firms are more likely to adopt an EMS with respect to large and small size private firms. Regulatory pressure may also be one of the key variables to influence the adoption of EMS. The result does not support the role of regulatory pressure on the firm's adoption of an EMS, as the coefficient of the regulation index at state is insignificant. EMS adopted firms have better performance in terms of energy-saving as compared with non-EMS adopted firms. ATE supports the effectiveness of EMS adoption for reducing the energy intensity and enhancing energy utilization efficiency.

The comparative analysis of top four steel producing companies shows that TATA Steel outperforms in terms of carbon emission intensity of 2.26 tCO_2/tcs as compared with average Indian firms of 2.7 tCO_2/tcs, whereas SAIL, Jindal, and JSW do not perform better than average Indian firms. However, all four companies have much higher energy intensity against Posco steel of 1.9 tCO_2/tcs and GBP. All companies are worst in water consumption against Posco and GBP. Posco steel has achieved lower energy and emission intensity due to the adoption of advance EETs of which off-gas utilization (waste gas like CO, SOx, and NOx utilization) and WHR have become prime importance. The Indian steel company has lagged behind in applying different EETs like Coke Dry Quenching (CDQ) and TRTG, which is cost-effective and widely applied. Though WHR provides direct economic benefit, it has been applied in the limited number of facilities at Indian firms. The Indian steel industry has massive energy-saving potential, which can be harnessed through applying commercialized EETs. Furthermore, SOx, NOx, and dust emissions are considerably higher than that of Posco level. Hence, the end of pipe technology should be applied in the Indian steel industry. However, these emissions are under the regulatory limit but significantly higher than GBP. As technological advancement helps reduction in emission level, the regulatory limit needs to enhance in order to move towards GBP. Finally, the VEP and BAT should be promoted in order to reduce the environmental consequences of steel production in a developing country like India.

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APPENDIX A

TABLE A1 State-wise firm distribution

Name	Number of ISO certified firms	Total number of firms
Assam	1	12
Bihar	0	13
Chhattisgarh	31	102
Goa	3	4
Gujarat	2	67
Haryana	8	39
Himachal Pradesh	2	9
Jammu and Kashmir	1	6
Jharkhand	19	40
Karnataka	11	35
Kerala	0	9
Madhya Pradesh	6	30
Maharashtra	24	102
Meghalaya	1	14
Odisha	20	87
Punjab	5	37
Rajasthan	7	49
Tamil Nadu	11	44
Telangana	4	19
Uttar Pradesh	9	51
Uttrakhand	1	8
West Bengal	26	98
Total	199	907

Abbreviation: ISO, International Organization for Standardization.

TABLE A2 Correlation analysis of variables

Variables	ISO14	Size_s	Size_m	Size_l	Age	Export	Owner	EI_1	EI_2	Capint	Regulation
\	1										
Size_s	-−0.169	1									
Size_m	0.044	-−0.155	1								
Size_l	0.173	0.748	0.540	1							
Age	0.123	0.034	0.038	0.054	1						
Export	0.076	-−0.114	0.049	0.130	0.019	1					
Owner	0.075	0.110	0.123	-−0.176	-−0.072	-−0.113	1				
EI	-−0.011	0.080	0.044	-−0.098	-−0.010	0.018	0.049	1			
EI_l	-−0.031	0.033	0.075	-−0.078	-−0.015	0.012	-−0.094	0.773	1		
Capint	0.030	0.140	-−0.049	0.152	-−0.015	-−0.002	-−0.123	0.009	0.019	1	
Regulation	0.259	-−0.118	0.079	0.154	0.099	0.186	-−0.234	0.017	0.04	0.124	1

Abbreviation: ISO, International Organization for Standardization.

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Does innovative capability enhance the energy efficiency of Indian Iron and Steel firms? A Bayesian stochastic frontier analysis

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ABSTRACT

This paper aims to estimate energy efficiency and quantify the energy-saving potential of Indian iron and steel firms. Further, we explore the influence of different innovative capability channels that can enhance energy efficiency. Firm-level data of 82 Indian iron and steel firms over the period of 2003–2017 has been taken to investigate the issues. Bayesian stochastic frontier analysis (SFA) has been adopted to measure underlying energy efficiency. The results show that most of the firms can reduce half of their energy consumption, while substantial heterogeneity exists in terms of energy efficiency. The Bayesian SFA outperforms classical SFA and documents slightly declining evidence of energy efficiency over time. The analysis also depicts that investing in R&D expenditure, patenting activity, and disembodied technology flow enables firms to achieve higher stage energy efficiency. ISO 14001 certified firms do not perform better than non-certified firms, and there is no significant effect of embodied technology on the firms' energy efficiency.

1. Introduction

Energy efficiency has been seen as a crucial policy option to reduce energy use and prevent environmental degradation. It has huge potential and can save energy by 40% in most industrial production processes (IEA 2018). It has remained largely untapped by developing countries' firms and hence there has been a persistence of the energy efficiency gap with reference to global best practices (GBP). Energy efficiency improvement can provide a better strategy to cope with uncertainty in energy price and environmental regulation. It will help to gain competitive advantage through cutting energy cost and upgrading technology. It works according to the market-based mechanism of investment, cost-effectiveness, ease of compliance, and efficiency gain in management (Na et al. 2019).

Investment in energy-efficient projects is seen as financially viable but the lack of technical knowledge, barriers and financial risk prevent harnessing of the fullest benefit of such investment. To tackle these problems, the Energy Service Company (ESCO) provides essential support through the assessment to implementation of energy-saving projects. However, the Indian ESCO is at the beginning stage and utilizes only 5% of its estimated potential (BEE, 2020). Diffusion and commercialization of energy-efficient technologies (EETs) are limited to the government-driven demonstration, with the low scale of the installation (Haider et al. 2019). While it is mainly concentrated in the renewables and building sector, the industrial sector is lagging. Implementing the energy-saving products in industrial units can bring about seamless transformation in improving operational efficiency.

Growing industrial energy demand and its environmental impact pose a severe challenge to climate change. Thus, energy-intensive firms are under regulatory and market pressure to reduce their energy consumption and environmental impact. Notably, technological, financial and managerial constraints restrict firms from investment in energy efficiency projects in developing countries such as India (Prasad and Mishra 2017). Longer expected payback period, technical risk and lack of capital are barriers for iron and steel firms in Germany (Arens et al. 2017). Generally, firms have the perception that pursuing eco-friendly operations will barricade their profit-maximizing objective. However, organization growth theories such as natural resource-based view (NRBV) recognize the importance of building environmentally-oriented innovative capacity to achieve long-term growth and competency (Hart and Dowell 2011). Signalling and legitimacy theory asserts that eco-friendly production enables firms to create a legitimate image among stakeholders while enhancing their innovative capability (Alam et al. 2019). Hence, it will be a win-win game if firms strategically improve its energy and environmental performance through gain in their managerial and technological capacity. Environmental management system (EMS) paves the way to build managerial capacity. In this context, note that the ISO 14001 certification has gained vast popularity to reduce a firm's impact on the environment. ISO 14001 is an objective-based measure and requires third-party verification. Hence, ISO 14001 certified firms (hereafter, certified firms) perform better in energy and environmental resource utilization (Hazudin et al. 2015;

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Singh et al. 2015). However, some scholars find that a firm's actual pollution reduction is uncorrelated with certification and serves as a green symbol only (Potoski and Prakash 2013; Shetty and Kumar 2017).

