IIIEE Theses 2011:08

The proposed Perform Achieve and Trade (PAT) scheme in India

A policy evaluation

Arijit Paul

Supervisor

Naoko Tojo

Thesis for the fulfillment of the
Master of Science in Environmental Sciences, Policy & Management
Lund, Sweden, June 2011

MESPOM Programme:

Lund University – University of Manchester - University of the Aegean – Central European University

iiiee

Erasmus Mundus Masters Course in
Environmental Sciences, Policy and Management

MESPOM

This thesis is submitted in fulfillment of the Master of Science degree awarded as a result of successful completion of the Erasmus Mundus Masters course in Environmental Sciences, Policy and Management (MESPOM) jointly operated by the University of the Aegean (Greece), Central European University (Hungary), Lund University (Sweden) and the University of Manchester (United Kingdom).

Supported by the European Commission's Erasmus Mundus Programme

Education and Culture

Erasmus Mundus

IIIEE Theses 2011:08

© You may use the contents of the IIIEE publications for informational purposes only. You may not copy, lend, hire, transmit or redistribute these materials for commercial purposes or for compensation of any kind without written permission from IIIEE. When using IIIEE material you must include the following copyright notice: 'Copyright © Arijit Paul, IIIEE, Lund University. All rights reserved' in any copy that you make in a clearly visible position. You may not modify the materials without the permission of the author.

Published in 2011 by IIIEE, Lund University, P.O. Box 196, S-221 00 LUND, Sweden,
Tel: +46 – 46 222 02 00, Fax: +46 – 46 222 02 10, e-mail: iiiee@iiiee.lu.se.

ISSN 1401-9191

Acknowledgements

First and foremost I would like to thank my supervisor, Dr. Naoko Tojo for diligently guiding me through this thesis writing process. I thank Naoko for taking the pain of conducting extremely detailed review of each of my draft version and providing me with immensely valuable comments, which helped me to improve the content of the thesis after each of her review. Without Naoko's support the thesis could not have been completed.

I would also like to sincerely thank Dr. Lars Hansson. Lars despite being abroad took time out of his busy schedule and provided extremely valuable comments particularly on economic efficiency and cost-effectiveness aspect of the assessment. Lars's constructive comments helped me to bring more clarity into the assessment.

I express my sincere gratitude to all the people who has agreed to give me interviews for the purpose of my thesis. All of their input greatly helped in completion of my thesis. I particularly like to thank, Dr Avinash Patkar and Mr Ashok S Sethi from TATA Power, Mr Pranab Mondal from Essar Steel, Mr Aditya Kumar from Adhunik Metaliks Limited, Mr Ch Ankarao, Mr B Laxmi Prasad from GVK Power and Infrastructure Limited and Mr Saurabh Diddi from Bureau of Energy Efficiency.

To Susmita

Abstract

Perform, Achieve and Trade (PAT) scheme, proposed in 2008,is the first of its kind energy efficiency trading scheme in India. PAT aims for improving the energy efficiency in the eight most energy intensive large scale industrial sectors, covering almost 54% of the total energy consumption in India, through certification of energy savings which can be traded. This thesis seeks to provide an early insight into the design and functionality of PAT and its potential impact on the targeted energy intensive industries through an ex-ante evaluation. , It focuses on two of the eight sectors covered under the PAT scheme, namely, thermal power and iron and steel sectors during their first compliance period, which is from 2011 to 2014. Four criteria are chosen for the analysis: (i) design of PAT; (ii) economic efficiency; (iii) cost-effectiveness; and; (iv) assessment of barriers to energy efficiency improvement. . The result of the assessment reveals that PAT should be able deliver significant net positive socio-economic benefit to the society. However, in its first cycle it does not appear to promote cost-effective improvement in energy efficiency. The design of PAT scores well on simplicity and with respect to flexibility of compliance to designated consumers, however the main concern with the design are lack of a detailed monitoring and verification protocol and seemingly low level of penalty for non-compliance. The barrier analysis reveals that institutional and certain elements of technological barrier are the most important barriers which can potentially hamper the performance of PAT.

Keywords: PAT, energy efficiency, thermal power, iron and steel, India, Bureau of Energy Efficiency.

Executive Summary

Government of India has published its National Action Plant on Climate Change (NAPCC) on 30th June of 2008 (Government of India 2008).National Action Plan on Climate Change has formulated eight core missions. National Mission for Enhanced Energy Efficiency (NMEEE) is one among these eight missions.

Four initiatives have been prescribed under National Mission on Enhanced Energy Efficiency. Perform Achieve and Trade (PAT) scheme is one of these four schemes. PAT is first of its kind energy efficiency trading scheme in India. PAT aims for improving the energy efficiency in the most energy intensive large scale industrial sector in India through certification of energy savings which can be traded. PAT was scheduled to be officially launched on 1st April 2011 (BEE 2011)[1]. PAT covers eight major energy intensive industrial sectors, covering almost 54% of the total energy consumption in India as per 2007-08 national energy consumption figures (BEE 2011).

The PAT scheme is a market based scheme to facilitate improvements in energy efficiency among industries in a cost effective manner. Under PAT scheme, target specific energy consumption (SEC) will be specified for each industrial plant covered under the scheme. Plants exceeding their target energy efficiency will be issued energy efficiency certificates known as EScerts. These EScerts can be sold to those plants which fail to meet their respective energy efficiency targets. This facility of trading within the PAT scheme is provided with an aim to allow plants to meet their energy efficiency target in a cost effective way by equalizing the maximum marginal cost of energy efficiency improvement across the participating plants (BEE 2011).

PAT is the first of its kind market based instrument for energy efficiency improvements introduced in India. The literature with respect to use of market based instruments in relation to energy efficiency is limited in India. Considering the lack of assessment and experience in administering such mechanism in India, PAT provides an excellent research opportunity to further the understanding of the potential of market based instruments in India.

The aim of this thesis is to provide an early insight into the design and functionality of PAT and its potential impact on the targeted energy intensive industries. Four research questions were formed to guide the evaluation of PAT. These include the following;

Does the design of PAT incorporate the key elements of a well-functioning market based regulatory instruments?

What is the potential economic efficiency of the PAT scheme?

Does PAT promote cost-effective improvement in energy efficiency in the industry?

What are the potential barriers that can prohibit PAT in facilitating penetration of energy efficient technologies?

[1] The launch of PAT is currently being delayed, since the plant specific targets are yet to be approved by Law Ministry of India and BEE is working to fine tune some specific design elements of the PAT scheme (Climate Connect, UK 2011, Robins *et.al.,* 2011).

The focus of the thesis for evaluation is on the two of the eight sectors covered under PAT, namely iron and steel and the thermal power sector. The temporal scope of the thesis has been limited to the first cycle of PAT, that is, from 2011 to 2014.

The primary source of data collection for the thesis was through archival research. Limited number of interviews were also conducted to perform a reality check on the data obtained through archival research and to substantiate the analysis to the extent possible. The analysis of the data in this thesis is being carried out using the analytical framework formulated for the purpose of this thesis[2]. The method of triangulation has been chosen, to the extent possible, to increase the robustness of both the input data and the findings of the assessment. Official documents, academic publications and interviews were the primary means for the triangulation process.

An analytical framework was developed to guide the assessment of the PAT as per the four research questions formulated in the thesis. The two main element of this analytical framework are (i) elaboration on the basis of choice of each of the four assessment criteria and (ii) formulation of specific guiding questions under each criterion to define the specific scope of evaluation under each assessment criterion.

