Sustainable Business Model with Minimum Generation of Waste Using Optimum Resources: An Empirical Research in Sponge Iron Sector in India

Sarbani Mitra[1]; Nupr Dattagupta[2] ; Murari K Agrawal[3]

Abstract- **Environmental management through resource conservation helps in industrial waste management through cleaner production and also is an issue of sustainable business practice. But, there are limited industry-specific studies on sustainable business practices and even the existing studies are focused on few regions of the world. Therefore the first step in formulation of the research problem was to assess the consumption of different raw materials and production of wastes by the sponge iron industry sector. The focus of the study was identification and evaluation of the industrial process to capture the implications of sustainable use of resources which may help the industries to minimise waste generation through optimum use of natural resources. To be more specific, it was considered that the first step in addressing the issue of sustainable development in business practice is making industrial operations more cost effective through efficient use of resources and minimisation of generation of waste through recycling and reuse of waste. Furthermore, the study ranked the surveyed industries according to their resource efficiency using Data Envelopment Analysis (DEA) and evolved sustainable business model for operationalizing the above concept for sponge iron industrial sector. Further a curve fitting application, taking dolochar generation along Y axis and consumption of power along X axis, was carried out to check whether the linear model is the best fit model for prediction of dolochar generated in a process. The findings showed that minimum generation of waste can be explained in a better way using optimum power and iron ore.**

Key words **- Sponge Iron, Optimum Resource, Minimum Waste Generation, Sustainable Business, Data Envelopment Analysis, Case Study.**

I. Introduction

Ministry of Environment and Forest & Climate Change (MoEF&CC), Government of India launched the Charter on "Corporate Responsibility for Environmental Protection (CREP)" in March 2003 with the purpose to go beyond the compliance of regulatory norms for prevention and control of pollution through various measures including waste minimization, in-plant process control and adoption of clean technologies. The Charter set targets concerning conservation of water, energy, recovery of chemicals, reduction in pollution, elimination of toxic pollutants, process and management of residues that are required to be disposed off in an environmentally sustainable manner. The action points are addressed to corporate bodies as well as regulatory agencies and therefore require a commitment of partnership and participatory action from the concerned stakeholders.
[1]

Scientists have found that a critical threshold has been reached in respect of using natural resources. If resources are exploited beyond this threshold limit, ecological disaster cannot be avoided (Lyon and Maxwell, 2004; Uberoi, 1999). Traditional pollution control strategies and techniques can no longer handle the complex situation. It is time for the development planners to integrate social, economic and environmental aspects at all levels of planning process (Shafik, 1994).

The steel sector in India contributes nearly 2% of the country's gross domestic product (GDP) and employs over 6,00,000 people. Rapid rise in production has resulted in India becoming the world's 3rd largest producer of crude steel in 2015 as well as in 2016. India's steel production in 2017 stood at 101.4 million tonnes (MT). Steel production in India is forecast to double by 2031, with growth rate expected to go above 10% in coming years. The Iron and Steel sector is also classified as one of the major polluting sector of the country.

Sponge iron is an intermediate product used for the manufacture of steel. Also referred to as Direct Reduced Iron (DRI) or Hot Briquetted Iron (HBI) in its compacted form, sponge iron is not a new route to steel production. The country was the largest producer of sponge iron or DRI in the world during the period 2003-2015 and emerged as the 2nd largest global producer of DRI in 2016 (after Iran). The coal based route accounted for 89% of total sponge iron production in the country in 2016-17.

Industrial development is an important constituent in our pursuit for economic growth, employment generation and betterment of quality of life. On the other hand, industrial activities without proper precautionary measures for environmental protection are known to cause pollution and

[1,3] Department of Environment Management , Indian Institute of Social Welfare and Business Management, Kolkata, West Bengal 700073
Email: sarbani_iiswbm@yahoo.co.in/km_agra@yahoo.com

[2]West Bengal Pollution Control Board, Kolkata, West Bengal 700106
Email: sgnupur@gmail.com

associated problems. The metallurgical and mineral processing industries are always known to be major contributors to environmental pollution. Amongst them, the iron and steel sector finds predominance simply because of the significant volume of effluents, emissions and solid wastes generated from the various process streams. A large number of innovations in waste management have resulted in implementation of integrated waste management plans in the steel sector as well as development of many value-added products (Bandhopadhyay et al., 2005). Hence it is necessary to comply with the regulatory norms for prevention and control of pollution. Alongside it is also imperative to go beyond compliance through adoption of clean technologies and improvement in management practices.

A good number of review is available in Shrivastava (1995), Porter and Linde (1995), Robèrt et al. (2002), Rennings and Rammer (2009), Sheng and Chen (2011), Yunus and Rahman (2014), Nivlouei and Khass (2014), Bennett et al. (2018) defining sustainable business practices.

As our study focuses sustainable business practice for sponge iron industry sector, therefore we provide a review of literature (Raja and Pal, 2006; Cerana Foundation, 2006; Battacharjee, 2007; CPCB, 2007; CSE, 2011; Setyorini and Ishak, 2012; Chatterjee, 2014; Mourougan, 2015; Lahiri et al., 2015; SIMA, 2015; Handayati, 2015; Tata Sponge, 2019) that examines how various technologies related to cleaner production are adopted for this industry sector.