Innovative capability can be defined as the firm's technological ability that results in superior production technology and competence to adopt an efficient production process. It is cumulative technical know-how that the firm gains through implementing different advance technologies that prevail or are new to the industry. It is essentially the firm's ability to effectively adapt, assimilate the better technology for commercial ends uses "The capacity of a firm to 'appropriately adapt, integrate, and reconfigure internal and external organizational skills, resources, and functional competencies in changing environment to sustain its competencies' is termed as dynamic capability" (Teece and Pisano 1994). Hence, it is multidimensional, which accrues to the firm over time through the different channel as discussed below.

Research and development (R&D) investment enhances the firm's absorptive capacity and helps to upgrade its technology. R&D activities facilitate the learning of advanced technology and customize solutions pertaining to material and fuel efficiency. It creates quality human resources and technical know-how, which can reduce energy consumption without compromising on output (Aggarwal 2018; Bi et al. 2014). Successful R&D investment results in the product or process patenting, which create either a new product or a superior production process. Hence, it strengthens the firm's competitiveness and facilitates efficient utilization of resources. Corporate R&D and patenting activities are crucial factors for building dynamic capability and promoting efficient use of energy input (Alam et al. 2019; Haider and Bhat 2020). The transfer of advanced technology from developed countries to developing countries affirm up-gradation of old obsolete technology. It may be either through the import of efficient machinery (embodied technology) or outright/royalty-based purchase of the technical license or technical know-how (disembodied technology) (Aggarwal 2018). These innovative measures and technical know-how need to be effectively assimilated into the firms' 'processes' through organizational and managerial restructuring. Hence, it should certainly improve the energy efficiency of highly energy-intensive firms, which can reflect the successful penetration of innovative measures. In the end, it is an empirical question to verify the impact of managerial and technological advancement on energy efficiency.

Indian iron and steel firms provide an excellent setting to study the issue. The iron and steel sector is one of India's fastest-growing industries, with India becoming the world's 2nd largest producer of crude steel in the year 2018, with an output of 106.4 Million Tonnes (MT). It hosts the world largest coal-based direct reduced iron (DRI) production (Haider et al. 2020). With the existing capacity of 138 MT, the National Steel Policy, 2017 aims to expand it by 300 MT in the country by 2030–31 (MOS, 2017). The industry requires massive amount of energy and other resources (water, raw materials and land). It has set a target to achieve CO_2 emission intensity of 2.2–2.4 tons per tonne of crude steel (TCS) by the terminal year of 2030 (MOS, 2017). This target is still short of the current GBP of 1.8 tons per TCS (WSA 2019). Further, the industry is fragmented; 62% of the total crude steel production comes from six big companies, while the rest is accounted for by many small-scale firms (Green Rating Project 2019). Therefore, monitoring the energy efficiency performance can provide valuable inputs for evaluating the efficacy of energy efficiency programme. It helps to reduce fossil-fuel consumption also as a way to achieve sustainable development through cost-effective methods.

This study has a two-fold objective. First, it will quantify the level of energy efficiency using a Bayesian version of stochastic frontier analysis (SFA) using the concept of the distance function. Second, it will empirically assess the impact of the firm's innovative performance on energy efficiency. This study contributes to the scant literature on the role of technological flow and certified EMS on the firm's energy efficiency at micro-level and provides insights for corporate policies. Though at the macro level, different studies highlighted the role of technological progress on aggregate energy consumption, these have limited policy relevance at the firm-level. Hence, we have analyzed the Indian iron and steel firms—one of the most energy-intensive sectors that requires a better energy efficiency programme. We developed a Bayesian SFA to incorporate prior information from the previous studies to improve the accuracy of estimation. Further, We modified the Bayesian SFA model to reveal the best-fitted model based on information criteria for the current dataset. Insights to improve energy efficiency have been enumerated so that policymakers and corporate managers of energy-intensive industry (such as iron and steel) can adopt the same.

The rest of the paper has been arranged as follows: Section 2 describes related literature and brief methodology review. Section 3 introduces the method applied in this study and data sources, while Section 4 provides empirical results and discussion. Finally, Section 5 draws the conclusion and states the policy implications.

2. Literature review

Quantification of energy efficiency or energy demand is one of the crucial areas of research. While both methods provide essential tools, the engineering method to measure energy efficiency differs from the economics one. The engineering approach measures the specific energy requirement for a particular 'process' based on theoretical law of thermodynamics (Bhat et al. 2018). The economic approach measures the relative efficiency based on benchmarking tools. Moreover, conservation supply curve (CSC) represents an engineering approach extensively used to quantify energy-saving potential. It can be derived through production function when inefficiency is present (Boyd and Lee 2019). Assuming an implicit CSC, this paper applied the microeconomics concept of the production function with a statistical method to quantify the energy efficiency gap. It measures energy efficiency with reference to best practices (benchmarking) within sample firms, which is identified through statistical tools. Hence, it is called a total factor productivity approach rather than partial factor productivity such as energy-output ratio. Recent studies view energy intensity as a traditional measure which does not take other factors of production and structural changes into account (Zhao and Lin 2019).

DEA is a flexible and non-parametric approach which can be easily modified for constructing different energy and environmental performance indicators. It is extensively applied in constructing production frontier to benchmark the performance of the different organizations at the sectoral or economy level and to quantify potential performance at current technology. Scholars have investigated energy and environmental performance by using different variants of DEA (Bi et al. 2014; Chen and Jia 2017; Honma and Hu 2009; Jebali et al. 2017; Yang and Li 2017; Zhu et al. 2017).

In order to incorporate statistical noise arising due to measurement errors and other random factors, stochastic frontier proves to be a better characterization. The Stochastic Frontier Analysis (SFA) is a parametric approach to efficiency analysis, initially used to evaluate the energy efficiency of buildings and industrial plants. Boyd (2008) suggested the use of SFA technique to examine plant-level energy use efficiency. Zhou et al. (2012) measure the economy-wide energy efficiency and highlight the higher discriminating power of SFA in comparison with DEA. The vast majority of studies focused on Chinese industrial sectors such as paper, iron and steel, chemical and cement industry or aggregate manufacturing. Lutz et al. (2017) found that innovating firms are more energy efficient. Na et al. (2019) provide a methodological review of energy efficiency estimation and found that DEA and SFA are widely used to gain economic benefit. Ouyang et al. (2018) applied SFA for energy efficiency analysis in the case of China and highlighted the problem of price distortion. Fan et al. (2017) found that energy efficiency improvement enhances the financial performance of Chinese energy-intensive firms. Recently, some studies focused on technological and production (resource) efficiency to reduce emission level with improved energy efficiency (Javid and Khan 2020; Takayabu 2020;

Takayabu et al. 2019). Liu et al. (2020) found that technological innovation had mixed effects on energy efficiency in the case of China. Fujii et al. (2010) examined the economic and environmental sensitivity productivity of 27 Chinese iron and steel firms based on DEA. They revealed that machinery up-gradation decreases economic productivity while it enhances environmental productivity.

