International Journal of Mechanical Engineering (IJME)
ISSN(P): 2319-2240; ISSN(E): 2319-2259
Vol. 3, Issue 4, July 2014, 49-60
© IASET

International Academy of Science, Engineering and Technology
Connecting Researchers; Nurturing Innovations

A SYSTEM DYNAMIC ANALYSIS OF ENERGY CONSUMPTION AND CO_2 EMISSION OF INDIAN IRON AND STEEL INDUSTRIES

R LAKSHMAN & A RAMESH

Department of Mechanical Engineering, Government Engineering College, Thrissur, Kerala, India

ABSTRACT

The iron and steel sector is one of the largest energy-consuming manufacturing sectors in the world. India was the fifth largest producer of steel and hence has a greater importance in this iron and steel industry. Energy conservation techniques in iron and steel industry are a main area of research today. Developments in Iron and Steel industry are still in basic level. Any improvements in this field are very important. System dynamic analysis is a suitable approach to model a complex problem involving multiple decision making, technological limitations etc. A system dynamic model is presented in this paper to analyse steel demand, production, consumption and mitigation of CO_2 in an integrated frame work. “POWERSIM” software was utilized for the system dynamic analysis of this study. Through system dynamic modelling the energy consumption in steel industry is estimated under various steel production scenarios and various energy conservation techniques can applied and its feedback can be obtained. Finally, the model was modified and applied to the projection of steel production and associated CO_2 emissions in India up to 2031 starting from 2011 as base year. This modified model was run under three scenarios; such as baseline scenario, scenario- 1(S1) and scenario-2(S2). Energy efficient scenario was also incorporated in the model to estimate the future CO_2 emissions reduction.

KEYWORDS: CO_2, Emission, POWERSIM, Steel Production, System Dynamic Model

INTRODUCTION

Steel, aluminium, cement are the largest consumers of commercial energy compared to other industrial sectors. Steel, cement and aluminium are the main industries which are the key drivers of industrial growth in India, like other economies in transition. Most of other industries are heavily dependent on these industries for supply of raw materials and other intermediate goods. Fuelled by growing demands for construction and manufacturing sector, India has experienced a sharp rise in the demand for steel, aluminium and cement over the years. Iron and steel are the main constituents of many products used in everyday life. Crude steel is used to make semi-finished and finished products destined for the consumer market or as inputs for further processing.

The iron and steel industry used to be an important source of air pollution and waste. However the steel industry has improved its environmental performance significantly during the last 50 years. The emission of carbon dioxide (CO_2) is probably the most important remaining environmental problem. The iron and steel sector accounts for about 19% of global final energy use, about a quarter of direct CO_2 emissions from the industry sector, and roughly 3% of global GHG emissions, mainly CO_2 (OECD, IEA, 2007).Semi-finished products include steel shapes (blooms, billets or slabs) that are later rolled into finished products such as beams, bars or sheet. Finished products are subdivided into two basic types: flat and long products. There are more than 3,500 different grades of steel with many different properties – physical, chemical and environmental. Alloyed steels, which are sometimes also called special steels and may be considered specialty products, contain small portions of alloying elements such as chromium, cobalt, manganese, molybdenum, nickel, niobium, silicon, tungsten or vanadium. They are used in special applications, particularly those requiring high strength or corrosion resistance.

SYSTEM DYNAMICS MODEL FOR IRON AND STEEL SECTOR

In a system dynamics model, the simulations are essentially time-step simulations. The model takes a number of simulation steps along the time axis [9]. The dynamics of the system are represented by $dN(t)/dt=kN(t)$, which has a solution $N(t)=N_0expt(kt)$. Here, N_0 is the initial value of the system variable, k is a rate constant (which affects the state of the system) and t is the simulation time. For the simulations to start for the first time, initial values of the system variables are needed.

Flow Diagram

A software package “Powersim Studio 7”, available for system dynamics analysis has been used in developing the model for forecasting CO_2 emissions. The flow diagram shown in the Figure 1 is useful for showing the physical and information flow in the system dynamic model for Steel industries in India. The level variables are shown as rectangular boxes which represent accumulated flows to that level. A double arrow represents the physical flows, and the flow is controlled by a flow rate. Source and sink of the structure are represented by a cloud. The cloud symbol indicates infinity and marks the boundary of the model. A flow diagram is useful for showing the physical and information flows in the SD model. The level variables are shown as rectangular boxes which represent accumulated flows to that level. A double arrow represents the physical flows, and the flow is controlled by a flow rate. A single line is for showing information flow. Source and sink of the structure are represented by a cloud. The cloud symbol indicates infinity and marks the boundary of the model.