The extent of severe health impact due to coal based DRI plant has been revealed by Cerana Foundation (2006), Radhika and Mitra (2006), Asher and Mumtaz (2007), Patra et al. (2009), Parida et al. (2015). In view of these environmental and health impacts due to sponge iron industry sector, Tata Sponge (2019) focused on environment friendly process management practices. Rommer (1990) suggested that the technological change is an important factor to contribute output growth. Chen et al. (2004) have suggested that technological leapfrogging could serve as an alternative pathway towards a more environmentally sustainable iron and steel industry. In addition to this, Chan et al. (2010) have reported a need to carry out energy audits in the iron and steel industry to get more in depth understanding of state-of-the-art quality management initiatives in these industries. Srajkumar (2011) observed for Indian steel industry that productivity improvement is possible through usage of state-of-the-art technology, higher quality raw materials, higher level of efficiency of operations, effective management practices and higher level of motivation amongst employees. Gorantiwar and Shrivastava (2014) indicated that there is a dearth of literature pertaining to SI industry in general and the quality management issue in this industry in particular. Debnath and Sebastian (2014) applied Data Envelopment Analysis to get insights on productivity efficiency of the steel manufacturing firms in India. Dey et al. (2015) made a survey on a typical coal based Indian sponge iron plant of capacity 500 t/d in order to identify the largest energy losses and find ways to increase the efficiency. According to their research findings, the largest improvements would be made by design modifications adopting a novel energy conservation scenario by process integration and thereby decreasing the coal and water consumption and by decreasing the cold fresh air. Florén et al. (2019) made an empirical study to explore how raw materials should be managed in iron and steelmaking firms.

It is perceived that environmental management through resource conservation helps in industrial waste management through cleaner production and also is an issue of sustainable business practice. But, there are limited studies on sustainable business practices of sponge iron industries and even the existing studies are focused on few regions of the world. Sustainability is a diverse issue and studies available do not touch upon industry-specific business practices of different geographies and societies. The studies in Indian context are again very limited and those available (Srajkumar, 2011; Gorantiwar and Shrivastava, 2014; Rao, 1984) focused on a few aspects of the same. Farla and Blok (2001) mentioned that as there is absence of comprehensive studies for the SI industry of India, it is imperative that there is a need to generate company specific data and it is suggested that the comparative assessments be made after critical statistical evaluation of the generated data for the purpose of quality management related decision making.

Therefore the first step in formulation of the research problem was to assess the consumption of different raw materials and production of wastes by the sponge iron industry sector. The focus of the study was identification and evaluation of the industrial process to capture the implications of sustainable use of resources which may help the industries to minimise waste generation through optimum use of natural resources. To be more specific, it was considered that the first step in addressing the issue of sustainable development in business practice is making industrial operations more cost effective through efficient use of resources, and minimisation of generation of waste through recycling and reuse of waste. Furthermore, sustainable business model has been evolved for operationalizing the above concept for sponge iron industrial sector. Further, a curve fitting application, taking dolochar generation along Y axis and consumption of power along X axis, was carried out to check whether the linear model is the best fit model for prediction of dolochar generated in a process.

The paper is structured as follows. Section 2 provides details about data and methodology adopted followed by a discussion of the findings relating to the development of sustainable environmental model for business practice in section 3. Section 4 sums up and gives concluding remarks.

II. Data, Sample and Methodology

This section describes the research design of the study including sample description and data collection.

Sample

The DRI plants are mostly located in the 6 districts of West Bengal - Paschim Burdwan, Bankura, Purulia, parts of

Paschim Medinipur, Purba Medinipur and Jhargram. Out of about 60 numbers of sponge iron plants in West Bengal, Paschim Burdwan district has 29 sponge iron plants in the State, followed by Purulia district (14) and Bankura district (11). Clusters of coal based rotary kiln sponge iron industries are located in areas like Barjora in Bankura District and at Angadpur, Durgapur, Ranigunj and Jamuria Industrial Estate of Burdwan District. Amongst these clusters, the maximum number of plants is located at Jamuria of Paschim Burdwan District. More than 50% of the total installed capacity in the State is attributed to these clusters. Table 1 shows the details of the major clusters of DRI industries in West Bengal.

TABLE 1
Details of Sponge Iron Clusters in West Bengal

Name of Clusters	No. of DRI Units of Capacity			Total Capacity (million tonnes per year)
	Small	Medium	Large	
JIE	2	8	2	1.245
Durgapur	1	7	-	0.675
Raniganj	3	4	-	0.435
Barjora	1	4	-	0.285

The State contributes about 17% of the total sponge iron produced in India and houses only coal based production units with the maximum number of medium scale plants in the country. Of the total number of DRI industries in the State, 73% are medium scale, 15% are small scale and a mere 12% (7 plants) are large scale. Table 2 shows the distribution of DRI industries in West Bengal in respect of their scale of operation. Because of this scale of operation and the huge number of small and medium scale plants operating in the State, the contribution to environmental degradation is appreciable and calls for urgent attention.