There is a growing body of studies in the Indian context to evaluate the energy efficiency of the manufacturing sector. Earlier studies used energy intensity as an indicator of energy efficiency (Reddy and Kumar 2011; Sahu and Sharma 2016). There is scant literature on the firm-level analysis of underlying energy efficiency using production function approach. A majority of studies have focused on energy efficiency estimation but omitted to investigate the causes of inefficiency (Haider et al. 2019). Mukherjee (2008; 2010) used the aggregate manufacturing sector provincial-level data. Mandal and Madheswaran (2010, 2011) have determined energy efficiency of the Indian cement industry using state-level and company-level data. Dasgupta and Roy (2017) studied the level of energy intensity across major energy-intensive firms and decomposition of energy intensity over a period. Prasad and Mishra (2017) found a positive impact of ISO 14001 certification and carbon emission through panel regression of firm-level data of iron and steel industry. The majority of the studies have used provincial-level data and found regional disparities across provinces or states (Bhat et al. 2018; Haider and Bhat 2020; Haider and Mishra 2019). Chen et al. (2015) estimated cost efficiency using data of Chinese electricity companies and recommended Bayesian SFA over classical SFA. There is a substantial research gap in conducting an energy efficiency analysis at micro-level in the context of India, particularly in the iron and steel industry which consumes a significant amount of industrial energy.

3. Method and data

3.1. Energy efficiency as an input distance function

Energy efficiency can be estimated through the production function approach, which can be viewed as measuring the input distance function with reference to frontier technology. Standard production function can be modified to measure energy efficiency, which is considered to be Shephard's input distance function.

$$D_i(y,x;E) = sup\{\lambda > 0 : (x/\lambda; E/\lambda, y) \in T\} \tag{1}$$

Eq. (1) proposed a reduction in the use of all factor inputs, both energy and non-energy to the minimum possible without reducing the level of output. Analogously, non-energy inputs can also be fixed, and only the energy input can be minimized, and then the sub-vector input distance function can be written as:

$$D_{si}(y,x;E) = sup\{\lambda > 0 : (x; E/\lambda, y) \in T\} \tag{2}$$

Assuming that the sub-vector input distance function is linearly homogeneous of degree one in energy and specifying a functional form of optimal energy input (E^*) form as:

$$D_{si}(y,x;E) = E^*/E = f^*(y,x)/E \tag{3}$$

Where $f^*(y, x)$ is the optimal input requirement function. Taking logs on both sides of the equation and suppressing subscripts, Eq. (3) can be written as:

$$ln\,(D_{si}(y,x;E)) = -\,ln\,(E) + ln\left(f^*(y,x)\right) \tag{4}$$

$f^*(y, x)$ can be approximated by a standard production function. In this case, the translog production function is used as it is flexible and provides a better approximation. Finally rearranging both sides of eq. (4) and replacing $f^*(y, x)$ by a translog function and $ln(D_{si}(y,x;E))$ as one-sided inefficiency term ($-u_{it}$) along with the usual measurement error term (v_{it}), we have the following parameterization:

$$ln\,E_{it} = \left[\alpha + \sum_{j=1}^{4} \beta_j \ln X_{jit} + \frac{1}{2}\sum_{j=1}^{4}\sum_{k=1}^{4} \beta_{jk} \ln X_{jit} \ln X_{kit} + v_{it}\right] - u_{it} \tag{5}$$

Eq. (5) is the SFA specification of production function where energy consumption is applied as the dependent variable, while output and non-energy inputs (labor, capital and materials) are used as the explanatory variables. We have also captured the process heterogeneity by including a dummy variable in the SFA model. The energy use also depends upon whether a firm operates with basic oxygen furnace (BOF), electric arc furnace (EAF) or induction furnace (IF) process. About 44% of Indian firms operate under the BOF route, while 26% are under the EAF route and 30% are under the IF route (GOI 2019). Hence, we have incorporated EAF/IF route as reference route and assigned 0 for it, and 1 for the BOF route. Globally, the share of crude steel production by the EAF process increased from 38% to 54.5% over the period 2003 to 2017 (WSA 2019). In a nutshell, distance from the frontier is represented by one-sided error term u_{it} that forces production function on or below the production frontier.

3.2. Bayesian SFA model

SFA, a well-established tool for efficiency evaluation in applied economics, was developed by Aigner et al. (1977) and Meeusen and van Den Broeck (1977). Classical SFA typically assumes homogeneous production function across firms which differ only in inefficiency level. It constructs a single production frontier and measures the relative efficiency of each firm with reference to the frontier. However, in real-world operation, production technology differs due to different factors (market friction, time lag, etc.) beyond the control of managers. Hence, it is not sensible to assume that each firm faces similar production technology. To deal with this issue, Tsionas (2002) proposed a random coefficient model in a Bayesian framework, which allows production frontier to vary across firms, hence incorporating heterogeneity in efficiency level. The computational scheme is arranged within Markov chain Monte Carlo (MCMC) methods, particularly with the help of Gibbs sampler. To illustrate, consider the following production function equation with a random coefficient:

$$E_{it} = \alpha + X'_{it}\beta_i + v_{it} - u_{it}, \quad i = 1, \ldots, N, t = 1, \ldots, T \tag{6}$$

Where E_{it} is a vector of the dependent variable for the ith observation of year t, X_{it} is a vector of explanatory variables, v_{it} is a random disturbance capture measurement error, distributed i.i.d $N(0, \sigma^2)$, u_{it} is a non-negative error term measuring inefficiency. β_i is a vector of random coefficients, and α is a non-random intercept. Distribution of v_{it} needs to be specified to complete the model; in Bayesian context, it is generally assumed that v_{it} follow an exponential distribution with a parameter θ[1] specified as below.

$$f(u_{it}) = \theta \exp(-\theta u_{it}) \tag{7}$$

Further, the probability distribution of random coefficient of the production function β_i is assumed to follow a multivariate normal distribution with the mean vector $\overline{\beta}$ and positive-definite covariance matrix Ω.

$$\beta_i \sim N(\overline{\beta}, \Omega) \tag{8}$$

[1] Alternative distributions such as truncated and gamma are also possible which are computationally more demanding, while the exponential distribution is most commonly used in the Bayesian framework.

Given the specification, u is drawn from an exponential distribution with parameter θ, while the prior mean of θ is $q = -\ln r^*$; the Gibbs sampler for an exponential distribution model of Tsionas (2002) draws β_i and (a, b) from the conditional normal distribution, σ and θ from the conditional gamma distribution, Ω from the conditional Wishart distribution while u_{it} is drawn from the conditional truncated normal distribution. Further, it is assumed that $\beta_i/\overline{\beta}$, Ω are independent, and u_{it} as well as v_{it} are independent of X_{it}. Hence, it becomes a hierarchical model, with two-levels of latent variables that are β_i and u_{it}. At first, β_i varies across firms which indicates that each firm has its own specific set of production functions drawn from distribution (8) to consider the heterogeneity across firms. At the second level, each firm has production shock which is accounted by its inefficiency level u_{it} drawn from distribution (7) with parameter θ. It is important to note that intercept remains fixed as it is not possible to keep both measurement error and a random intercept. The Bayesian estimation of model (6) works in the following three steps.

Step 1: Specifying the prior distribution of parameters in the model.