Once the simulation is over, at the end of each step, system variables are brought up to date for representing the results from the previous simulation step. The rate variables are represented by valves. The information from the level variables to the rate variables is transformed by a third variable called the auxiliary variable, represented by circles. The diamonds represent constants, which do not vary over the run period of simulation. A constant is defined by an initial value throughout the simulation. To avoid messing up and criss-crossing in the diagram the variables repeated in the diagram are represented in the form of snapshot variables.

The proposed system dynamic model is composed of 4 main sub systems, steel demand module, production module considering capacity expansion, energy consumption module and the CO_2 emission module. The paper covers the following important issues which are elaborated in the proposed model:

- The impact of population and GDP on steel demand in future
- The structure energy consumption under various productions.
- Analysis of energy savings achieved by possible technology changes in the steel industry.
- Analysis of the CO_2 emission and electricity generation need by the steel industry.

The Proposed System Dynamic Model for Iron and Steel Industry

In each substems, stock and flow diagram has been developed and feed backs among subsytem are presented.

Steel Demand

Final steel demand surges with population and per capita steel demand.Per capita steel demand increases by percapita GDP growth. The structure of steel demand is presented in Figure 1. Final crude steel production can be obtained from final domestic steel demand.

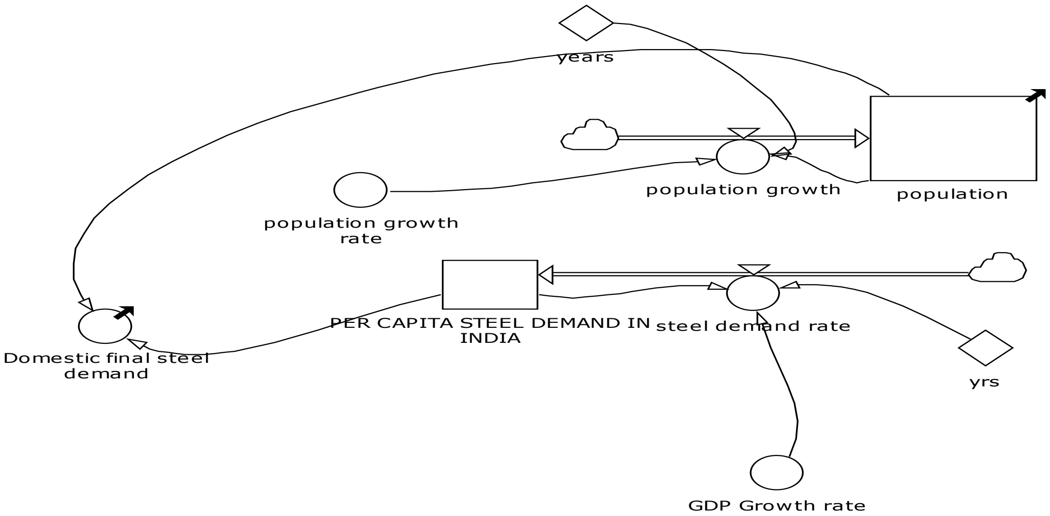

Figure 1: Final Steel Demand Stock and Flow Diagram

Total Thermal and Electric Energy Consumption

From the various steel production methods total Steel demand the total Steel production can be obtained by considering steel import and steel export. From the total steel production of various production methods can be found out namely, Blast oxygen furnace (BOF), Electric arc furnace (EAF) and Direct reduction iron (DRI). In Indian steel industries 45% of production is through BOF,24% by EAF, 31% through DRI [6].India was the highest producer of sponge iron have imminent capability of producing steel by DRI method.So in future by utilising the DRI method india can achieve much higher productivity with lesser effect on the environment. Presently, in India, EAF based industries are yet to switch over to induction furnace route. An induction furnace is an electrical furnace in which heat is generated through electromagnetic induction in an electrically conductive medium. Induction furnaces use steel melting scraps,sponge iron and pig iron/cast iron. On an averagethe proportion of these items is 40% sponge iron + 10% cast iron or pig iron and the remaining is steel melting scraps. Induction furnace has capability to operate on a charge up to 85% DRI(sponge iron). There are 1,114 induction furnaces with an aggregate capacity of 24.40 million tonnes. These units reportedly produced about 22.07 million tonnes steel in 2010-11 as againstproduction of 19.83 million tonnes in 2009-10. In this paper a scenario with higher proportion of DRI method was also analysed