The design assessment of PAT reveals that PAT provides number of flexibility to designated consumers with respect to compliance options. This aspect together with the formulation of simple methodological rules with respect to baseline and target setting and compliance assessment are the positive features of the design. The main concerns with respect to design are the lack of a detailed monitoring and verification protocol and low level of penalty which is not found to be a sufficient deterrent to non-compliance. It is learnt during the research that Bureau of Energy Efficiency is currently in the process of preparing a detailed monitoring and verification protocol and is also considering to revise the penalty amount. Addressing these two concerns is deemed to be important to achieve satisfactory performance of PAT.

The evaluation indicates that if the two sectors comply with the energy efficiency target assigned to them, the same would provide significant net positive benefit to the society. Thus it can be said that PAT promises to improve energy consumption behavior in the industry in an economically efficient way.

The cost-effectiveness assessment of PAT indicates that there exist wide variation in the marginal cost of energy efficiency improvement between the thermal power and the iron and steel sector. However, at least in the first cycle of PAT, equalization of maximum marginal cost of energy efficiency improvement is not expected, due to setting of apparently easier level of target for energy efficiency improvements in these sectors. Thus the first cycle of PAT does not promise to enable cost effective energy efficiency improvement in the chosen sectors.

The potential for improvement of energy efficiency has been found to be substantial in both thermal power and the iron and steel sector. The role of PAT is expected to be important, considering PAT is the first regulatory instrument which mandates energy efficiency improvement in the large scale industrial sectors. However certain barriers, particularly the institutional and technological barriers are found to be the most important which can hamper the performance of the PAT in near future.

[2] See Chapter 3 for the details on analytical framework.

In general it can be said on the basis of the assessment, that PAT is a very promising instrument which has the potential to play a major role in providing momentum to the improvement of energy efficiency in Indian industrial sector. The most significant positive aspect of PAT is in its potential to provide substantial net positive socio-economic benefit to the society. However, this socio-economic benefit will be only realised if PAT achieves 100% compliance. Two most important issues which can hinder the 100% compliance level in near future are penalty for non-compliance and institutional barrier. The assessment reveals the present level of penalty does not appear to be a significant deterrent to non-compliance. In addition, institutional barrier with respect to capacity of Bureau of Energy Efficiency to administer the scheme can be a major hindrance to achieve 100% compliance. Further in future beyond the first compliance period, informational, financial and technological barriers can be a major deterrent for full compliance, unless efforts are taken to alleviate these barriers. Another drawback of PAT at least in its first cycle is the lack of ambitious target. This reduces the cost-effectiveness of the scheme. In absence of cost-effective compliance of energy efficiency targets, the least cost equilibrium outcome of PAT will be prohibited. This in turn will reduce the net positive socio-economic benefits to the society by increasing the total cost of compliance. The transaction cost has been estimated to be nominal in the present format of PAT. However, in future when the scope of PAT is expected to have wider sectorial coverage, unless various barriers are eased, the transaction cost will tend to be higher and in turn will impact both economic efficiency as well as cost-effectiveness of the scheme.

Table of Contents

List of Figures

List of Tables

Abbreviations

PAT: Perform Achieve and Trade

BEE: Bureau of Energy Efficiency

1 Introduction

1.1 Background

The role of energy is pivotal in the quest of human development. The advent of climate change, due to human induced greenhouse gas emission, as a result of the consumption of fossil fuels to meet the energy demand, has put the energy usage pattern of the mankind into serious question. There is now a global consensus that sustainable energy consumption which minimizes the rise of greenhouse gas emission in the atmosphere is of primary importance to mitigate the adverse impact of climate change. There is a greater realization globally that the adverse economic impact of climate change and the mode of energy generation and consumption are closely interlinked with each other. These realizations are bringing the debates of climate change, energy and economy closer to each other. As the world is debating the future of an internationally binding emission reduction agreement, various governments across the globe are increasingly looking to forge domestic policies that would help in attaining better harmonization of energy, environment and economy. A prime example is the EU wide so called “20-20-20” target. Through this target the EU is striving to achieve by 2020, (a) 20% emission reduction within EU as compared to 1990 level, (b) 20% energy consumption within EU from renewables and (c) 20% reduction in primary energy consumption as compared to projected levels through improvement in energy efficiency (European Parliament 2008). U.S., the second biggest greenhouse gas emitter after China (United Nations Statistics Division 2010), is also in the process of approving a climate and energy bill which aims to a better harmonization of energy, environment and economy (PEW Center on Global Climate Change “nd”). China, the biggest GHG emitter in the world, has implemented strict energy efficiency improvement targets for its industries. Further it is aggressively pursuing policies to promote growth of renewable energy generation domestically (National Development and Reform Commission, People’s Republic of China 2007). It has also voluntarily committed to reduce GHG emission per unit of GDP by 40%-45% by 2020 as compared to the 2005 level (Agriculture Carbon Market Working Group “n.d”).

The impact of climate change as it is seen elsewhere in the world is also visible in India. A report published by Ministry of Environment and Forest, Government of India (2010) indicates a rise in mean annual surface temperature in India by 0.4^{o}C, change in rainfall patterns across the nation, and, a rise in the sea level at the rate of 1.06 – 1.25 mm/year. Indian economy and the livelihood of the people in the Indian subcontinent are closely linked with climate sensitive sectors like agriculture, water and forestry, thus making India highly vulnerable to the impact of climate change.

India’s challenge in the energy front is also formidable. Nearly 600 million people in India do not have access to electricity (Ministry of Environment and Forest, Government of India 2007). With its overriding policy objective of eradication of poverty and inclusive growth, providing access to energy to all is of primary importance for India. The challenge for India is to sustain its rapid economic growth while simultaneously tackling the threat of climate change. India is ranked among the biggest and the fastest growing economies in the world and is currently the fourth largest economy in the world[3] with an average annual growth rate of 6.4% per annum during the period 2000-08, making it the second fastest growing, emerging economy in the world (USDA Economic Research Service 2009). This rapid growth rate is consequently fuelling a rapid rise in energy demand. According to Planning Commission of India (2005), in order to sustain the growth of Indian economy at the rate of 8%, the total

[3] http://presidentofindia.nic.in/sp250110.html

installed power generation capacity needs to be around 800,000 MW, by 2030, under business as usual (BAU) scenario. This is about an increase of 370% as compared to the current installed capacity of 170,000 MW (CEA 2010).

Considering the present trend of coal dominated power generation practice in India, continuation of the business as usual growth model of power generation will increase the per capita greenhouse gas emission level in India from the present level of 1.2 tons to 5 tons by 2030 (The Energy Resource Institute 2008). This increase in level of greenhouse gas emission is not desirable under the present threat of climate change owing to the continuous rise in the concentration of greenhouse gases in the atmosphere. Thus the challenge for India is to meet its energy demand while minimising the growth of greenhouse gas emission.

Faced with this dual challenge of climate change and energy poverty, the Government of India has now started to take steps towards better harmonization of environment, energy and economic policies. The first policy document in this regard is the National Action Plan on Climate Change (NAPCC), published in 2008 (Government of India 2008).

National Action Plan on Climate Change has formulated eight core missions to bring about the harmony in energy and climate policy. National Mission for Enhanced Energy Efficiency (NMEEE) is one among these eight missions.