The Bayesian framework requires prior information in the form of parameter distribution which can be obtained from previous studies. Most often, the prior distribution for α and β is specified as flat, which means imposing no prior information on means value of parameters. Following Tsionas (2002), the prior of the model can be specified as:

$$\alpha_{i,} \beta_i \sim N[(a,b),\Omega\,], i=1,\ldots.N; (a,b) \sim N[(0,0),W] \tag{9}$$

While Ω ~ Inverted Wishart; θ ~ two-parameter gamma; and σ ~ inverted gamma type distribution.

Combining the conditional probability distribution of all parameters into a joint density function and marginalizing over u, the likelihood of the joint model in Eq. (6) can be expressed as:

$$L = NTln\theta + \left(\frac{\theta^2}{2}\right)\sum_{t=1}^{t}\sum_{i=1}^{N} W_{it} + \sum_{t=1}^{t}\sum_{i=1}^{N}\left[ln\varphi\left(\frac{-\varepsilon_{it}-\theta W_{it}}{W_{it}^{1/2}}\right)+\theta\varepsilon_{it}\right] \tag{10}$$

Where $\varepsilon_{it} \equiv E_{it} - \alpha - X'_{it}\overline{\beta}$; $W_{it} \equiv \sigma^2 + X'_{it}\Omega X_{it}$; $\varphi(.)$ denotes the standard normal cumulative distribution function, and X is a matrix of explanatory variables (Tsionas 2002). And finally, energy efficiency can be obtained from the following equation.

$$\textit{efficiency} = \exp\left(-\widehat{u}\right) \tag{11}$$

3.3. Second stage regression and hypothesis testing

Bayesian SFA can also incorporate the inefficiency effect (factor explaining the estimated inefficiency) in the mean function of inefficiency. Following Koop et al. (1997), we have run the Bayesian SFA with inefficiency effect. Since there are lots of parameters to estimate in the model, the sampler does not converge and has higher autocorrelation. The trace plot shows that the sample does not mix well and fails to converge. Hence, we rely on truncated regression analysis for estimating the impact of crucial factors on the energy efficiency level to accommodate the true underlying process of efficiency score estimation. The bootstrap technique has been used to build an empirical data generating process for correct finite sample bias in the standard error and confidence interval (Simar and Wilson 2000). Energy efficiency score from the Bayesian model has been used as the dependent variable in the regression analysis. A set of dummies and continuous explanatory variables has been used, as discussed in the introduction section.

We also performed a non-parametric hypothesis test to know whether any statistical difference exists between certified and non-certified firms, and innovative and non-innovative ones. For this purpose, three dummy indicators have been taken: 1. Firms with ISO 14001 certification, 2. Firms with R&D expenditure, and 3. Firms with a patent application. Furthermore, taking the above three indicators as treatment, propensity score matching (PSM) method has been used to know the average treatment effect on treated (ATT) on the energy efficiency score. PSM is generally used to know the ATT, by matching the treated and control group. Matching, in this case, has been done on the basis of the potential determinant of the above treatment dummy indicators (age, size, profitability, import intensity, royalties & technical fee, etc.). Propensity score has been estimated through the logit model and then matched between treated and control group by using the nearest-neighbor and kernel matching method.

3.4. Data and variable

Company-level data for the analysis is sourced from PROWESS database managed by the Centre for Monitoring Indian Economy. The database consists of audited data from the companies' annual balance sheets. Data on Indian iron and steel industry is taken according to the classification provided by national industrial classification 2008. Four input variables— capital, labor, energy, and materials—and a single output have been used for the so-called KLEM (capital–labor–energy–material) production function. Labor is taken as wages and salaries as expenses in the absence of data in the physical term, energy as expenditure on power and fuel, and materials as raw material expenditure. Gross fixed assets is used to estimate capital stock and net sale value for output used in the analysis. All variables are given in monetary terms and adjusted to account for the price level following Balakrishnan et al. (2000). After cleaning the data and accounting for missing data, we have ended up with 82 firms which operate across the Indian states. Out of the total market shares of the iron and steel industry in India, the sample firms share 72% of market share.

Four indicators of innovation have been utilized. The first is an input-based indicator (R&D expenditure), while the second is an output-based indicator (patent application). The patent application data for each firm has been extracted from the Indian Patent Office (IPO). The third and fourth are embodied and disembodied technology proxied by royalties & technical fee and import of capital goods data respectively. Since the iron and steel industry is not a high-tech industry, few firms have incurred R&D expenditure. Also, firms expend a very small amount of their turnover on R&D, hence the presence of R&D activity has been taken as a binary variable. Similarly, a binary variable has been considered for patent application count, and royalties & technical fee data. Patent dummy indicates the presence of innovation (product or process), while royalties & technical fee dummy shows whether firms purchase technical know-how. Therefore, in such case, the dummy indicator is supposed to provide a better proxy for innovative firms.

We have made an index for innovative capability using principal component analysis based on different indicators. These indicators are ISO 14001 certification, R&D expenditure, patent application count, embodied (capital import) and disembodied technology (royalties & technical fee). The innovative capability index is then added into the regression analysis. Size, age and ownership are widely used in the firm-level literature to capture a firm's heterogeneity (Prasad and Mishra 2017). In the case of Indian iron and steel industry, it is dominated by the private sector. Hence, we have only included size and age as control variables. Description of variables has been given in Table 1 and descriptive statistics in Table 2.

4. Results and discussion

The energy efficiency estimation follows the microeconomic concept of input distance function as derived in the methodology section. The selected time period is relatively long, and there may be changes in the efficiency level over the sample period. Hence, it is quite pertinent to exploit the time dynamics of energy efficiency. We have run 100,000 iterations with a burn-in of first 10,000 iterations to avoid the effect of initial values. We have checked for the convergence property

Table 1
Variable description.

Variables	Definition	Symbol
Output	Net Sale	lnY
Capital	Gross fixed asset	lnK
Labour	Wages and salaries expenses	lnL
Energy	Fuel expenditure	lnE
Materials	Material expenditure	lnM
ISO 14001 certification dummy	Dummy indicator takes value 1 if firm have ISO 14001 certification	ISO_D
R & D expenditure dummy	Dummy indicator takes value 1 if firm undertake R & D expenditure	RD_D
Patent application dummy	Whether firm have applied for any patent	PAT_D
Disembodied technology dummy	Dummy indicator takes value 1 if firm incurred Royalties and technological fees otherwise 0	DISEMBD_D
Process dummy	Binary variable assign 1 for BOF/OF, 0 for EAF/IF	Proc_D
Age of the firms	Number of years from the incorporation of the firm	AGE
Size of the firms	Log of average total asset	SIZE
Embodied technology	Imports of capital (machinery and equipment) goods divided by sales	EMBD
Index for innovative capability	An index for innovative capability created using principal component analysis	Inn_index

Table 2
Descriptive statistics.

Variable	Observation	Mean	Std. Dev.	Min	Max
LnE	1230	14.339	1.950	8.047	19.557
LnK	1230	16.886	2.080	12.52	22.50
LnM	1230	16.612	1.632	7.569	20.934
LnY	1230	17.417	1.648	11.926	21.922
LnL	1230	17.639	2.090	11.71	24.211
ISO_D	1230	0.4146	0.492	0	1
AGE	1230	29.024	15.64	2	110
RD_D	1230	0.2048	0.407	0	1
DISEMBD_D	1230	0.170	0.167	0	1
EMBD	1230	0.0091	0.028	0	0.292
SIZE	1230	8.3529	2.053	0	13.95
PAT_D	1230	0.0837	0.277	0	1
Proc_D	1230	0.4756	0.499	0	1
Inn_index	1230	0.0003	1	−0.257	8.133

of simulation through the dynamic trace plot and autocorrelation of coefficients. All models performed well, and a proper mix of the sample was evident.