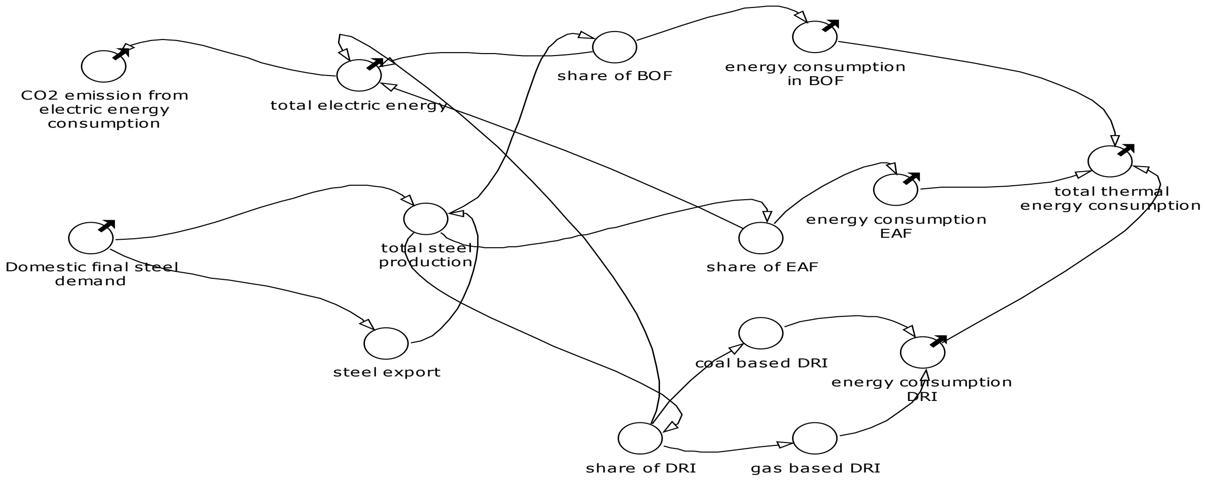

Figure 2: Total Thermal and Electric Energy Consumption Stock and Flow Diagram

Total CO_2 Emission

The total CO_2 emission can be analysed from the share of different steel production methods. The CO_2 emission due to BOF is 2.10 tonnes/tonnes of carbon steel, CO_2 emission from EAF is 1.18 10 tonnes/tonnes of carbon steel and CO_2 emission from DRI is 3.45 10 tonnes/tonnes of carbon steel for coal based and 1.57 10 tonnes/tonnes of carbon steel for gas based [1]. From the obtained data the emission forecast can be done using POWERSIM. From the data obtained it was concluded that the emission from BOF and the emission from coal based DRI is at higher rate compared to other production methods. It may be due to the reason of higher utilisation of coal as fuel. Proper allocation of these production processes can be utilised to mitigate emission level.

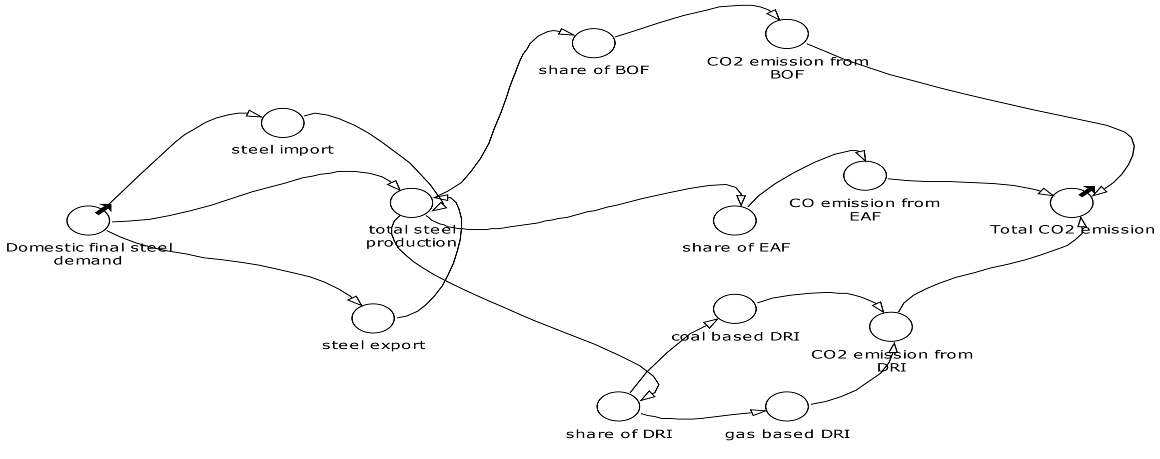

Figure 3: Total CO_2 Emission Stock and Flow Diagram

Model Validation

The values obtained from the models created were then validated using the historic data of steel production. From the data collection, it was found that the total steel production in the steel industries in the year 2001 was 29.27 million tonnes (from annual reports of ministry of steel) and the per capita steel demand was 29.8 Kg. The above value is taken as the initial value for the projection with the base year 2001 and the model estimates steel production and the per capita steel demand for the period 2001 to 2011. The model results give good agreement with the actual values as in

Figure 4 and figure 5. Points representing the actual and model values of steel production show an overall increasing trend.