The aim of National Mission on Enhanced Energy Efficiency is to harness the potential of energy efficiency improvements in the Indian economy. Energy efficiency, among other things, plays a crucial role in achieving a low carbon growth path for India. Planning commission (2005) estimated that through energy efficiency improvement 25,000 MW worth of capacity addition can be avoided by 2030.

National Mission for Enhanced Energy Efficiency strives to achieve improvement in energy efficiency in Indian economy through harnessing the market potential. Bureau of Energy Efficiency (BEE) together with Ministry of Power has been entrusted with the formulation and implementation of policy and programs under the National Mission for Enhanced Energy Efficiency (BEE 2011). Four initiatives have been prescribed under National Mission on Enhanced Energy Efficiency. Perform Achieve and Trade (PAT) scheme is one of these four schemes. PAT is first of its kind energy efficiency trading scheme in India. PAT aims for improving the energy efficiency in the most energy intensive large scale industrial sector in India through certification of energy savings which can be traded.

The focus of this thesis is on evaluation of PAT. The PAT was scheduled to be officially launched on 1st April 2011 (BEE 2011)[4]. PAT covers 8 major energy intensive industrial sectors, covering almost 54% of the total energy consumption in India as per 2007-08 national energy consumption figures (BEE 2011). The PAT scheme is a market based scheme to facilitate improvements in energy efficiency among industries in a cost effective manner. Under PAT scheme, target specific energy consumption (SEC) will be specified for each industrial plant covered under the scheme. Plants exceeding their target energy efficiency will be issued energy efficiency certificates known as EScerts. These EScerts can be sold to those plants which fail to meet their respective energy efficiency targets. This facility of trading within the PAT scheme is provided with an aim to allow plants to meet their energy efficiency

[4] The launch of PAT is currently being delayed, since the plant specific targets are yet to be approved by Law Ministry of India and BEE is working to fine tune some specific design elements of the PAT scheme (Climate Connect, UK, 2011; Robins *et.al.,* 2011).

target in a cost effective way by equalizing the maximum marginal cost of energy efficiency improvement across the participating plants (BEE 2011).

1.2 Research problem and research questions

In India like elsewhere in the world, the policy approaches towards environmental issues have been traditionally command and control driven (Gupta 2002). However as explained in the previous section the increasing convergence of the policy debate around the energy, environment and economy are motivating Government of India to look for newer ways in policy formulation to harmonise different policy elements of energy, environment and economy. Introduction of PAT by Government of India is a step towards this quest for the harmonisation, which is a first of its kind market based energy efficiency trading scheme in India.

The policy discourse on energy efficiency in India has been broadly located within the context of energy security of India (Bambawale and Sovacool 2011). The focus of this discourse has been primarily on impact assessment of existing energy policies (e.g., Nandi & Basu 2008; Yang 2006; Balachandra *et al.* 2010); discussion on barriers to energy efficiency improvement (e.g., Nagesha & Balachandra, 2006; Reddy A.K.N, 1991; Reddy B.S, 2003) and potential of energy efficiency improvements (e.g., Parikh *et al.,* 2009; Dutta & Mukherjee, 2010; Mallah & Bansal, 2009).

The importance of a well devised incentive structure to improve energy efficiency and thus the use of market based instruments in India has been acknowledged in the studies mentioned above; however a detailed elaboration on the same is missing.

In addition the literature on use of market based instruments in the context of India is concentrated on environmental pollution.[5] The literature with respect to use of market based instruments in relation to energy efficiency is limited in India. Gupta (2003) has explored the potential of the use of market based instruments in curbing India's rising GHG emission from fossil based energy consumption. Krishnan *et al* (2010) have identified a number of key issues with respect to the design of PAT in Indian context based on the reviews of similar scheme in rest of the world. However, their research was part of providing design input to the PAT scheme and not an evaluation of the same in post design phase.

As mentioned above PAT is the first of its kind market based instrument for energy efficiency improvements introduced in India. Considering the lack of assessment and experience in administering such mechanism in India, PAT provides an excellent research opportunity to further the understanding of the potential of market based instruments in India. Furthermore, considering that PAT covers 8 most energy intensive sectors in India, representing about 54% of total national energy consumption, the potential impact of PAT will be an important factor in realising India's quest for low carbon growth path.

The aim of this thesis is to provide an early insight into the design and functionality of PAT and its potential impact on the targeted energy intensive industries. Considering that neither

[5] Sawhney (1997) and Gupta (2002) argue for the use of market based instruments instead of command control measures to reduce pollution load from industries in India. Priyadarshini & Gupta (2003) argues in favour of market based instruments to improve the compliance level in the industries with respect to environmental norms. Kumar *et al* (1996) have suggested the use of market based instruments in reducing pollution load in Indian steel sector.

the government nor the industry has any prior experience with an energy efficiency trading scheme in India, the results of this analysis might prove to be useful in improving the understanding about PAT and use of market based instruments in general to them and also to the academic community. In addition, the results of the analysis might also be of interest to NGOs as well as to civil society.

The assessment of PAT scheme will be conducted on four fronts. These include the following.

1. Analysis of the design of PAT to assess if it incorporates the key elements of well-functioning market based regulatory instruments.

2. Analysis of PAT from the point of view of economic efficiency.

3. Analysis of PAT from the point of view of cost-effectiveness.

4. Analysis of the barriers to energy efficiency improvement and its potential impact on performance of PAT.

In order to guide the above mentioned analysis following research questions are formulated.

Research question 1:

Does the design of PAT incorporate the key elements of a well-functioning market based regulatory instrument?

Research question 2:

What is the potential economic efficiency of the PAT scheme?

Research question 3:

Does PAT promote cost-effective improvement in energy efficiency in the industry?

Research question 4:

What are the potential barriers that can prohibit PAT in facilitating penetration of energy efficient technologies?

Further justifications on the choice of these four elements of assessment are provided in the next section. A more detailed discussion on the characteristics of these four elements and their relevance to PAT is provided in Section 3, in which the analytical framework for the assessment of PAT is presented.

1.3 Scope

The scope of this thesis is defined under the following three categories. These are sectorial scope, temporal scope and the scope of criteria for evaluation.

Sectorial scope:

The first cycle of PAT covers 8 industrial sectors. These include: (i) thermal power stations, (ii) iron and steel, (iii) cement, (iv) fertilizers, (v) textiles, (vi) aluminium, (vii) paper and pulp, and (viii) chlor-alkali. Considering the time availability for completion of this thesis, analyzing all the eight sectors covered under the scheme is not feasible. In this thesis two of the above eight sectors are chosen for the evaluation. These two sectors are thermal power sector and iron and steel sector. Thermal power and iron and steel sectors together consume around 196.4 mtoe of energy per annum. This represents about 85% of the total annual estimated energy consumption of all the 8 sectors under the PAT scheme (BEE 2011), see the Figure 1-1 for details. Further, being the two most dominant sectors under the PAT scheme they would also potentially help to understand the cross sectorial dynamics and contrasting features between these two sectors.