4.1. Energy efficiency estimate

In a nutshell, classical SFA has been compared with Bayesian SFA model to gain insight into robustness and sensitivity of different estimation methods. Later, efficiency estimates of these models have been compared. For this purpose, drawing on Battese and Coelli (1992), the time-decay SFA model has been estimated. The results of posterior estimates have been given in Table 3. Looking at the statistical significance of the variable, classical SFA has less number of the significant coefficient. On the contrary, Bayesian SFA has mostly significant coefficients with lower MCMC error. Hence, the classical model remains inadequate to utilize the in-hand information efficiently. There is some similarity between both models, as most coefficients are of similar sign and are reasonably close. The difference may be probably owing to simulation and prior information provided in the Bayesian model. Nevertheless, there are considerable differences between the Bayesian and the classical model concerning the magnitude of the σ^2 (variance of the model) and the θ. The differences reflect the treatment of observation and nature of heterogeneity in the data. The differences in the value of θ depict important insights for the estimation of efficiency in the SFA. The value of σ^2 of the basic Bayesian SFA model is 0.08 whilst it is 0.64 under the standard SFA. Meanwhile, θ of the basic Bayesian SFA is 7.24 while it is 12.36 in the classical SFA. Given the higher value of θ in the classical SFA than the Bayesian one, it shows a higher probability of near-perfect efficiency in the case of the classical SFA model than in the Bayesian SFA models (Tsionas 2002). Therefore, the efficiency estimates from the Battese and Coelli (1992) model is higher than those of Bayesian models and it seems to overestimate the efficiency level. After considering both the estimation procedures, it seems more sensible to adopt a Bayesian framework for energy efficiency estimation in this case.

Having a better performance of Bayesian SFA, it is further possible to improve the model. Hence, in this paper, three Bayesian SFA models have been estimated and compared for best fit. Firstly, we estimated the basic model discussed in the methodology section; we then applied t-distribution of the error term in the basic model, and finally a time-varying efficiency (TVE) model following Griffin and Steel (2007). All

Table 3
Bayesian and classical SFA estimation.

Node	Basic model		T-distribution		Time-varying		Classical SFA	
	Mean	MC error	mean	MC error	mean	MC error	mean	Robust Stand. Error
Constant	5.339	0.0019	4.23	0.014	3.992	0.01	4.547[a]	23.12
lnk	−0.782	0.0042	−0.831	0.003	−0.762	0.003	0.215[a]	0.610
lnm	−3.433	0.0060	−3.034	0.005	−3.468	0.02	−1.025	0.383
lny	4.396[a]	0.0021	3.339[a]	0.007	3.325[a]	0.021	1.791[a]	1.317
lnl	0.024	0.0002	−0.076	0.003	−0.657	0.004	−0.481[a]	1.066
capsq	0.047	0.0002	0.087	0.001	0.323	0.001	−0.054[a]	0.057
matsq	−0.240[a]	0.0004	−0.287	0.002	−0.442	0.003	−0.074[a]	0.054
outsq	−0.315	0.0002	−0.587	0.001	−0.545	0.007	−0.242	0.130
labsq	0.028	0.0005	0.058[a]	0.001	0.051	0.001	0.006[a]	0.031
capmat	−0.048	0.0006	−0.124	0.003	−0.429	0.001	−0.005[a]	0.101
capout	0.091	0.0004	0.168	0.001	0.345[a]	0.001	0.086[a]	0.115
caplab	−0.082[a]	0.0005	−0.069	0.001	−0.399	0.001	0.024[a]	0.103
matout	0.512	0.0006	0.817	0.0004	0.874	0.01	0.275[a]	0.163
matlab	0.132	0.0010	0.284[a]	0.001	0.317[a]	0.003	−0.075	0.03
outlab	−0.103	**0.0003**	−0.196	0.001	−0.0358	0.004	0.069[a]	0.122
Proc_D	−0.374	0.0003	−0.43	0.002	−0.631	0.001	−0.686	0.243
sigmasq	0.081	0.0003	0.089	0.0002	0.087	0.647	2.64	0.781
θ	7.24	0.0001	6.65	0.0003	6.87	0.0011	12.36	0.144
Eta					0.054	0.001	−0.002	0.003

Note: “a” denote statistical insignificance at 5% level. Eta is the coefficient of time-term.

Table 4
DIC criteria for Bayesian SFA model.

	Dbar	Dhat	pD	DIC
Basic model	683.244	−268.968	963.683	1628.39
T-distribution of error model	578.183	−538.475	1316.67	1684.49
TVE Model	1133.25	70.158	1133.09	2196.52

DIC: Deviance Information criteria used for better model fitting.

models have been compared by Deviance Information Criteria (DIC) given in Table 4, and the higher value of DIC is desirable.

The model with t-distribution of error term has higher DIC value against the basic model. Hence, it shows that using t-distribution of error term better fits the model than using the basic model with the normal distribution of error. Furthermore, keeping the t-distribution of the error term and allowing the efficiency to vary over time has been incorporated in the TVE model. The value of DIC in the TVE model is higher than both the former models, hence it is a more appropriate model as per the DIC criterion. Therefore, we rely on the TVE model for the final analysis. It is interesting to look at the time-varying nature of energy efficiency. A flexible form of TVE model has been specified, and the positive coefficient of *eta* shows increasing inefficiency over time. Hence, the Indian iron and steel firms in the sample experience decrease in average energy efficiency because of the expansion of technological gap rather than the decrease in absolute energy efficiency.

Contrary to this, the coefficient of eta in the classical SFA turns out to be statistically insignificant and of a different sign. The coefficient of Process Dummy is also statistically significant across all models and has a negative sign. It reflects lower energy consumption of the BOF process as compared to the EAF/IF process. This may be due to the fact that the BOF process is adopted to produce a primary product (DRI or crude steel) through an integrated process, while the EAF/IF process is used to produce the final product as per the requirement (also to enhance quality), thus requiring more energy. Though scrap-based EAF/IF process requires less energy, however, Indian firms mostly use DRI as backward linkage to the EAF/IF process to produce different final products such as wire, TMT bar, hot/cold rolled steel (GOI 2019). These firms mostly use electrical energy which is relatively costlier than other sources of energy such as coal and gas, thus incurring a higher fuel cost.

There are 82 firms under analysis, and there may be considerable variation in the energy efficiency levels across firms. Hence, to show the distribution of energy efficiency across firms, box plots of average energy efficiency from classical and Bayesian SFA have been given in Fig. 1. Boxplot provides a quick view of distribution over four quantiles. The box inside the plot shows the inter-quantile range and the line inside the box shows the median of the energy efficiency score.