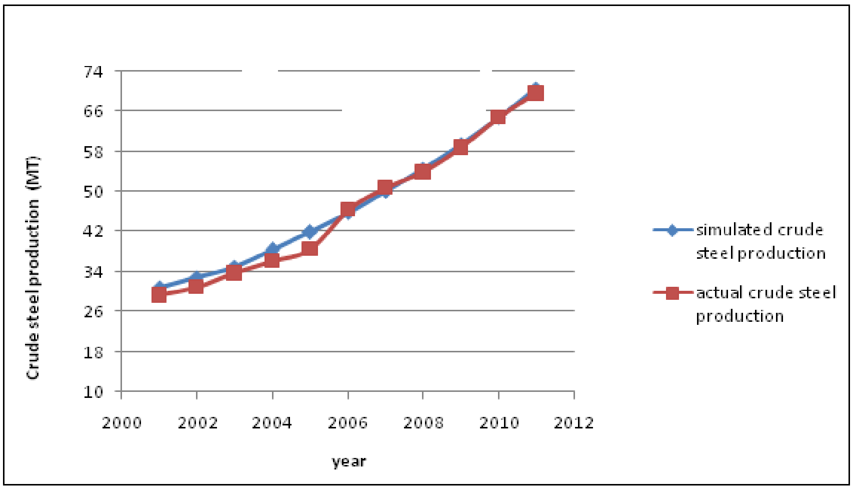

Figure 4: Comparison of the Quantity of Steel Production with Model Projection

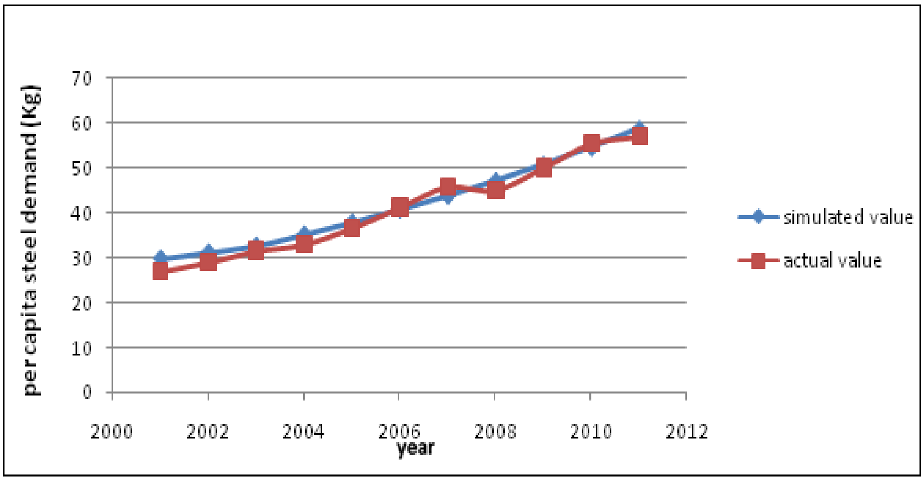

Figure 5: Comparison of the Per Capita Steel Demand with Model Projection

RESULTS AND DISCUSSIONS

The results of different scenarios of CO$_2$ emissions from the steel industries in India are discussed here. Trends are evaluated for a span of 20 years starting from the year 2011

Base Line Scenario

The rate of population growth and GDP as applicable in the year 2011 were kept as same as the actual rate and it was assumed that the population growth rate will be dipped to 1.1% after 2017 from 1.3% as on 2011.The GDP growth rate was taken as 8 % and was given a hike to 8.2% [18] after 2017. The technology employed in making the steel was kept unaltered. Using these options India's population is projected to reach 1528.52 million by the year 2031. The steel demand is shown in the Figure 6. The steel demand projected for the year 2030 by the model is 367.6 million tonnes and this is comparable to that of National energy map for India [14] (387 million tonnes in 2030) and by 15th Global iron ore and steel forecast [7] (374 million tonnes in 2030). The total thermal energy consumption by various production methods predicted for the year 2031 are shown in Figure 7. The thermal energy consumption predicted by this model in 2030 (6047x10^{15}J) is also comparable with TengfangXu [5] (6000x10^{15}J on 2030). The thermal energy consumption for BOF method is 4491.5 million GJ, whereas for EAF and DRI are 119.85 million GJ and 4821.727 million GJ respectively. The total thermal energy consumption was predicted to reach a value of 6603 million GJ at the end of 2031 (Figure 8). The total CO_2 emission are estimated to reach 1004.12 million tonnes by 2031 (Figure 9). This value is comparable to that of Saptarshi Mukherjee [11] (1070 million tonnes of CO_2 emission on 2031). The total electrical energy was predicted to reach 182735million KWhr (Figure 7).