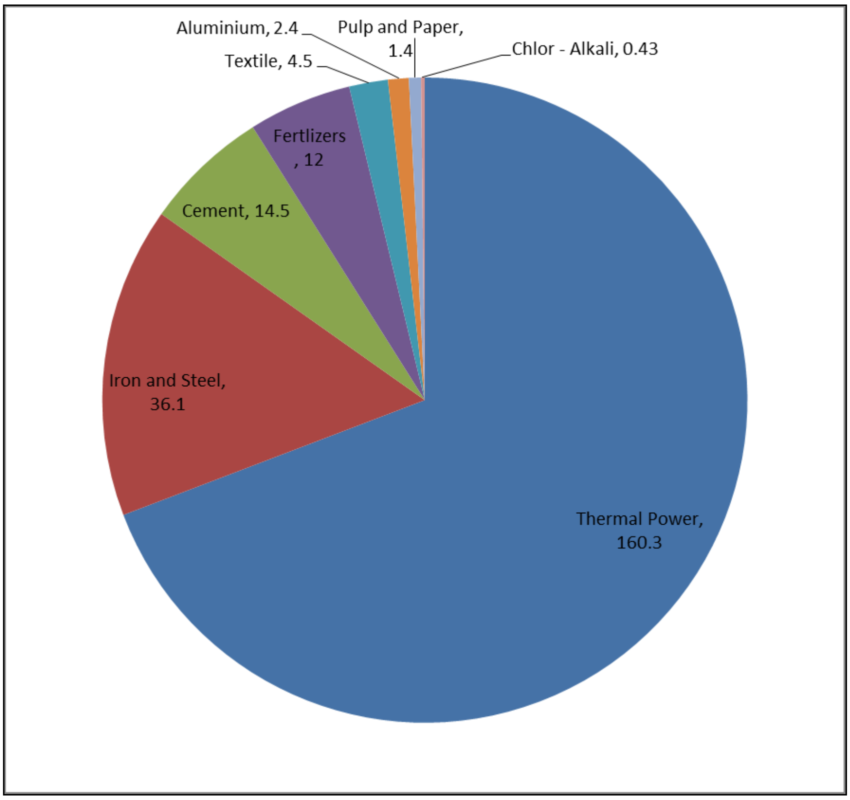

Figure 1-1 Average annual energy consumptions of industrial sectors under PAT in million tons of oil equivalent for the year 2007-08

Source: (BEE 2011)

Temporal scope:

The compliance period for PAT is fixed at 3 years. At the end of each cycle of 3 years, the targets would be reviewed and new targets would be set. The first PAT cycle was scheduled for the period of April-2011 to March-2014 (BEE 2011)[6]. The scope of evaluation of the PAT scheme in this thesis is chosen to cover the first PAT cycle only. Looking beyond the first PAT cycle at this stage of the thesis is not feasible since the particular features of second PAT cycles is not yet available.

Scope of criteria for evaluation:

Although literature on energy efficiency certificate trading schemes in the Indian context is not available, a number of studies have been done on similar schemes elsewhere in the world.

[6] The launch PAT is currently being dealyed, please refer to footnote 2.

Energy efficiency trading scheme are currently operating in a number of European countries. These include Belgium, France, Italy and The United Kingdom (Lees 2007). Studies of energy efficiency trading scheme in general mentions that energy efficiency trading schemes have the potential to achieve energy efficiency improvements in an economically efficient and cost-effective way (e.g., Bertoldi & Rezessy, 2006; Langniss & Praetorius, 2006; Monjon, 2006). Thus these two criteria are selected for evaluation with respect to PAT. Studies for energy efficiency trading scheme also points out that such schemes facilitates in penetration of energy efficient technologies (e.g., Langniss & Praetorius, 2006; Mundaca, 2007). Thus, the potential of PAT in catalyzing the implementation of energy efficient technologies is also envisaged to be assessed in this thesis to check the validity of this argument in Indian context. The choice of the assessment of design of PAT is based on studies, which indicate existences of certain key design elements are essential for a well-functioning market based instrument (e.g., Stavins ,2001; Hahn and Hester, 1989a; Mundaca and Neij, 2009). Another criterion which is identified by scholars as an important factor that impact the formulation of the energy efficiency trading scheme is the political acceptability (e.g., Monjon, 2006; Pavan, 2002). However this criterion is not chosen for assessment since the decision to launch PAT is already taken, which indicates a general political consensus on the political legitimacy of this scheme.

1.4 Methodology

This section of the thesis elaborates on the methodology adopted for the research conducted in this thesis. The methodology consists of data collection process and the data analysis process. In addition the limitations of the research process are also commented upon.

1.4.1 Data collection

The primary source of data collection for the thesis is archival research. Limited number of interviews have also been conducted to perform a reality check on the data obtained through archival research and to substantiate the analysis to the extent possible.

1.4.1.1 Archival research

The three main sources of information that constituted the archival research are (i) peer reviewed articles published in academic journals; (ii) information published by relevant government agencies; and; (iii) audited annual reports of listed companies.

The main inputs from the academic publications are used in the formulation of the analytical framework which guides the analysis conducted in this thesis. In addition, data from academic publications have also aided the actual analysis.

Information from government sources are the main inputs that constituted the bulk of the primary data analyzed in this thesis.

Part of the analysis, particularly for the iron and steel sector required certain individual company specific information. These have been obtained from the published audited annual reports of the relevant corporations.

1.4.1.2 Interviews

As mentioned above interviews are the secondary sources of information for this thesis. In total thirty two interview requests were sent. Of these thirty two requests, two were made to officials from the Bureau of Energy Efficiency and the rest were made to company representatives from thermal power and iron and steel sectors, through email. These names are obtained from the published list of attendees in the stakeholder consultations for PAT organized by Bureau of Energy Efficiency. Of these thirty two persons, eight persons showed interest to participate in the interview. However, finally only six interviews could be conducted; the rest of the two individuals could not provide time for the interview[7].

Of the six interviewees, three are from the thermal power sector, two are from the iron and steel sector and one is the representative of Bureau of Energy Efficiency. Five of the six interviews conducted are telephonic and one through Skype. For industry representatives, questionnaires are designed to understand the sector specific perspective with respect to PAT while keeping in view the objective of the thesis. For representative of Bureau of Energy Efficiency the questionnaire is designed to understand the regulatory perspective of PAT while keeping in view the objective of the thesis.

1.4.2 Data analysis

The analysis of the data in this thesis is done using the analytical framework formulated for the purpose of this thesis[8]. The method of triangulation is chosen, to the extent possible, to increase the robustness of both the input data and the findings of the assessment. Official documents, academic publications and interviews are the primary means for the triangulation process.

Archival research forms the backbone of the data collection to conduct the analysis. An overview of the existing information regarding the proposed thesis topic is conducted through archival research. A working bibliography of journal articles, books, and official documentations from Government of India, conference papers, audited annual reports of companies and other relevant materials is formed. These sources, identified as primary sources of information, are then researched and analyzed. The data gaps that are found during the process of the analysis are researched again through further archival materials. This cycle of archival research, which is followed by analysis and the revelation of data gaps and further archival research, is continued till the level of data gap is minimized to the reasonable extent possible. Figure 1-2 below provides a schematic representation of the data analysis process.