The vertical axis shows the scale of average energy efficiency, with energy efficiency score scaled between 0 and 1. Fig. 1 shows a lower limit of 0 (fully inefficient) while a maximum average score of around 0.8 and 0.75 for classical and Bayesian SFA respectively.z[2] Both plots show more concentration of energy efficiency score in the lower and middle quantiles. Hence, a higher number of firms lie between 0 and 0.40 over the scale of 0 to 1 of efficiency score. While, as per Bayesian SFA, relatively highly energy-efficient firms have 25% further potential to enhance their energy efficiency.[3] The boxplot shows that classical SFA overestimates the efficiency score over a margin of 5%. Relying on the estimates given by TVM of Bayesian SFA, there is enormous energy efficiency gap across the firms. The median energy efficiency of TVE Bayesian SFA and classical SFA is around 0.40 and 0.42 while that of the mean level is 0.39 and 0.43 respectively. Iron and steel industry consumes a massive amount of energy which can be minimized by an average of 60%. Vast energy saving opportunities exist for developing countries' firms which can be harnessed through technology transfer and adopting best practices. Average energy efficiency plot over the sample period has been given in Fig. 2. The plot depicts a slight increment in the energy efficiency gap across firms in the sample as there is a declining trend of average energy efficiency. It essentially means a decrease in relative measure of energy efficiency while it may be the case that absolute energy efficiency has increased for some firms. The plot shows that throughout 2003 to 2009, energy efficiency remains stagnant around 0.43, while after 2009, it starts decreasing slowly. The results have very serious policy implications for the iron and steel industry. Most of the Indian iron and steel industry firms require 6.9 Gcal/t against the world average of 4.5Gcal/t (Ramakrishnan et al. 2016).

4.2. Second stage analysis

After getting reliable estimates of energy efficiency, we have investigated the influence of crucial factors that drive the energy efficiency levels. There is a set of theoretical and emprical literature that shows that firm's heterogeneity is crucial in explaining the firm's performance. At the firm-level, heterogeneity across firms in terms of experience, scale of operation and ownership remains essential in explaining the differences in energy efficiency (Haider et al. 2019). We have tested for innovation-efficiency nexus based on NRBV advanced by Hart (1995). They advocated that firms should build innovative capability to gain sustainable competitiveness over the long term. Particularly, firms need to pursue eco-friendly strategies to sustain over the long term rather than to look at short-term benefits. So, the NRBV visualizes integrated link among a firm's resources (financial and physical resources) and sustainable competitiveness. Hence, we tested the hypothesis: a firm's general innovative capability results in higher energy efficiency, which is an indicator of sustainability and competitiveness. Higher energy efficiency firms will significantly reduce energy cost, which is a major component in the total cost of iron and steel production.

We have focused on the innovative and managerial capacity of firms, which may primarily enhance technical efficiency and overall productivity. Hence, energy efficiency estimated from TVE model of Bayesian SFA has been used as a dependent variable. ISO 14001, an EMS, is used as a proxy for better energy and environmental management while four different indicators of innovative capacity have been considered. The hypothesis is that there is a significant positive relationship between energy efficiency and ISO 14001 certification. Hence these indicators are supposed to positively associated with the energy efficiency score. As the iron and steel industry is one of the energy-intensive sectors, innovation and technical know-how will enable firms to use energy efficiently during the production process. Firms' heterogeneity has been captured by the size and age of firms and used as control variables. There is a high correlation between R&D expenditure and patent application variables; hence we have used it separately in the analysis. Further, we have run a separate regression to link energy efficiency with the constructed index of innovative capability along with control variables and exclude all indicators used in the other model.

First, we have estimated the model without control variables and then checked the results after including control variables. The estimated coefficient from truncated regression has been given in Table 5. Certification turns out to be statistically insignificant with a negative sign in all the models. Hence, the result is unambiguous regarding the same, while it has been expected to have a positive impact on energy efficiency. In case of R&D and patent dummy, the coefficient is positive and significant in both models, while the magnitude of the coefficient is less in the model with control. The result is consistent and stable: R&D and patent application stimulate energy efficiency of firms as they enable firms to successfully assimilate advanced technology into the production

[2] A score of 1 shows fully energy efficient, here the maximum score is 0.8 or 0.75 as it is average over the years of sample of only show cross-section variation, full data of energy efficiency score (82*15)has been in suplementary material.

[3] In the Bayesian SFA, mean energy efficiency shows mean taken out of considered iteration.

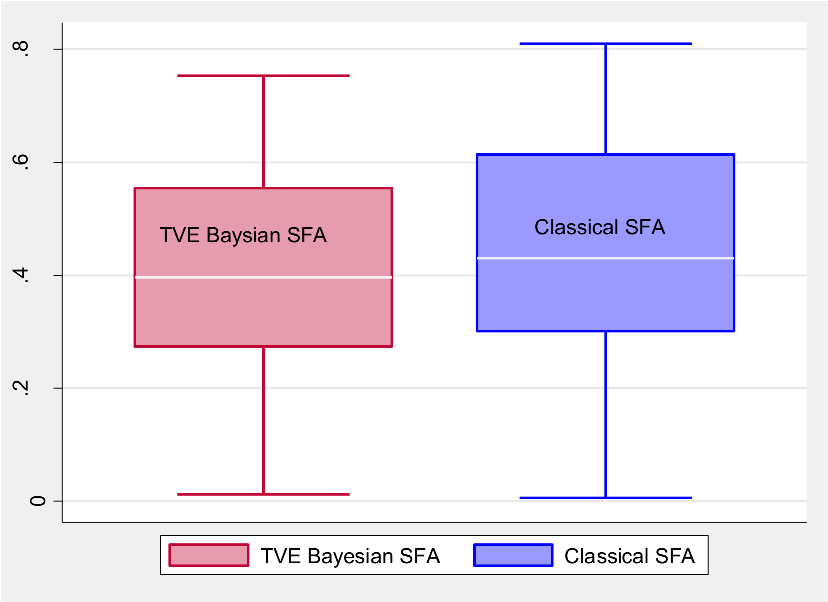

Fig. 1. Box Plot of average energy efficiency.

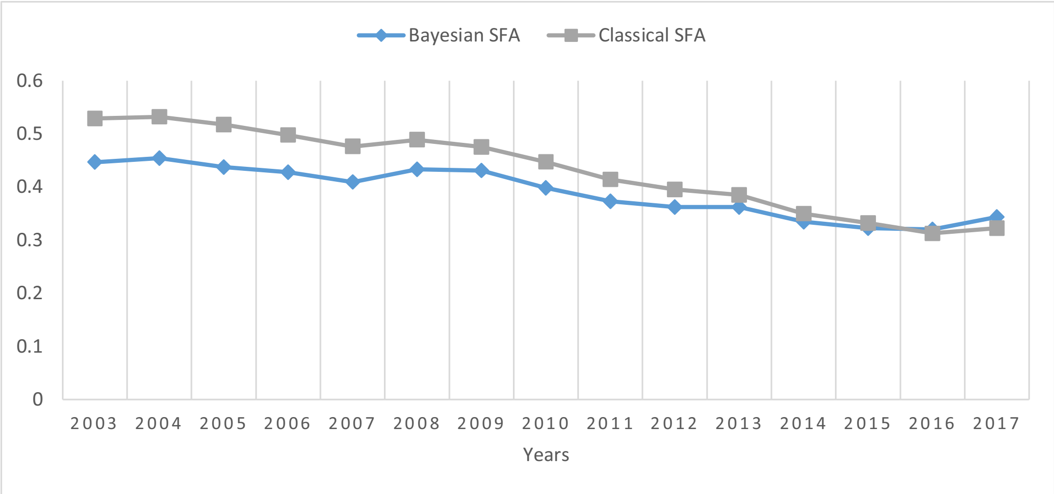

Fig. 2. Plot of average energy efficiency over 2003 to 2017.