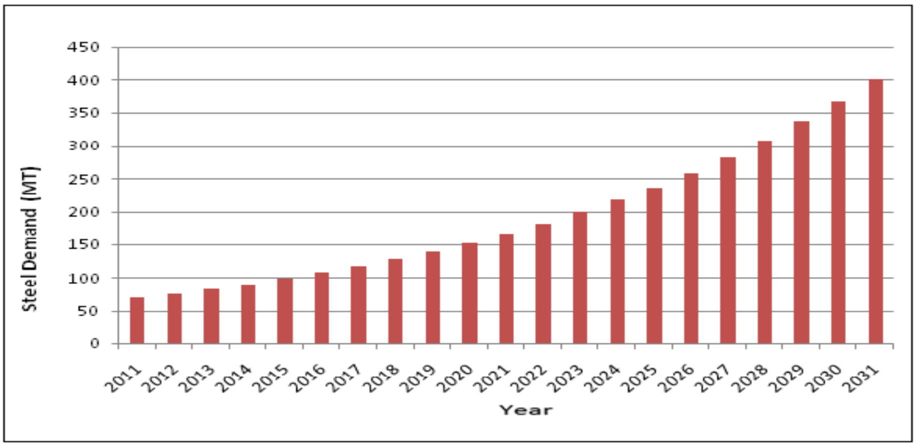

Figure 6: Projections for Domestic Steel Demand of India under the Baseline Scenario (BS)

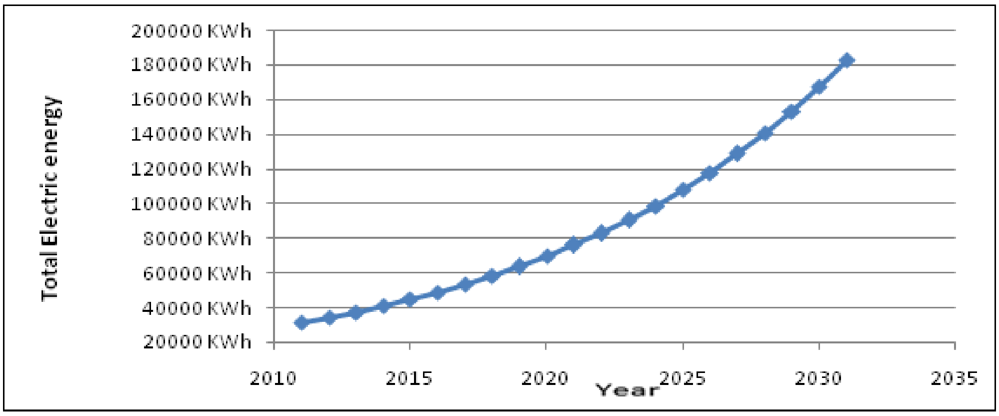

Figure 7: Projections for Electric Energy Consumption in Indian Steel Industries under the Baseline Scenario (BS)

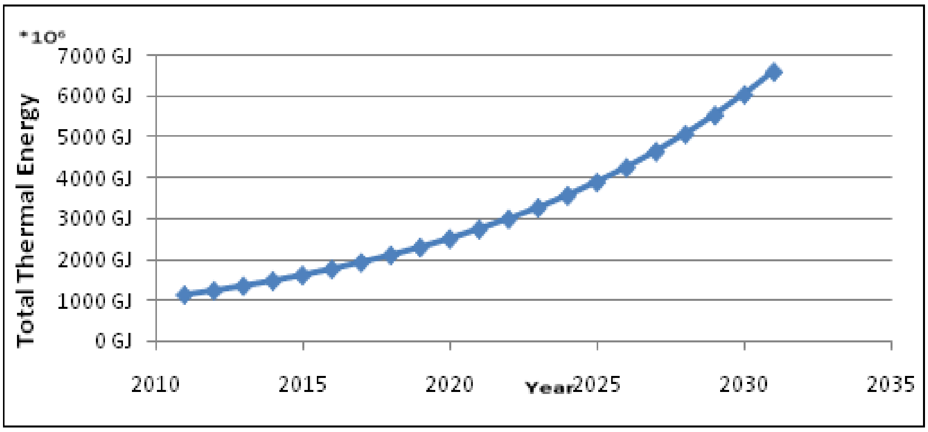

Figure 8: Projections for Total Thermal Energy Consumption of India under the Baseline Scenario (BS)