TABLE 2
Distribution of DRI Industries in West Bengal According to Production Capacity

Scale of Operation	Annual Installed Capacity (Tonnes per annum)	Number of Industrial Units
Small Scale	Less than 50,000	9 (15%)
Medium Scale	50,000 – 150,000	44 (73%)
Large Scale	Above 150,000	7 (12%)

There are 163 kilns of various production capacities in the State, out of which, only about 5% of the kilns are above 300 TPD capacity. Table 3 presents district wise distribution of sponge iron industries in West Bengal in respect of kiln capacity. It is observed that in West Bengal 100 TPD kilns are maximum in number and their share is nearly 75% of the total number of rotary kilns installed in the State.

TABLE 3
Distribution of DRI Industries in West Bengal in respect of Kiln Capacity

Districts	Rotary Kiln Capacity (TPD)					
	500	350	300	100	50	Total
Bankura		2	1	20	1	24
Burdwan (Purba and Paschim)		2	2	52	26	82
Purulia				26	3	29
Others (Purba Medinipore, Paschim Medinipore and Jhargram)	1	1		23	3	28
Total	1 1%	5 3%	3 2%	121 74%	33 20%	163

Data and Methodology for the Study

In this research study, since the population size is small (60), census survey was adopted. In the present study, one-off or cross-sectional surveys have been used to take a snapshot of the population at one point in time. For the purpose of this research, it was assumed that the production process and technology used by the concerned industries for pollution abatement remains unchanged over the period of time within the framework of this research study (Johnson, 1951). Therefore there is no requirement of longitudinal survey in the present case.

For commencement of data collection, it was decided to conduct a telephonic interview as the first stage to collect the data from the respondents industries. In some cases, where it was noticed that the response is low or inaccurate, personal interview method was adopted in the second stage of data collection. However, this was limited to very few industries only. Respondents were also requested to maintain diaries of some specific events related to environmental aspects and impacts of their industry like clarifications sought during an environment audit or observations made by inspectors from regulatory authorities at some stage of the survey period. During personal interview, such events were reviewed and assessed. Also specific measures to combat and control pollution like installation of new pollution control device or managerial policies undertaken by the industry was noted.

Primary data on raw materials selection, production process and waste generation were collected through the telephonic interview mode for which respondents were selected from DRI Industries who are the senior officials of the companies under study and are well versed with process operation and environmental management issues of these companies and had worked at the decision making and execution levels for last five years.

Apart from this, during the interview, general information about an industry like size of the industry, year of commissioning, power supply agency and capacity, number of persons employed in the factory, capital investment, etc. was also collected. This helped in ascertaining the capacity of the industry to manage their environmental impacts on the surrounding environment as a part of their corporate social responsibility. Detailed information pertaining to air pollution, water pollution and solid waste management and the prevention measures adopted by the unit were discussed with industry personnel. For air pollution, information relating to detailed sources of emission from various process units, fuel used, stack height, air pollution control devices installed etc. were collected. Information on use of DG set as power backup was also enquired from the industry. Data on details of types of waste generated, including quantity, nature of waste and mode of disposal was enquired and noted.

Specific data on yearly production capacity, average production, amount of coal consumed, iron ore consumed, power consumed and dolochar generated were collected. Though this category of industry is not expected to generate significant amount of water pollution, but information regarding water consumption, source and quantity of liquid waste discharged including place of discharge was collected.

The questionnaire has been designed in such a manner so that data collected on process emissions and waste generation could be compared easily with records from secondary sources viz. Annual reports of Industry Association, Comprehensive Industry Document (COINDS) of Central Pollution Control Board (CPCB) for the sponge iron sector to identify the key environmental problems associated with this sector and current environmental management practices by industries in West Bengal. The purpose of the questionnaire was also to collect information for identifying environmental parameters influencing the regional environment like raw materials utilization, production process and waste generation and their appropriate disposal practices and their impact on air quality, water quality, immediate land environment, noise generation etc.

Tools used for Data Analysis

Data Envelopment Analysis (DEA) is a linear programming based technique to evaluate the relative performance of different homogenous units known as Decision Making Units (DMUs) based on multiple inputs or outputs. It is a non-parametric approach where its initial use was to find the operational efficiency. It has been mostly used for the evaluation of not-for-profit organisations, however the technique can be successfully applied to other situations and multi criteria decision making. DEA makes it possible to identify efficient and inefficient units in a framework where results are considered in their particular context (Santos *et al.*, 2013). In addition, DEA also enables the comparison of each inefficient unit with its "peer group", that is, a group of efficient units that are identical with the units under analysis. These role-model units can then be studied in order to identify the success factors which other comparable units can attempt to follow. According to some researchers (Thanassoulis, 1993) DEA is preferable to other methods, such as regression analysis, which also make it possible to contextualise results.

Mathematical Formulation for DEA: In DEA, efficiency of a specific decision making unit under analysis is defined as the ratio between the a weighted sum of 's' outputs and a weighted sum of 'm' inputs, a natural extension of the concept of efficiency used in the field of physics and engineering (Charnes *et al.,* 1978). The input-oriented VRS technique requires the solution of the following Linear Programming problem (Banker *et al.*, 1984):

Min θ

Subject to

$$\sum_{j=1}^{n} w_j x_i^j \leq \theta x_i^t; \; i=1,2,3\ldots m$$

$$\sum_{j=1}^{n} w_j y_r^j \geq y_r^t; \; r=1,2,3\ldots s$$

$$\sum_{j=1}^{n} w_j = 1;$$

wj ≥ 0 (j=1,2,3…,n);

Where wj is the weight of the jth DMU, x_i^j is value of the ith input variables for jth DMU, y_r^j is value of the rth output variables for jth DMU and x_i^t is the value of ith input variable for tth DMU. Number of inputs is m, number of outputs is s and the number of DMU is n. Here the value of θ signifies the efficiency of the DMU.