process. Disembodied technology has a significant positive impact on energy efficiency, while embodied technology does not have any significant impact. The results are stable across the models. Therefore, it indicates that technical know-how flows from advanced firms through technical license purchase are essential for efficiently utilizing energy inputs. Regression results show the uneven impact of different channels of innovative capability on the energy efficiency level. Finally, we found positive and statistically significant impact of index of innovative capability on energy efficiency. Hence, on the whole, a firm's innovative capability carries a profound impact on energy utilization efficiency and facilitates firms to dynamically improve their production process. The coefficient of age is negative and significant in all the models, which shows that younger firms are more energy-efficient than older firms. Size of the firm carries a positive coefficient while it is statistically significant at 10% level of significance. The magnitude of the coefficient is shallow and not highly significant. Hence, it suggests that the effect of size is neutralized in the second stage. This may be due to the scale of production (size) being adjusted in the translog production function.

4.3. Robustness test

The regression results are further confirmed by non-parametric tests conducted to know the statistical differences between the energy efficiency of certified and non-certified firms, and innovative and non-innovative firms. The results of three non-parametric tests for the equality of distribution, rank and median level have been given in Table 6. The results show that the differences in energy efficiency exist only for innovative and non-innovative firms; while in the case of certified and non-certified firms, no statistical difference exists in this case of equality of distribution, rank and median level. The energy efficiency of innovative firms is higher than non-innovative firms and differs in terms of distribution, ranking and median level, while the energy efficiency of certified firms remained in line with regression results. The results from all three tests are in line with that of regression analysis and thus validate the truncated regression results.

In order to reveal the average difference in energy efficiency, we have run PSM estimator and estimates ATT. It shows the average

Table 5
Truncated regression on energy efficiency score.

Variables	Without control (Model 1)		With control (Model 2)		With innovation Index (Model 3)
Constant	0.165 (0.01)	0.763 (0.03)	0.604 (0.03)	0.396 (0.04)	0.356 (0.05)
ISO_D	−0.048[a] (0.16)	−0.049[a] (0.12)	−0.030[a] (0.32)	−0.026[a] (0.36)	
RD_D	0.191 (0.02)		0.184 (0.04)		
PAT_D		0.143 (0.01)		0.115 (0.02)	
DISEMBD_D	0.062 (0.04)	0.043[a] (0.08)	0.093 (0.03)	0.103 (0.00)	
EMBD	−0.560[a] (0.46)	−0.076[a] (0.34)	−0.061[a] (0.26)	0.156[a] (0.29)	
AGE			−0.002 (0.02)	−0.001 (0.01)	−0.002 (0.00)
SIZE			−0.009[a] (0.07)	−0.003[a] (0.09)	−0.002[a] (0.10)
Inn_index					0.066 (0.01)

Note: a denote statistical insignificance at 5% level. *P*-value is given in parenthesis.

Table 6
Non-parametric test for equality of energy efficiency between two groups.

Variables	Kolmogorov-Smirnov test for equality of distribution		Kruskal-Wallis rank equality test		Equality of median test	
	D-value	*P*-value	chi-squared	*P*-value	Pearson chi-square	*P*-value
ISO_D	0.063	0.28	0.47	0.42	0.003	0.93
RD_D	0.323	0.01	19.41	0.01	23.21	0.01
PAT_D	0.421	0.03	3.73	0.05	6.32	0.03

difference in energy efficiency level between treated and control firms. Taking certified and innovative firms as a treated group, a control group of firms are matched using the PSM based on other similar characteristics of the treated group. The results have been given in Table 7. As in the case of certified firms, the difference is not statistically significant, while the magnitude of ATT is negative. Hence, certified firms have lower energy efficiency (by 1%) on an average. On the contrary, innovative firms have a positive impact on energy efficiency. Firms with R&D expenditure have higher energy efficiency ranging from 0.05 to 0.07, which is statistically significant, while firms that file patent application have only around 0.03 higher energy efficiency as compared to firms without any patent application. It is only significant in the case of nearest-neighbor; matching the magnitude of the difference is nevertheless the same.

Nearest-neighbor matching provides estimates of ATT based on the matching of control group firm in the neighbor. Kernel matching matches similar control firms within a radius of propensity value of 0.1. The value of ATT are almost similar for both kernel, and nearest-neighbor matching method, and this shows the robustness of results. The magnitude of the difference is not very high, but taking it as a real impact of treatment on the outcome, it can be a considerable difference. The lower differences in energy efficiency between innovative and non-innovative firms may be due to two reasons. Firstly, very few number of firms have undertaken R&D activities and filled any patent application, and secondly, the scale of R&D activities are not such that they can produce a relatively higher difference in energy efficiency level.

Table 7
Average Treatment effect by propensity score matching.

	Matching method	n. treat.	n. contr.	ATT	Bootstraped Std. Err.	*t*-value
ISO_D	Kernel Matching	510	716	−0.021	0.014	−1.31
	Nearest Neighbor Matching	510	318	−0.027	0.019	−1.17
RD_D	Kernel Matching	252	950	0.059	0.019	1.90
	Nearest Neighbor Matching	252	166	0.071	0.028	3.09
PAT_D	Kernel Matching	103	73	0.041	0.039	1.21
	Nearest Neighbor Matching	103	1122	0.028	0.022	1.04

4.4. Discussion on the results

At the first stage, the estimation of the energy efficiency level provides energy-saving potential with a given level of output and using current production technology. Median energy efficiency is 0.40 and this indicates that half of the sample firms lie between 0 and 40% of the energy efficiency score. Therefore, these firms can save their energy input by at least 60% in order to become fully efficient. Bayesian SFA provides a comprehensive measure of energy efficiency. The energy efficiency score is lower than that of classical SFA. The results are in-line with the specific energy consumption (SEC) trend of the average Indian firm. We have documented this by examining the SEC of Steel Authority of India Limited (SAIL), taken from the annual reports over the period 2003 to 2018.[4] The time series plot of SEC, given in Fig. 3, shows an almost stagnating trend, with a meagre decline in SEC. The energy intensity of SAIL is decreasing (i.e., its absolute energy efficiency is increasing).

Certification does pay for business firms, even though it may fails to achieve the intended target, recent trends support its overwhelming adoption across the world. Indian firms are also found to have adopted ISO 14001 standard due to peer pressure. The energy efficiency gap across firms widens over the years and seems far away from the GBP (Haider and Bhat, 2018). The second stage result fails to show any significant impact of ISO 14001 on energy efficiency as compared to other firms. EMS is not found to be very effective to enhance energy efficiency; hence, even though firms are adopting the ISO 14001 standard, there is a lack of innovative capacity building and technical know-how. India's R&D investment in the steel sector is very limited in absolute and relative terms. It ranges between 0.05 and 0.5% of turnover as against 1–3% in the case of foreign steel companies (GOI 2019). EMS must be complemented by innovative capability for achieving higher energy

[4] SAIL is one of the leading Indian state-owned steel companies, located in eastern part of the country. It has five integrated steel plants, most of which have ISO 14001 certification. SEC is given as per data provided by the Ministry of Steel annual reports, and it is averaged across all the plants.