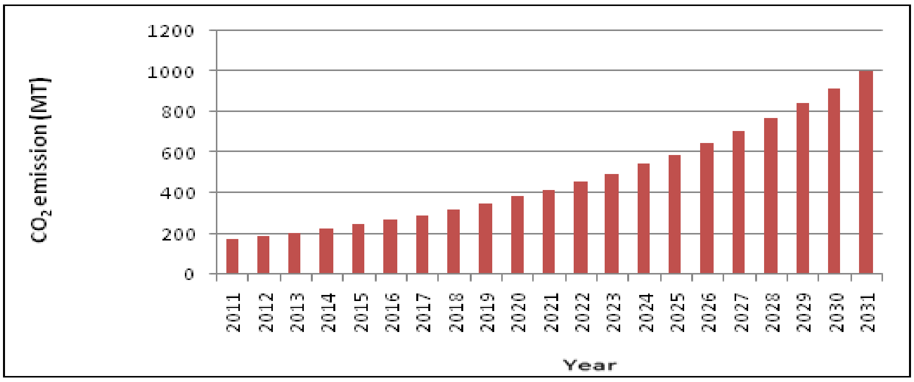

Figure 9: Projections for Total CO_2 Emission under the Baseline Scenario (BS)

Revised Scenario

The demand and production of steel is very much depended on population growth rate. The amount of CO_2 emission, electric energy consumption and thermal energy consumption were depended on steel demand. Hence one of the CO_2 mitigation opportunities is to regulate the population growth rate. Hence the effect of CO_2 emission are analysed in two modified scenario, Scenario-1 (S1) and Scenario-(S2). In Scenario 1 the population was assumed to reach saturation by the year 2025 and in scenario-2, a faster decline in population growth rate was analysed, where the growth rate reaches zero value by the year 2017.

Scenario-1 shows that the Indian population would reach 1429 million in the year 2031. The domestic steel demand for the year 2031 will be 375.53 million tonnes, a reduction of 6.37% from base line scenario. The electric consumption and thermal energy consumption for the required amount of steel production will be 171084.55 million KWhr and 6182 million GJ respectively. The thermal energy consumption forecasted in scenario-1 was shown in Figure 1. The amount of CO_2 emission on 2031 for scenario-1 was 940.105 million tonnes (Figure 13). In scenario-2 the population was assumed to reach saturation point (zero growth rate) by the year 2017. In this case a faster attainment of population was applied. The steel demand for the year 2031 in this scenario was 343.956 million tonnes (Figure 11). The electric and thermal energy consumption will be 156697 million KWhr and 5662.3million GJ respectively. The CO_2 emission in 2031 forecasted was 861.05 million tonnes. The emission levels are reduced to 14.23% from baseline scenario.

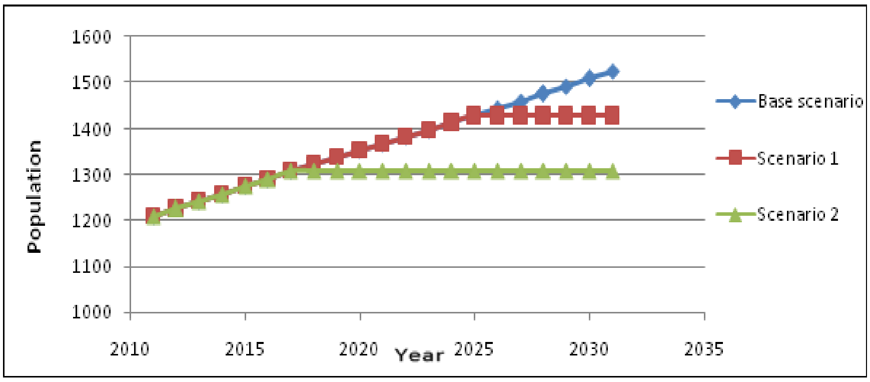

Figure 10: Projections for Population for the Baseline Scenario (BS), Scenario-1 (S1) and Scenario-2 (S2)

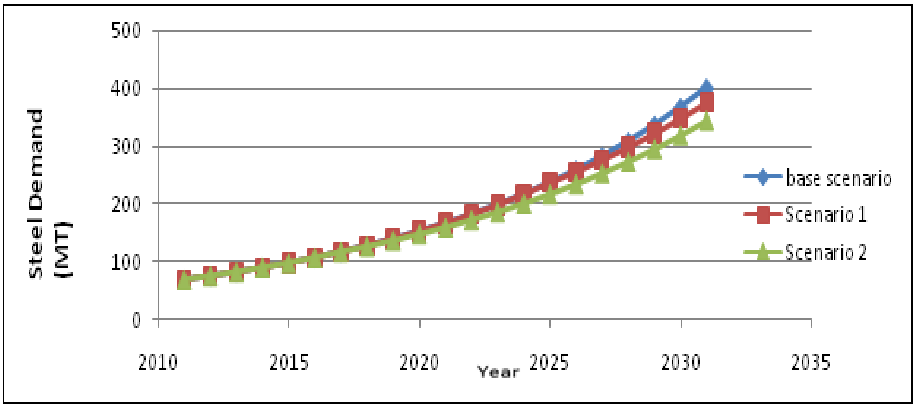

Figure 11: Projections for Domestic Steel Demand for the Baseline Scenario (BS), Scenario-1 (S1) and Scenario-2 (S2)