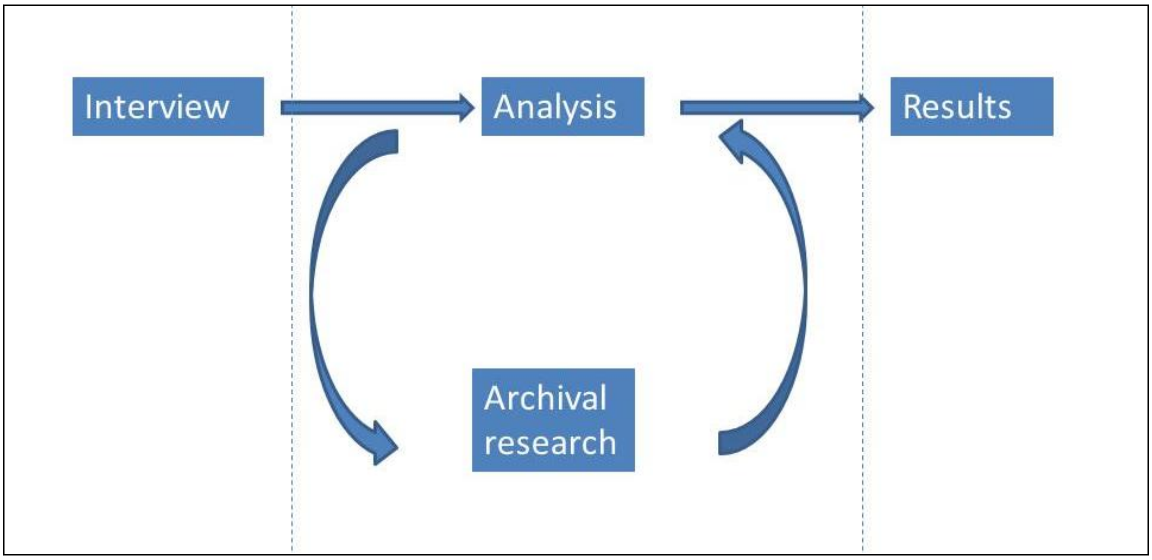

Figure 1-2 Data analysis

[7] Please see table 0-7 for the list of interviewees.

[8] See Chapter 3 for the details on analytical framework.

1.4.3 Limitation

There are a number of limitations that affect this thesis. The limitations exist both with respect to data collection and with respect to data analysis.

With respect to data collection from interviews, only 6 interviews could be conducted. Of these, 5 are representatives of the industries. Considering that PAT will cover about 247 industrial units in the thermal power and the iron and steel sectors, 5 interviewees represent about 2% of the total coverage in these sectors. Thus data obtained from the interviews can't be considered to be representative of these two sectors. To mitigate this limitation, efforts are made to validate the data obtained from the interviews through literature review, to the extent possible.

The triangulation of the data collected is performed to the extent made possible by the availability of information.

Efforts are made to obtain primary data to reduce the uncertainty associated with the use of the secondary data. However, it is not possible to follow this approach always. Fundamental research to construct all the input data used in this thesis is not possible due to time and resource limitation. Thus, during various stages of the analysis, results of other researchers are relied upon.

The data analysis is conducted using a macro approach. In doing this analysis, thermal power sector and the iron and steel sector each is assumed as one unit. However, this is not true in the practical sense. Intra-sectorial dynamics both within the thermal power and the iron and steel sector might have important factors affecting the outcome of the macro analysis conducted. This intra-sectorial dynamics was not investigated in this thesis and is kept out of the scope of research. However, efforts were made to comment upon this inter-sectorial dynamics during the archival research, whenever certain relevant information was obtained.

There is no consensus among the researchers on the single best policy evaluation framework (Mundaca & Neij 2009).Efforts are made to construct the analytical framework which best serves the research objectives. However, it needs to be mentioned, that this framework does not preclude adoption of another better framework to conduct an evaluation of PAT.

The limitations mentioned above are broadly the main limitations of this thesis. However, a number of specific limitations exist with respect to specific evaluation processes. These are mentioned at relevant sections of the analysis.

1.5 Structure of thesis

The rest of the thesis is structured as follows. Chapter 2 delineates the characteristics of the PAT. Chapter 3 describes the analytical framework. Chapter 4 consists of the actual ex-ante evaluation of PAT. This chapter is the most important component of the thesis, presenting the assessment of PAT and discussion on each of the four criteria of assessment. Finally, Chapter 5 makes some concluding remarks.

2 Characterization of PAT

In this chapter, firstly, some basic theoretical discussion is provided with respect to fundamental principles of market based instruments in general and within the scope of market based instrument some of the basic principles of energy efficiency trading scheme is discussed. This is followed by the presentation of the basic characteristics of the PAT scheme.

2.1 Market based instruments and energy efficiency trading schemes

In comparison to command and control approach, where industries are mandated to follow certain pre-determined technology or performance based environmental standards, market based instruments rely on market forces to encourage industries in mitigating environmental problems. It is argued that market based instruments allow industries more flexibility of compliance in comparison to command and control approach and if designed properly it encourages firms to reduce pollution in their own interests while helping to reach the overall policy goals (Stavins 2001).

Market based instruments can be of many types, tradable permit system is one of them. Tradable permits can again be classified in two types.

One is credit system and another is cap and trade system (Stavins 2001). Under credit system, credits are given in the form of permits when participants of the scheme exceed a predetermined norm specified by the regulator. These permits are then tradable among other participants of the credit scheme. This trading facility allows under achiever to comply with the specified norms by buying the credits from the over achiever and provides incentives to the over achiever through revenue generated by means of sale of the permits created.

Under cap and trade an overall limit of the targeted pollutant is first set and then they are allocated among the participants in the form of permits. The allocation can be either free or auctioned by the government. These permits are again freely tradable among the participants, providing incentives to those which remains below their allocated pollution permits through sale of their respective surplus allowances to participants who have overshoot their allocated pollution permits and are thus in deficit with respect to their allocated permits.

A number of examples exist of both types of systems particularly in the U.S. and in the EU. In the U.S. the examples of credit system includes EPA's emission trading program, lead trading program, heavy duty motor vehicle engine emission trading, water quality permit trading (Stavins 2001). In U.S. the examples of cap and trade program includes CFC trading, SO_2 allowance trading, state level NOx and VOC emission trading etc. (Stavins 2001). In the EU the example of credit system include tradable white certificates schemes in France, Italy and Great Britain (Mundaca and Neij 2009). In the EU the example of cap and trade system is the world's biggest GHG emission trading scheme in the form of EU- Emission Trading Scheme (EU-ETS) (Kossoy & Ambrosi 2010).

PAT is an instance of credit system. Under PAT scheme, target specific energy consumption (SEC) is specified for each industrial plant covered under the scheme. Plants exceeding their target energy efficiency are issued energy efficiency certificates known as EScerts. These EScerts can be sold to those plants which fail to meet their respective energy efficiency targets. This facility of trading within the PAT scheme is provided with an aim to allow plants to meet their energy efficiency target in a cost effective way by equalizing the maximum marginal cost of energy efficiency improvement across the participating plants (Ministry of Power and Bureau of Energy Efficiency 2008).

2.2 Key design features of PAT

The key characteristics of the PAT scheme are elaborated below under the following 16 elements. These elements are (1) legal framework; (2) Institutional structure; (3) sectorial scope; (4) energy threshold and eligible parties; (5) baseline; (6) target; (7) compliance period; (8) monitoring and verification ; (9) certificates ; (10) certificates' lifetime; (11) trading parties; (12) trading phase; (13) penalty; (14) scheme financing; (15) links with other schemes; and (16) additionality. Unless specified otherwise, the information as presented below, are from the PAT consultation document prepared by BEE (2011). The PAT consultation document, till date, provides the most comprehensive information on various aspects of PAT scheme. Thus, the same is considered as the base document for assessment of PAT.