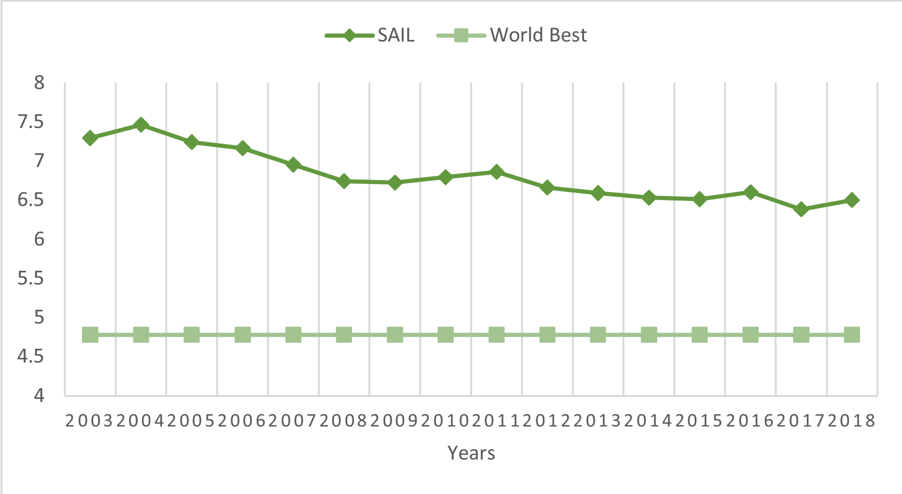

Fig. 3. Energy intensity in Giga calories per tonne of steel production.

efficiency. The result indicates that better energy efficiency would require dynamic innovative capability through different technological channels. Therefore, Indian firms need to adopt a *techno-managerial approach* to come up with a superior production process and assimilate advanced technology. It will enables firms to cope up with low-quality material and coal by providing customized solutions. R&D and patenting activities invoke an efficient production process that will propel firms into tapping the huge energy-saving potential. Integrating EETs with better managerial efficacy may speed up the diffusion of technical know-how through knowledge exchange. Further, it should generally assimilate into managerial practices with higher quality skilled labor. A technically skilled employee is crucial for implementing standard energy and eco-friendly saving processes. Both certified and non-certified firms need to introduce organizational reforms in the system and invest in building local absorptive capacity (R&D expenditure). Further, Indian firms need to collaborate with developed countries for EETs transfer through clean development mechanism and other similar measures. Disembodied technology acquired by firms (mainly from foreign firms) provides excellent impetus to enhancing energy efficiency.

The adoption of ISO 14001 may also be intended for signalling a green identity among stakeholders without necessarily putting in serious efforts to outperform non-certified firms. Though the number of ISO 14001 certifications issued has increased among Indian firms, its real objective of environmental improvements may be undermined. The level of energy efficiency, on an average, is quite low though firms have been ISO 14001 certified. This result is in line with the findings of Shetty and Kumar (2017), who did not find any significant relationship between EMS and environmental performance for a sample of Indian firms. Business motives and market pressure may undermine the actual target to reduce environmental pollution. Even though a wide variety of cost-effective EETs are available, they have a lower payback period. Certain exogenous factors such as lower energy prices, managerial negligence and organizational barriers may cause unleashing of such an opportunity (Acharya and Sadath 2017).

EETs such as Sinter Cooler-Waste Heat Recovery and Coke Dry Quenching are employed at some large-scale integrated plants but need to be adopted widely. Given the uncertainty in the fuel prices and international competition, the industry should cut the per-unit energy cost. Firms can gain completive advantage to invest their resources and enhance technical capability in eco-friendly operations. Moreover, the findings of our study have significant policy implications for business managers, policymakers, and regulators since it provides the empirical evidence on the importance of R&D investment in improving energy efficiency and reducing carbon emissions (Zhang et al. 2020).

5. Concluding remarks

The energy-intensive industry not only forms the industrial base of a country but also produces a large chunk of pollution. Enhancing the energy utilization efficiency is one of the crucial and cost-effective policy options for sustainable development. Different EETs can be employed to reduce energy use in the production process. This study quantifies the energy efficiency level and respective energy saving potential, using firm-level data of the Indian iron and steel industry. Bayesian SFA has been applied with its classical counterpart. Classical SFA model remains insufficient to utilize the in-hand information while Bayesian SFA performs far better. Particularly, the TVE model with t-distribution of error is seen to better fit the model. The results show that Indian iron and steel firms have experienced a stagnant and slightly increase in energy efficiency gap over the sample period. While there is more concentration of energy efficiency score in the lower and middle quantiles, the majority of the firms lie between 0 and 40% of efficiency level. Around half of the sample firms can reduce their energy consumption by at least 60%. Over the period of 2003 to 2009, energy efficiency remained stagnant at around 0.43 while after 2009, it started decreasing slowly. The results have serious policy implications in terms of tapping the huge energy saving potential for the iron and steel industry. This is in line with the trend of energy intensity of SAIL, which has seen as almost stagnating level of energy intensity with reference to GBP.

Using a second-stage analysis, we have documented that building innovative capability and technical know-how enables firms to achieve higher energy efficiency. Technology transfer needs to be accelerated from best energy efficient firms of advanced countries to developing countries firms to reduce the energy efficiency gap. The findings support the arguments of NRBV that firms that invest in building innovative capacity for eco-friendly operation results in competitive advantage through better energy and environmental performance. In the case of voluntary measures, ISO 14001 certified firms have not shown higher energy efficiency levels than their counterparts. Hence, EMS adoption in the Indian iron and steel industry needs an effective implementation through adoption of EETs and structural transformation for efficient use of energy resources. Technological innovation appears to be a crucial solution for better utilization of scarce resources. It can be instrumental for enhancing energy efficiency level. Size and age of the firm also matters for firm's energy efficiency. Younger firms have higher energy efficiency, which also indicates the importance of the use of the latest and advanced vintage of capital. While the larger size firms have relatively higher energy efficiency, small and medium scale firms need to coordinate and require proper policy support to enhance their energy efficiency.

Indian iron and steel companies are heterogeneous in terms of the resources and capabilities based on their local conditions. The government should integrate the regulatory policies with market-driven measures through institutional reforms and lower transaction costs. Moreover, the ESCO model of energy efficiency investment should be strengthened to foster commercialization and adoption of EETs. Our study takes a broader view on the level of energy efficiency by considering the aspect of heterogeneity. Hence, it is strictly not comparable to those studies which assume homogenous production technology across firms and estimated energy efficiency. Similarly, this paper is not comparable with DEA-based efficiency estimates as it is non-parametric and does not incorporate measurement error. However, the paper has some limitations related to sample data. Firstly, the focus has only been on the Indian iron and steel industry, hence the results cannot be strictly generalized to other countries' firms. Secondly, the analysis is only restricted to listed firms. Therefore, the interpretation of results should take cognizance of this, and a more extensive data set may be required to rigorously link innovative capability to energy efficiency.

Declaration of Competing Interest

None.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.eneco.2021.105128.

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