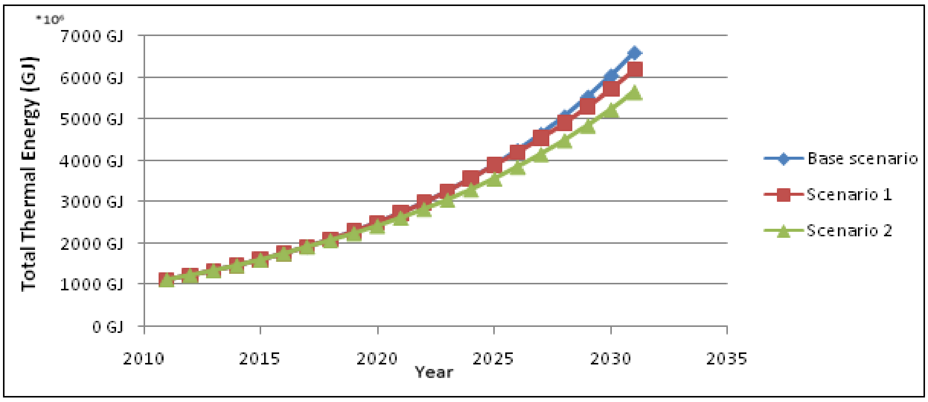

Figure 12: Projections for Thermal Energy Consumption for the Baseline Scenario (BS), Scenario-1 (S1) and Scenario-2 (S2)

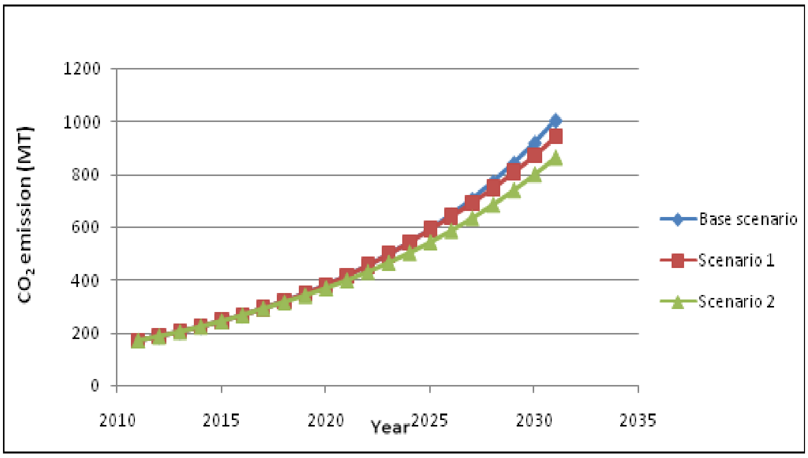

Figure 13: Projections for CO_2 Emission for the Baseline Scenario (BS), Scenario-1 (S1) and Scenario-2 (S2)

Energy Efficient Scenario

An energy efficient scenario was also analyzed on the created system dynamic model. In this scenario, a thermal energy recovery of 35 % was assumed compared to 30% in base ine scenario. The share of steel production methods are also altered for the efficient usage of energy. The share of BOF was taken as 45% (38.8% in base line scenario), share of EAF was taken as 20% (13.3% in base line scenario) and share of DRI was taken as 35% (48% in base line scenario) [17]. Figure 14 shows the reduction in CO_2 emission on different scenario when the energy efficient scenario is applied.The emission on 2031 was reduced to 942.71 million tonnes from 1004.12 in base line scenario.For scenario-1 and scenario-2 the emission level was reduced from 940.105million tonnnes to 882.62 million tonnesand 861.05million tonnes to 808.401million tonnnes respectively. A reduction of 5.3% in thermal energy consumption canbe achieve for base line scenario and a reduction of 12.1% in thermal energy consumption will be obtained for scenario-1 and scenario-2. CO_2 emiison on energy efficient scenario was found tohave a reduction of 6.1% compared with the base line scenario.