(i) Legal framework:

The Energy Conservation Act (2001) is the first legislation that provided legal and institutional framework for issues related to energy conservation and energy efficiency in India (Nadi & Basu 2008). The legal framework of the PAT scheme is established by amending The Energy Conservation Act (2001). The amended law is designated as The Energy Conservation (Amendment) Bill (2010) (herein after referred to as the bill). The bill facilitates the implementation of the NMEEE and among other things also provides the legal foundation for the PAT scheme. The bill empowers BEE as the government agency who will be responsible for giving policy direction towards meeting the objectives as specified under the NMEEE, including PAT. The bill also provides the legal basis for the establishment of an Appellate Tribunal for settlement of disputes that might arise during the operational phase of the PAT scheme.

(ii) Institutional structure

The institutional structure for the governance of PAT is provided in the Figure 2-1 below.

The role of each of the stakeholders as presented in the Figure 2-1 below is briefly presented below.

Ministry of Power (MoP):

The Ministry of Power is the principal government agent with respect to development of electrical energy in India. Bureau of Energy Efficiency is a statutory body under Ministry of Power, instituted through the enactment of The Energy Conservation Act (2001). Ministry of Power together with Bureau of Energy Efficiency has been entrusted in formulation and implementation of the schemes covered under NMEEE. Ministry of Power has entrusted Bureau of Energy Efficiency for the governance of the PAT mechanism.

Bureau of Energy Efficiency (BEE):

The Energy Conservation Act (2001) instituted BEE to implement the provision of The Energy Conservation Act (2001). The role BEE with respect to PAT is that of market regulator and scheme administrator. Following are the roles and responsibilities of BEE with respect to PAT mechanism.

1. Setting of targets both at the sector level as well for individual plants, known as designated consumers under the PAT scheme for each cycle of the PAT scheme.

2. Accreditation of energy auditors, known as designated energy auditors who will perform independent compliance audit of individual designated consumers.

3. Issuance of energy efficiency certificates, known as EScerts based on audited PAT assessment document (PAD) by designated energy auditors.

4. Maintaining the overall integrity of the PAT system.

5. Periodically conduct performance assessment of designated energy auditors

6. Development of an electronic infrastructure to facilitate reporting, assessment and trading activity of the PAT scheme. This electronic infrastructure is termed as PATNET and is currently under implementation phase.

7. Co-ordinate among designated consumers, State Designated Authorities and designated energy auditors to facilitate smooth operation of the PAT scheme.

8. Maintain a central registry with complete information on deficit or surplus of energy efficiency certificates of designated consumers.

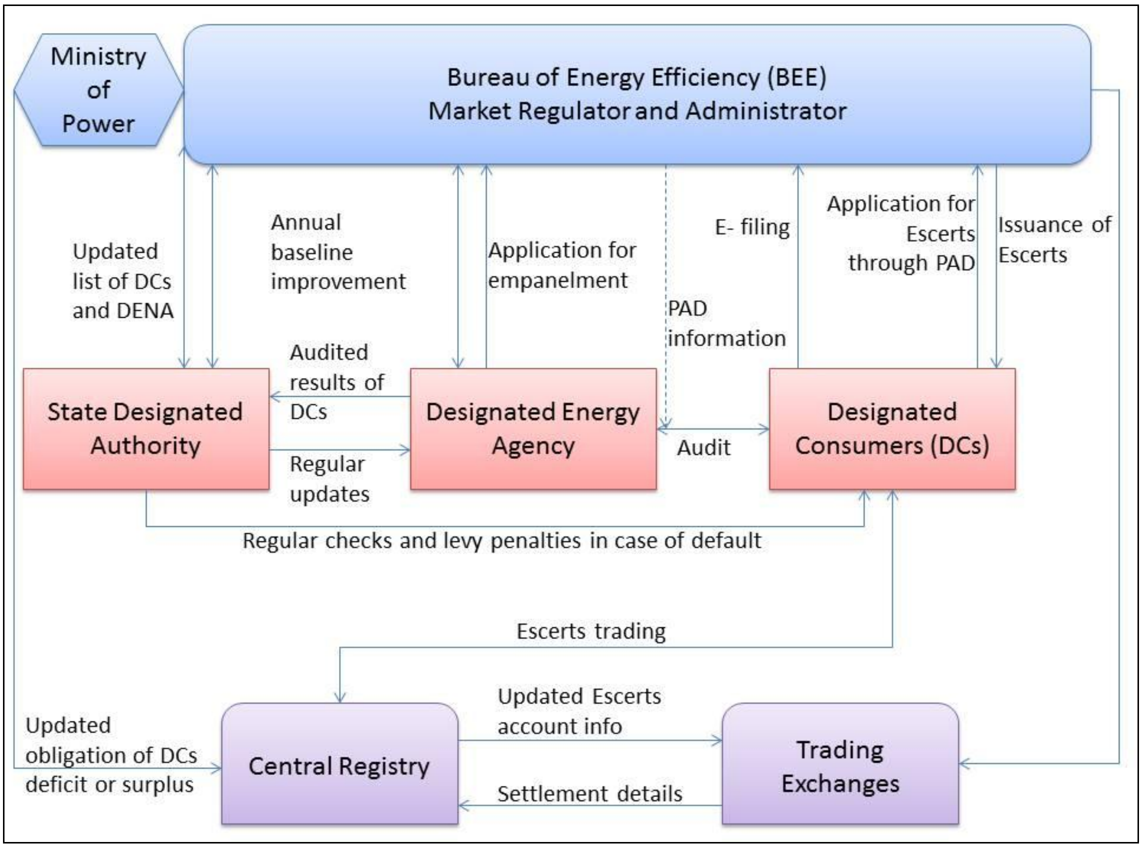

Figure 2-1 Schematic representation of PAT scheme

Source: BEE (2011)

State Designated Authority (SDA):

In India the regulatory regime of pollution control has a two tier approach. Central Pollution Control Board (CPCB) is entrusted with the formulation of specific pollution prevention norms under the guidance of relevant pollution prevention laws and State Pollution Control Boards (SPCB) has the authority to enforce these norms at respective industries and take punitive measures as and when necessary (Babu & Manasi 2007). For PAT state pollution control boards are given the responsibilities of State Designated Authority (SDA). The specific roles and responsibilities of SDAs are given below.

1. Coordinate with BEE to stay informed on number of designated consumers under their jurisdiction, the targets of individual designated consumers for each compliance period and on the details of the functioning of the designated energy auditors.

2. Assess compliance of designated consumers in consultation with designated energy auditors at their respective states.

3. Levy penalty on designated consumers in case of non-compliance as per the penalty norms set by BEE.

Designated Energy Auditors (DENA):

Designated energy auditors are the independent energy auditors accredited by BEE. They have the following two responsibilities.

1. Conduct independent audit of the PAT assessment documents (PAD) prepared by designated consumers for compliance assessment

2. Share the results of the audit with BEE and State Designated Authorities.

Designated consumers (DCs):

Designated consumers are the individual plants under 8 different sectors that are covered under the PAT scheme. Designated consumers are the obliged parties under PAT, who has to comply with its assigned mandatory target for energy efficiency improvement given by BEE. Below are the specific roles and responsibilities of the DCs.

1. Comply with the mandatory target as specified by BEE through following options.

    a. Through implementation of energy efficient technologies

    b. Through purchase of energy efficiency certificates

    c. Through a combination of both option (a) and option (b) as mentioned above

2. Prepare PAT assessment document (PAD) detailing its energy efficiency performance as per the regulatory requirements under PAT.