In Data Envelopment Analysis, DMUs are ranked according to efficiency score (according to value of θ). In many DEA models, the best performance of a DMU is indicated by an efficiency score of one. There is often more than one DMU with this efficiency score. DEA evaluates the relative efficiency of DMUs, but does not allow for a ranking of the efficient units themselves. A modified version of DEA based upon comparison of efficient DMUs relative to a reference technology spanned by all other units is developed to rank and compare efficient units, i.e. units with value of θ equal to 1 (cent per cent). Many techniques have been introduced under the name of super-efficiency methods to determine the most efficient DMU. Among these, one is Andersen and Peterson's (1993) super-efficiency model. This technique allows efficiency to be more than one, discriminating between efficient DMUs that otherwise are all ranked equal. The procedure provides a framework for ranking efficient units and facilitates comparison with rankings based on parametric methods.

In a number of researches, super-efficiency have been used for ranking the efficient units (Noura *et al.*, 2011; Shanling *et* *al.*, 2007). Accordingly, the same approaches have been followed in the present study.

If two or more DMUs have θ value equal to one, then super-efficiency is represented as:

Min θ
Subject to

$$\sum_{j=1}^{n} w_j x_i^j \leq \theta x_i^t ; \text{ i=1,2,3... } m$$

$$\sum_{j=1}^{n} w_j y_r^j \geq y_r^t ; \text{ r=1,2,3... s}$$

$$\sum_{j=1}^{n} w_j = 1;$$

$W_j \geq 0$ (j=1,2,3…,n); Where $j \neq t$

Finally, a multiple regression analysis was performed with the data pertaining to top 30 sponge iron units as per their rank obtained from DEA. The software used for the regression analysis is SPSS Statistics 24. An empirical model has been developed to predict the minimum generation of wastes using optimum resources. Further a curve fitting application, taking dolochar generation along Y axis and consumption of power along X axis, was carried out to check whether the linear model is the best fit model for prediction of dolochar generated in a process.

III. Analysis and Findings

To rank the surveyed industries of the sponge iron sector according to their resource efficiency and finally to evolve empirical model for assessing the environmental performance, detail study on understanding the resource consumption (raw material, power, water, etc.) and solid waste generation per unit of production were considered necessary.

Environmental and Social Concerns Due to Sponge Iron Industry

As already observed from review of literature and survey, being inherently polluting in nature, coal based sponge iron units pose a major threat to the local biosphere mainly due to its huge emission potential, generation and indiscriminate disposal of dolochar as a solid waste leading to contamination of water resources and also for being a major cause of ground water depletion. Areas where such units are located in clusters are environmentally worst affected since such plants are located at distances of just 150-300 meters of each other. Occupational health and safety aspects in few cases are observed to be below average and due to dust emissions result in poor ambient air quality. A number of public complaints have been registered by local people regarding deposition of dust on their homes and on water bodies. This indicates inadequate or defunct pollution control equipment by industries in the cluster. It was also observed in some areas that coal ash is dumped in ditches near the highway. The water quality of some village ponds have been severely affected having a tarry layer over the surface of water bodies.

It has been reported that agricultural yield from fields located close to sponge iron plants has been degraded due to the indiscriminate disposal of dolochar in the fields. Many people claim a decrease in agricultural productivity after DRI industries have been set up in their vicinity. The rice produced in the nearby agricultural fields have become black and therefore fetches much less than the usual price. The major health problems of local people are the settling of dust on all surfaces including their bodies and respiratory illness in children are other health issues.

The major adverse environmental impacts of such industries as reported can be summed up as follows:

- Agricultural production, especially paddy crops affected before maturation resulting in serious production loss.
- Deposition of dust in residential areas, schools, leaves of plants due to emission from industries and disposal of solid wastes, that is char on roadsides and open fields.
- Water quality of village ponds acutely affected leading to a tarry layer over surface of water bodies.
- Due to excess withdrawal of underground water by the industries, adjoining areas are facing shortage of water especially during dry seasons

At this backdrop, the DRI Industries are required to follow certain codes of best practice for compliance with environmental norms and containment of adverse environmental impacts; these directives are issued by the Government and the environmental regulators from time to time. The conformance to these guidelines and codes of practice ensure that the industries are operating in an environmentally and socially responsible way.

In the present study, a data envelopment analysis (DEA) was performed with the following variables namely,

i. installed capacity of the plant for production of sponge iron in tonnes per year
ii. average consumption of iron ore in tonnes per year
iii. average consumption of coal in tonnes per year
iv. average consumption of power in Mega Watt Hour (MWH) per year
v. average consumption of raw water in cubic metres per year as the input variables
vi. average yearly generation of dolochar in tonnes

The number of input variables is five and the number of output variable is one. These variables along with their symbols used for analysis are presented in Table 4.