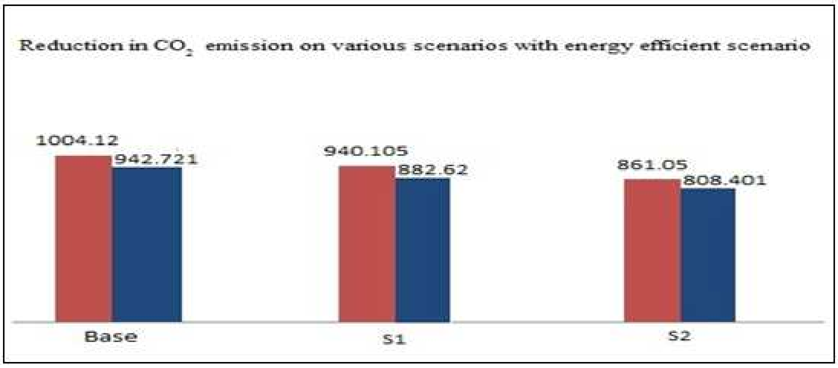

Figure 14: Projections for CO_2 Emission (Million Tonnes) for the Baseline Scenario (BS), Scenario-1 (S1) and Scenario-2 (S2) Compared with Energy Efficient Scenario on 2031

CONCLUSIONS

A base model for the projection of CO_2 emisission and energy consumption in indian steel industries for 20 years from 2011 was developed. The total CO_2 emission for the year 2031 was found to be 367.6 million tonnes and the total electric and thermal energy consumption wa found to be 182735 million KWhr and 6047 million GJ respectively.

The base model was then altered by providing mitigation stratergies for reduction of CO_2 emission. The emsission from the steel industries was depended on population growth rate. Models are created with varying population growth rate. From the analysis it was found that a combined scenario with population stabilization by the year 2017, 35% heat recovery and proper allocation of share for the various production proceses (BOF,EAF and DRI) the emission can be reduced by 19.4% after 20 years.

REFERENCES

1. Anjana das and Tara Chandra kandpal, (1997). Energy demand and associated CO_2 emission for the Indian steel industry.
2. A Ramesh, G Madhu and P A Soloman,(2013). System Dynamic Model to Forecast CO_2 emissions of Indian Cement Industries, International Journal of Environmental Engineering and Management Volume 4, Number 1, pp. 33-47
3. Department of Economics and Statistics, Demand of steel in India, (2006).Tata Service Limited
4. HongxuLi Daqiang Cang, Yunchi Guo, Hao Bai and Bei Jin, The analysis of energy structure of coal using and CO_2 emission of a typical steel industry

5. JaharRoy, Pinaki Sarkar, Subhashish Biswas and Ashim Choudhury (2009). Predictive equations for CO_2 emission factors for coal combustion, their applicability in a thermal power plant and subsequent assessment of uncertainty in CO_2 estimation, Fuel, pp.792–798.
6. KatjaSchumacher and JayantSathaye, (2011).India’s Iron and steel Industry: Productivity, Energy efficiency and carbon emission, pp.32-45
7. Magnus Ericsson, (2012) 15th Global iron ore and steel forecast.
8. Magnus Ericsson, 15th Global iron ore and steel forecast March 21st 2012 Perth WA, “China, India and the world market balance”
9. Mohapatra, P.K.J., Mandal, P., Bora, M.C., (1994). Introduction of System Dynamics Modelling. Orient Longman Hyderabad, India
10. MoM (Ministry of Mines), Government of India, Indian Minerals Yearbook (2011), Annual Report 2010–11.
11. Monica Dutta and Saptarshi Mukherjee, (2010). An outlook into energy consumption in large scale industries in India: The cases of steel, aluminium and cement, Energy Policy 38, pp. 7286–7298.
12. MoS (Ministry of Steel), Government of India, 2010–11., Annual Report 2010–11.
13. Nastaran Ansari and Abbas Seifi (2012), A system dynamic analysis of energy consumption and corrective policies in Iranian iron and steel industry, Energy 43, pp. 334-343
14. National Energy Map for India: Technology Vision 2030, (2006). ISBN 81-7993-099-8
15. Ran Rui, Weng Duan, (2006). $C0_2$ emission and reduction measures of steel production process in China," Science and Technology Review (in Chinese), no.10, pp.56-60, October 2006
16. Shalini Anand, PremVrat, R.P. Dahiya, (2005). Application of a system dynamics approach for assessment and mitigation of CO_2 emissions from the cement industry, Journal of Environmental Management
17. TengfangXu, NihanKaraliand JayantSathaye, (2014). Undertaking high impact strategies: The role of national efficiency measures in long-term energy and emission reduction in steel making, Applied Energy 122, pp.179–188
18. Twelfth Five Year Plan, Planning Commission, Government of India(2013), ISBN 978-81-321-1368-3
19. Yiping Zhu, Sectorial Study on the Iron and Steel Industry,
20. Wenjia Cai, Can Wang, Jining Chen, Ke Wang, Ying Zhang and Xuedu Lu, (2008). Comparison of CO_2 emission scenarios and mitigation opportunities in China’s five sectors in 2020, Energy Policy 36 1181–1194.