3. Appoint designated energy auditor for auditing of its energy efficiency performance with respect to PAT target.

4. Request BEE for issuance of EScerts, through audited PAT assessment document, in cases of overachievement of targets as specified under PAT for the respective compliance period.

5. Provide BEE with regular updates of its energy consumption figures during the compliance period.

6. Trade energy efficiency certificates if necessary, either directly with other designated consumers or through designated electronic trading platforms.

Trading exchange:

As per the PAT consultation document the trading of EScerts will be carried out in two trading exchanges. These are Power Exchange of India Limited (PXIL) and Indian Energy Exchange (IEX). The PATNET will ensure seamless electronic integration between central registry of PAT and these trading exchanges. The roles and responsibilities of these exchanges are given below.

1. Create efficient and transparent market for trading.

2. Facilitate trading of EScerts and thus help in price discovery of EScerts.

3. Safeguard market integrity and enhance transparency in operations

4. Maintain data of traded prices, traded volumes and trends

(iii) Sectorial scope

The PAT scheme covers 8 sectors, which together consumes around 232 million tons of oil equivalents (mtoe) of energy, which represents about 60% of the total national energy consumption in India. The sectors are (1) thermal power stations; (2) iron and steel; (3) cement; (4) fertilizers; (5) textiles; (6) aluminium; (7) paper and pulp; (8) chlor – alkali.

(iv) Energy threshold and eligible parties

The minimum energy consumption thresholds defined for selection of plants, for each sector, under the PAT scheme are given in table 2-1 below.

Table 2-1 Sector wise minimum energy thresholds and number of eligible plants under PAT

Sl No	**Sector**	**Energy consumption threshold (toe)**	**Number of Eligible plants/Designated Customer (DC)**
1	Thermal power plants	30,000	146
2	Fertilizer	30,000	23
3	Cement	30,000	83
4	Aluminium	7,500	11
5	Iron and Steel	30,000	101
6	Chlor – Alkali	12,500	20
7	Pulp and Paper	30,000	51
8	Textiles	3,000	128
Total			563

Source: BEE (2011)

(v) Baseline

The target would be set against a baseline Specific Energy Consumption (SEC), at each plant level. The baseline would be the average specific energy consumption for each plant during the 3 year period of April 2007 – March 2010.

(vi) Target

The target setting under PAT is being done using a two tier approach. First a sector wide target is fixed for each sector. Followed by the same this sector wide target is disaggregated among each of the plant, so that the total target from all the plants are equal to the sector wide target. The sector specific targets under PAT are provided in table 2-2 below. The total reduction target across all sectors for the first cycle of the PAT is about 10 mtoe.

Table 2-2 Sector specific energy efficiency targets under PAT

Sl No	Sector	Average annual energy consumption (mtoe)	Reduction target as a % of total average annual energy consumption
1	Thermal power plants	160.3	4.32
2	Fertilizer	11.95	4.25
3	Cement	14.47	4.14
4	Aluminium	2.42	4.58
5	Iron and Steel	36.08	4.32
6	Chlor – Alkali	0.43	4.65
7	Pulp and Paper	1.38	4.29
8	Textiles	4.5	4.44
	Total	240.53	4.31

Source: BEE (2011)

Due to the wide variation in the age of the equipment and the type of the product within each sector, plant specific target would be set, instead of, sector wide target. This variation in SEC has been defined as "bandwidth" for each sector. Plants will be classified in 3 to 4 groups within this "bandwidths". The best performers within a sector will have lower targets as compared to worst performers in the same sector. The table 2-3 below provides the estimated bandwidth of energy efficiency across different sectors covered under the PAT scheme along with the unit of measurements for the specific energy consumption.

Table 2-3 Estimated bandwidth of energy efficiency across various sectors covered under PAT

Sl No	Sector	Range of Specific energy consumption
1	Thermal power plants	2300 – 3400 kCal/kWh
2	Fertilizer	5.86 – 9.11 GCal/ton of Urea
3	Cement	665 – 900 kCal/kg of clinker (thermal) 66-127 kWh/tonne of cement (electrical)
4	Aluminium	15,875 – 17,083 kWh/tonne of Aluminium (smelter) 3.28 – 4.12 MkCal/tonne of Alumina

5	Iron and Steel	6.15 – 8.18 GCal/tcs (integrated steel plant) 4.4-7.6 GCal/tonne of sponge iron (thermal) 72 – 135 kWh/tonne of sponge iron (electricity)
6	Chlor – Alkali	2300 – 2600 kWh/tonne of caustic soda
7	Pulp and Paper	25.3 – 121 GJ/tonne of paper
8	Textiles	3000 – 16,100 kCal/ kg of yarn (thermal) 0.25 – 10 kWh/kg (electrical)

Source: BEE (2011)

The plant specific targets for the designated consumers are not yet available in public domain and thus not presented here. Further during the interviews conducted in the course of the thesis with the DCs, it is leant that the target setting exercise is still under process and none of the DCs at the time of the interviews have yet received their individual target.

(vii) Compliance period:

The three year period, April 2011 – March 2014, has been set as the first compliance period. The target specific energy consumption figures for the designated consumers have to be attained on the final year of the compliance period, that is, 2013-2014.

(viii) Monitoring and verification

Monitoring and verification under the scheme will be conducted by BEE accredited third party energy auditors.

(ix) Certificates

EScerts will be issued to those designated consumers which have exceeded their targets. The EScerts will be issued by the BEE. 1 EScert corresponds to 1 toe.

(x) Certificate's lifetime

The certificates' lifetime is 3 years, with a provision for banking for the next cycle upto 30% of the total EScerts received in the current cycle.

(xi) Trading parties

Trading parties are the designated consumers covered under the PAT scheme.

(xii) Trading phase

In the first cycle of the PAT the trading phase is the second and the third year of the 3 year cycle. In 1st year the trading is not allowed to help stabilization of the system.

(xiii) Penalty

Currently there are two component of penalty. One is a lump sum amount of INR 1,000,000 (USD 22,000 equivalent) and a daily fine of INR 10,000 (USD 220 equivalent) till the offence remains. However, during the interview with the BEE official, it is learnt that BEE is currently in the process of revising the second component of the penalty. The second part of the penalty will be based on the quantum of non-compliance. During the interview with the official of BEE, it is learnt that the second component of the penalty will be linked with the market price of the oil. The exact methodology for the same is still under process.

(xiv) Scheme financing

Energy Efficiency Financing Platform (EEFP), which is one of the four schemes within the National Mission for Enhanced Energy Efficiency has been envisaged to act as a facilitator to finance energy efficiency projects within PAT scheme.

(xv) Links with other scheme

EScerts will be fungible with renewable energy certificates generated from the recently launched Renewable Energy Certificates (REC) scheme in India.

(xvi) Additionality

Additionality will be addressed by setting targets which are over and above the average rate of improvement of energy efficiency at each plant.

3 Analytical framework

This chapter of the thesis elaborates on the analytical framework adopted to assess the PAT scheme on. The analytical framework is developed to guide the assessment of the PAT as per the four research questions framed in Section 1.2 of the thesis. The two main element of this analytical framework are (i) Elaboration on the basis of choice of each of the four assessment criteria and (ii) formulation of specific guiding questions under each criterion to define the specific scope of evaluation under each assessment criterion.