TABLE 4
Variables used in DEA along with Symbols

VI1	Installed Production capacity (yearly) of a company for DRI	Input Variable
VI3	Average yearly consumption of iron ore in tonnes	Input Variable
VI4	Average yearly consumption of coal in tonnes	Input Variable
VI5	Average yearly consumption of power in MWH per year	Input Variable
VI6	Average yearly consumption of raw water in cubic metres per year	Input Variable
VO7	Average yearly generation of dolochar in tones	Output variable

During the survey, data could not be made available from three DRI units and from a box plot analysis, data collected from six DRI units were discarded. Therefore the study was carried out with 51 DMUs. The primary data on yearly average production, consumption and waste generation figures have been collected from the DRI units with the help of questionnaire survey along with other relevant environmental information.

As explained in earlier sections, the initial data set has been normalized and negative numbers have been converted to positive numbers for the purpose of data analysis. The column means for each input and output variable has been calculated and then all the values of a given column is divided by the mean values to obtain the mean normalized value. Prior to this the negative values for output variables like dolochar generation (on a yearly basis) have been converted to positive non- zero values by addition of suitable number since waste generation is considered as negative output while considering efficiency of individual DMUs.

It is observed from the DEA analysis that the efficiency of more than one DRI unit is equal to one. When more than one DMU has efficiency score of 1, it is difficult to measure who among them is more efficient than the others. This problem is taken care of by measuring super-efficiency. As such super-efficiency is applicable only for efficient DMUs. Therefore a super-efficiency analysis is carried out for the said units in order to rank and compare the efficient units, i.e. units with efficiency equal to 1.

From the above analysis, a set of DRI units have been identified who are efficient in terms of the output and input variables selected for the analysis. These DRI units have been ranked according to their efficiency of use of resources (power, water, coal, iron ore etc.). The units which have been assigned a higher rank also generate lesser amount of solid waste during their production process, compared to others who hold a lower rank.

Development of Regression Model

From the results of Data Envelopment Analysis, the top 30 efficient units have been identified and selected for further analysis. Table 5 lists the code names of top 30 efficient units along with their rank obtained from DEA analysis.

TABLE 5
Top 30 DRI Industries Accoring to Rank Obtained in DEA

Code name of Sponge Iron Unit	Rank obtained in DEA Analysis
Bud23	1
Bud24	2
Bud14	3
Bud21	4
Bank10	5
Bank6	6
Pur11	7
Bank5	8
Pur12	9
Bud3	10
Bud4	11
Bank1	12
Pur8	13
Bud27	14
Oth2	15
Bud22	16
Bank4	17
Bud26	18
Pur3	19
Bud17	20
Bud19	21
Pur14	22
Bank11	23
Bank3	23
Bud28	23
Bud5	23
Oth3	23
Pur13	23
Pur4	23
Pur7	23

A multiple regression analysis was performed with the data pertaining to top 30 sponge iron units as per their rank obtained from DEA analysis. The software used for the regression analysis is SPSS Statistics 24. An empirical model has been developed to predict the average production of waste using optimum resources.

During data collection process, the average yearly consumption values of iron ore, coal, water, power and average yearly generation of solid wastes have been reported by industry personnel. Henceforth, all the variables, both predictors and dependant variables mentioned in this study will indicate the average yearly values only.

Development of Environmentally Sustainable Empirical Model with Minimum Generation of Solid Waste (Dolochar) Using Optimum Resources

In order to assess the environmental performance of the sponge iron sector, a regression model has been developed to establish the relationship between the waste generation and resource consumption for the efficient group of units (peer group) identified in the data envelopment analysis.

The variables used in regression analysis are:

(i)	average generation of dolochar in tonnes per year	Dependant variable
(ii)	Installed capacity of the plant for production of sponge iron in tonnes per year	Independent variable
(iii)	Average consumption of iron ore in tonnes per year	
(iv)	Average consumption of coal in tonnes per year	
(v)	Average consumption of power in MWH per year	
(vi)	Consumption of raw water in cubic metres per year	

The statistical hypothesis test for existence of a linear relationship between Y (in this case average yearly generation of dolochar, VO7) and any of the Xi [in this case five raw material input variables which are predictor variables, namely, installed capacity of the plant for production of DRI (VI1) in tonnes per year, consumption of iron ore (VI3) in tonnes per year, consumption of coal (VI4) in tonnes per year, consumption of power (VI5) in MWH per year and consumption of raw water in cubic metres per year (VI6)] is given by:

H0 : $\beta 1 = \beta 2 = \ldots\ldots \beta 5 = 0$

H1 : Not all βi (i=1,2.....5) are zero

First a correlation matrix (Pearson correlation) was obtained for all the independent variables. The correlation matrix is presented in Table 6.

TABLE 6
Correlation Matrix of Independent Variables

	Installed Capacity of SI	Iron Ore Consumption	Coal Consumption	Power Consumption	Water Consumption
Installed Capacity of SI	1				
Iron Ore Consumption	.624**	1			
Coal Consumption	.656**	.982**	1		
Power Consumption	.675**	.984**	.990**	1	
Water Consumption	.642**	.969**	.964**	.966**	1

** Correlation is significant at the .01 level (2 tailed)

It was observed from the analysis that highest pair wise correlation exists between coal consumption and power consumption.

The ANOVA table and F Test for existence of linear relationship between the five independent variables and the generation of dolochar are tabulated in Tables 7-11.

TABLE 7
Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	Water Consumption, Installed Capacity SI, Coal Consumption, Iron Ore Consumption, Power Consumption[b]	.	Enter

a. Dependent Variable: Dolochar_Generation
b. All requested variables entered.

TABLE 8
Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.998[a]	.995	.995	644.82473

a. Predictors: (Constant), Water_Consumption, Installed_Capacity_SI, Coal_Consumption, Iron_Ore_Consumption, Power_Consumption
b. Dependent Variable: Dolochar_Generation

TABLE 9
ANOVA[a]

Model		Sum of Squares	Df	Mean Square	F	Sig.
1	Regression	2196128042.000	5	439225608.400	1056.341	.000[b]
	Residual	9979174.428	24	415798.935		
	Total	2206107217.000	29			

a. Dependent Variable: Dolochar_Generation

b. Predictors: (Constant), Water_Consumption, Installed_Capacity_SI, Coal_Consumption, Iron_Ore_Consumption, Power_Consumption

TABLE 10
Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-109.431	297.505		-.368	.716
	Installed_Capacity_SI	-.002	.005	-.008	-.407	.687
	Iron_Ore_Consumption	.058	.021	.259	2.800	.010
	Coal_Consumption	.053	.030	.182	1.761	.091
	Power_Consumption	3.147	.704	.528	4.467	.000
	Water_Consumption	.002	.003	.039	.671	.509

TABLE 11
Residuals Statistics[a]

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	1705.0074	32491.7715	17791.6667	8702.21542	30
Residual	-1133.37317	1313.68262	.00000	586.60844	30
Std. Predicted Value	-1.849	1.689	.000	1.000	30
Std. Residual	-1.758	2.037	.000	.910	30

a. Dependent Variable: Dolochar_Generation

The F $_{(5,24)}$ value is 1056.341 with p value equal to "0.000". Here p value is less than 0.05, we reject the null hypothesis that the slope parameters βi (i=1,2.....5) are zero in favour of the alternate that the slope parameters are not zero. It is concluded that there is strong evidence of linear regression relationship between the generation of dolochar and any one of the five raw material input variables. This is further confirmed by the high coefficient of determination $R^2 = 0.995$. Thus the combination of the five raw material input variables explains 99.5% of the variation in generation of dolochar. The adjusted coefficient of determination adj R^2 is also high and equals to 0.995.

For n=30, k=5, the t statistic for 5% level of significance, the coefficient estimates (b_i) of predictor variable installed capacity and raw water consumption, null hypothesis cannot be rejected. It is observed from Table 10 that installed capacity of DRI, water consumption and coal consumption are not significant. Since highest pair-wise correlation exists between power consumption and coal consumption, the analysis is again carried out after dropping the variable power consumption (Table 12-16). It is observed that coal consumption becomes significant when power consumption is dropped. The variables Installed capacity and water consumption are not significant in this case also. R^2 value is 0.992 and adjusted R^2 is 0.990 which is lower than the previous case when power consumption was present in the regression analysis.

TABLE 12
Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	Water Consumption, Installed Capacity SI, Coal Consumption, Iron Ore Consumption[b]	.	Enter

a. Dependent Variable: Dolochar_Generation
b. All requested variables entered.

TABLE 13
Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.996[a]	.992	.990	855.04649

a. Predictors: (Constant), Water_Consumption, Installed_Capacity_SI, Coal_Consumption, Iron_Ore_Consumption
b. Dependent Variable: Dolochar_Generation

TABLE 14
ANOVA[a]

Model		Sum of Squares	Df	Mean Square	F	Sig.
1	Regression	2187829604.000	4	546957401.100	748.125	.000[b]
	Residual	18277612.320	25	731104.493		
	Total	2206107217.000	29			

a. Dependent Variable: Dolochar_Generation
b. Predictors: (Constant), Water_Consumption, Installed_Capacity_SI, Coal_Consumption, Iron_Ore_Consumption

TABLE 15
Coefficients

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-368.805	386.910		-.953	.350
	Installed Capacity SI	.005	.006	.022	.900	.377
	Iron Ore Consumption	.100	.025	.445	4.054	.000
	Coal Consumption	.142	.030	.484	4.684	.000

Water Consumption	.003	.004		.059	.761	.454

TABLE 16
Residuals Statistics[a]

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	1475.0992	32229.5312	17791.6667	8685.75847	30
Residual	-2043.09229	2120.68701	.00000	793.89073	30
Std. Predicted Value	-1.879	1.662	.000	1.000	30
Std. Residual	-2.389	2.480	.000	.928	30

a. Dependent Variable: Dolochar_Generation

Next, the regression analysis is again carried out after putting back the variable power consumption and dropping the variable coal consumption and the results are tabulated in Tables 17-21. The R^2 and adjusted R^2 value is more in this case compared to the previous analysis when the variable power consumption is dropped.

TABLE 17
Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	Power Consumption, Iron Ore Consumption[b]	.	Enter

a. Dependent Variable: Dolochar_Generation
b. All requested variables entered.

TABLE 18
Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.997[a]	.995	.994	657.20323

a. Predictors: (Constant), Power Consumption, Iron Ore Consumption
b. Dependent Variable: Dolochar Generation

TABLE 19
ANOVA[a]

Model		Sum of Squares	Df	Mean Square	F	Sig.
1	Regression	2194445483.000	2	1097222741.000	2540.361	.000[b]
	Residual	11661734.140	27	431916.079		
	Total	2206107217.000	29			

a. Dependent Variable: SI Production
b. Predictors: (Constant), Power Consumption, Iron Ore Consumption

TABLE 20
Coefficients

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-101.139	281.088		-.360	.722
	Iron_Ore_Consumption	.076	.018	.336	4.215	.000
	Power_Consumption	3.962	.475	.665	8.340	.000

TABLE 21
Residuals Statistics[a]

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	1692.1466	32574.2227	17791.6667	8698.88119	30
Residual	-1498.14563	1530.08716	.00000	634.13623	30
Std. Predicted Value	-1.851	1.699	.000	1.000	30
Std. Residual	-2.280	2.328	.000	.965	30

a. Dependent Variable: Dolochar_Generation

The final regression equation for prediction of generation of dolochar generated is Dolochar Generation (Tonnes/year) = -101.139+ 0.076 Iron Ore (Tonnes/year) + 3.692 Power (MWH/year). The normal P-P plot and histogram for the multiple regression analysis data is given in Figures 1-2.

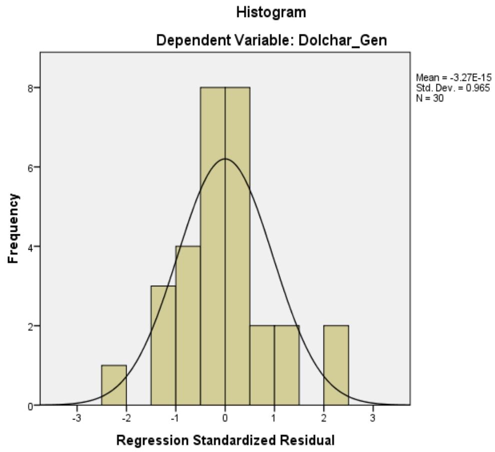

Figure 1

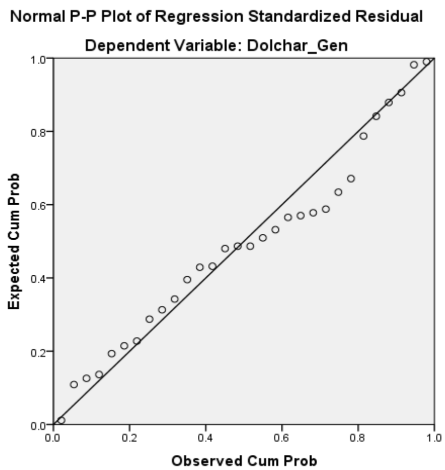

Figure 2

Further a curve fitting application, taking dolochar generation along Y axis and consumption of power along X axis, was carried out to check whether the linear model is the best fit model for prediction of dolochar generated in a process. The model summary and parameter estimates are given in Table 22-23.

It is observed that the R^2 values for the linear, quadratic and cubic equations are the highest (0.991 in all cases). In case of quadratic equation, the value of β_2 is zero. In case of cubic equation, the value of β_2 and that of β_3 of Table 23 is almost equal to zero. Hence both these equations are converging to linear model. Figure 3 shows that the linear equation best fits the data for regression model.

TABLE 22
Curve Fit - Variable Processing Summary

Description		Variables	
		Dependent	Independent
		Dolochar Generation	Power Consumption
Number of Positive Values		30	30
Number of Zeros		0	0
Number of Negative Values		0	0
Number of Missing Values	User-Missing	0	0
	System-Missing	0	0

TABLE 23
Model Summary and Parameter Estimates

Dependent Variable: Dolochar Generation

Model Summary						Parameter Estimates			
Equation	R Square	F	df1	df2	Sig.	Constant	β1	β2	β3
Linear	.991	3166.903	1	28	.000	129.724	5.933		
Logarithmic	.865	178.796	1	28	.000	-77500.736	12166.987		
Inverse	.457	23.598	1	28	.000	23000.676	-9865132.841		
Quadratic	.991	1533.334	2	27	.000	-43.586	6.084	-2.504E-5	
Cubic	.991	986.707	3	26	.000	-237.153	6.383	.000	1.291E-8
Exponential	.859	170.793	1	28	.000	4272.395	.000		

The independent variable is Power Consumption.

In the linear multiple regression model or sustainability model, the generation of dolochar has been expressed as a function of power consumption and iron ore consumption. It can be used for predicting the amount of dolochar generated with the help of variable power consumed and iron ore consumed in the said model. The variables water consumption and installed capacity of production are not significant as observed during the regression analysis and are therefore dropped from the regression model. With the help of this model and with the data used in analysis, the generation of dolochar can be explained 99.4% of the times. This empirical model can be used for prediction of minimum generation of waste (dolochar) using optimum power and iron ore.

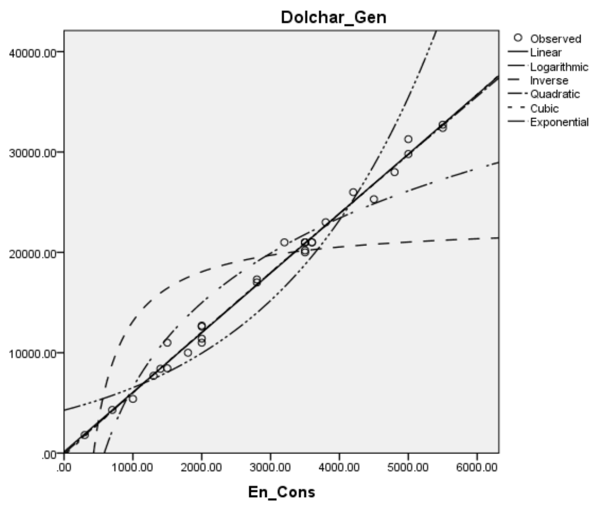

Figure 3 Dolochar Generation (Y) Vs Consumption of Power (X)

IV. SUMMARY AND CONCLUSION

On an overall basis, there are limited studies on sustainable business practices of sponge iron industries and even the existing studies are focused on few regions of the world. Sustainability is a diverse issue and studies available do not touch upon industry-specific business practices of different geographies and societies. The studies in Indian context are again very limited and those available focused on a few aspects of the same. As there is absence of comprehensive studies for the SI industry of India, it is imperative that there is a need to generate company specific data and it is suggested that the comparative assessments be made after critical statistical evaluation of the generated data for the purpose of quality management related decision making.

Further, this paper has tried to identify the key environmental issues of sponge iron industry sector by studying the major environmental aspects and their impacts on air environment, water environment and on land. It further critically reviewed the resource consumption (raw material, energy, water, etc.), emission/ effluent/ solid waste generation and release to the natural environment per unit of production and the mode of disposal. Finally the study ranked the surveyed industries of the sponge iron sector according to their resource efficiency using suitable statistical analysis and evolved empirical sustainable model for assessing the environmental performance of sponge iron industry sector.

In this model, the generation of dolochar has been expressed as a function of power consumption and iron ore consumption. It has been observed during data analysis and formulation of the regression model that minimum generation of waste can be explained in a better way using optimum power and iron ore. The variables water consumption and installed capacity of production are not significant as observed during the regression analysis and are therefore dropped from the regression model. By means of this model and with the data used in analysis, the generation of dolochar can be explained 99.4% of the times. Further a curve fitting application, taking dolochar generation along Y axis and consumption of power along X axis, was carried out to check whether the linear model is the best fit model for prediction of dolochar generated in a process. The result revealed that the linear equation best fits the data for regression model.

It is concluded from this study that the above model can be used for assessment of environmental sustainability with respect to DRI production, considering applicable aspects of resource consumption like iron ore, coal, water, power and generation of waste like dolochar. It is inferred that if raw materials consumed are in such proportions as predicted in this model, this will lead to maximum utilisation of resources with minimum production of waste.

As with all empirical work in this area, our results are subject to certain limitations. First, the study has been carried out for coal based sponge iron units of small and medium size. So the results of regression model are replicable for such units only. The units studied are using coal as fuel and therefore significant generation of carbon di-oxide (CO_2) which is a green house gas (GHG) is another noteworthy environmental impact of the coal based rotary kiln process. CO_2 is not classified as an air pollutant, but it has high global warming potential. The emission of CO_2 has not been quantified in this study; hence the contribution to GHG emission from this sector may be assessed as a further study. Despite these potential shortcomings, we believe that our findings contribute evidence on the recent practices of sponge iron industry sector.

There is need for continuing more exploratory and empirical research on different aspects of sustainable business practice in case of sponge iron industry sector. DRI can be produced using gas which is a cleaner mode of operation but it is expensive and gas availability is not assured. So, the other option is to produce steel using non-coking coal, through DRI. By 2030, more than 60% of the steel produced in India will come from coal-based sponge iron. As evident from this study, high grade iron ore and non coking coal are very scarce materials in India now and are unlikely to be available in the future also. Due to the limited availability of natural gas from domestic sources, high cost of imported gas and lack of proven techno-commercially viable alternate technologies, presently there is no other alternative but to follow the existing coal based technologies. Therefore, there is an urgent need to introduce eco efficient production process with the existing technology through optimum use of resources like coal, iron ore, water and energy. The present study aims to develop a suitable model for eco friendly, energy efficient and environmentally sustainable growth of the DRI industry in India.

Small kilns with less than 200 TPD capacities have some limitations in adopting cleaner technologies because it is not economically viable for smaller plants. Hence using the existing technology, with the help of this empirical model, a mitigation plan has been drawn for the sector to contain its environmental impact. With the current capacity of production using coal as fuel, the production process can be optimised for less environmental impacts using the model of DRI production derived in this study.

The Data Envelopment Analysis has been used to introduce a system of ranking amongst the DRI industries based on their environmental performance. Our current system of environmental monitoring and enforcement has to be strengthened and the ranking system can be used by policy makers to identify the better performers as "role models" from environmental point of view. Perpetual defaulters if getting a high rank may explore their environment management systems and re-evaluate their production process. In case of granting permission for expansion projects, better performers can be given a priority over others for setting up new initiatives.

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