It needs to be mentioned that the four assessment criteria namely, (i) design of PAT, (ii) economic efficiency, (iii) cost-effectiveness and (iv) technology penetration are not mutually exclusive to each other. Each of these criteria in some way or other is interdependent and influences each other. For example, inter alia, the design of the PAT can have influence on the cost effective outcome of the PAT scheme and on transaction cost. Various barriers to energy efficiency implementation can impact both economic efficiency and cost-effectiveness. Efforts have been made in selecting the elements of assessment within each criterion on the basis of relative relevance of the element of assessment with respect to the principal criteria of assessment. The potential influences and interdependencies of the criteria are also discussed to the extent possible.

In the rest of the section, each of the chosen criteria is introduced, the relevance of the chosen criteria with respect to PAT scheme is discussed and the guiding questions for each criterion are presented.

3.1 Criterion 1: Design of PAT

The assessment of this criterion will be with respect to design of PAT and its efficacy in facilitating a satisfactory performance of the scheme. The research question for this criterion is presented below.

Research question 1:

Does the design of PAT incorporate the key elements of a well-functioning market based regulatory instrument?

PAT is the first of its kind energy efficiency trading scheme in the domain of environmental policy in India. Thus within India there is no precedence of a similar scheme. However internationally a number of such market based instruments are in place. Although each such market based instrument has different goals and objectives, studies indicate a number of common key elements necessary for a well-functioning market based instrument. Each of these criteria is described briefly below.

1. Flexibility:

One of the critical elements for success of market based instruments is the flexibility provided to the participants with respect to compliance alternatives, both in terms of temporal and technological options (Stavins 2001). For example provision for banking of allowances for SO_2 trading scheme has been identified as one of the key reasons for its success (Ellerman *et al.,* 1997). The same argument has been put forward by Kerr and Mare (1998) for the success of U.S. lead rights trading program. Further instead of technology standards, allowing industries the flexibility of the choice of technology has led to greater technological change (Burtraw, 1996; Ellerman and Montero, 1998; Bohi and Burtraw 1997) and higher innovation (Doucet and Strauss 1994).

Following guiding question is formed to assess this parameter.

How flexible PAT is with respect to compliance options to obliged designated consumers?

2. Simplicity:

Simplicity with respect to rules is another crucial element for success. Simple and transparent methodology for target setting and compliance assessment increases the efficiency of the scheme and reduces the transaction cost (Stavins 2001). Complex procedural requirements were identified as a reason for underperformance of US EPA's emission trading scheme in the 1970s (Hahn and Hester 1989b). Similarly simpler and transparent rules were considered as a success factor for the SO_2 trading scheme in U.S. (Rico 1995).

Following question is formed to guide the simplicity assessment.

Do the rules of target setting and compliance assessment in PAT follow simple methodologies?

3. Robust monitoring and verification system:

Stavins (2001) argues that the design of an effective robust monitoring and verification system is a very crucial element for the success of a market based schemes. Lack of credible monitoring and verification system might render a market based scheme ineffective and thus will not achieve its desired outcome in a satisfactory manner.

The guiding question to assess this design parameter is presented below.

Does PAT design provide a robust monitoring and verification protocol?

4. Penalties:

Strict penalties much higher than the marginal cost of abatement are crucial to ensure sufficient incentive for compliance. In the U.K. tradable white certificate scheme, the penalty is as high as 10% of the total turnover of the participating company. This high level of penalty has been found to be a major cause of high level of compliance in the U.K tradable white certificate scheme (Mundaca and Neij 2009). Similar experiences are also seen in SO_2 trading scheme in the U.S. (Stavins 1998).

Following guiding question is formulated to assess this parameter.

Would the level of penalty under PAT scheme provide sufficient deterrent to non-compliance?

3.2 Criterion 2: Economic efficiency:

This criterion is selected to assess how PAT facilitates economically efficient energy consumption behavior in the industries. The research question for this criterion is given below.

Research question 2:

What is the potential economic efficiency of the PAT scheme?

From a theoretical perspective of environmental economics an activity will be considered economically efficient, if the marginal cost of the economic activity equals the marginal benefits associated with the economic activity after factoring in the positive and/or negative externality associated with it, in other words when the socially optimum level of production coincide with the private optimum (Kumar *et.al.,* 1996).

The crux of the economic efficiency issue with respect to environmental policy is how the policy is designed to approximate the equilibrium point of social and private optimum.

This criterion is selected to assess the overall economic efficiency of the PAT scheme, including social and environmental impact of the scheme. The target of the PAT scheme is to save energy through improvements in energy efficiency. Through this process of energy savings, equivalent amount of carbon intensive energy production in India would be avoided. There exist a number of negative effects with respect to carbon intensive fossil fuel based energy generation. These include, effect on human health, negative impact of climate change on global ecosystems and all of their associated negative social implications (European Commission 2003). Thus energy savings through PAT scheme should indirectly provide the social and environmental benefits of avoided fossil based energy generation. In economic terms, these indirect positive benefits can be called avoided negative externality or in other words positive externality.

One important element that affects the economic efficiency of tradable permit schemes like PAT is transaction cost (Stavins 2001). Transaction cost the way it is perceived today in economic terms is first presented by Coase (1960). The indirect costs associated with any investments, necessary not for the production of the goods and services but for realizing the transaction have been identified by Coase as the transaction cost. Menard (2004) provides a characterization of various forms of transaction costs; these include costs of information search, contract negotiations, monitoring and verification etc. Higher transaction cost reduces the margin of benefit over cost and thus reduces the overall efficiency of a tradable permit scheme (Taylor *et.al.,* 2008). Transaction cost can prohibit the achievement of the desired least-cost equilibrium outcome of the same (Montero 1997). Analysis of EPA's emission trading scheme in U.S. have revealed that high transaction cost have negatively impacted the performance of the scheme (Hahn & Hester 1989b). Mundaca and Neij (2009) have identified perceived high transaction cost as a key element in lack of equalization of marginal cost in the Tradable White Certificate (TWC) scheme in UK.

Thus within the economic efficiency assessment of PAT, an attempt has been made to estimate the transaction cost of the PAT scheme. Transaction cost will constitute an input variable in the estimation of economic efficiencies of the PAT scheme.

In this thesis, the economic efficiency will be assessed on macro level for the entire sector for steel and power separately. The efficiency will be assessed on two fronts; (i) industrial efficiency and (ii) socio-economic efficiency.

Following three guiding questions are formulated.

What is the estimated proportion of transaction cost with respect to the total cost of energy efficiency improvement investment under the PAT scheme?

At what potential industrial efficiency will the thermal power and iron and steel sectors comply with the sectorial target under PAT?

At what potential socio-economic efficiency will the thermal power and iron and steel sectors comply with the sectorial target under PAT?

Industrial efficiency will be assessed through a cost-revenue analysis where the potential positive economic impacts of positive externalities are not accounted for. Cost-revenue analysis has been chosen, since it is often used by business organization in making investment decision (Jones & Butler 1988).

Socio- environmental analysis will be assessed through a cost-benefit analysis where positive social and environmental externalities will be accounted for. Cost benefit analysis has been selected, since, this is the prevalent tool adopted for conducting similar exercise (e.g., Rossi *et.al.,* 2004; Stavins 2004). A more elaboration on the positive externalities associated with the PAT scheme is provided during the assessment of this criterion.

3.3 Criterion 3: Cost effectiveness:

This criterion is selected to assess how PAT facilitates cost effective improvement in energy efficiency in the industries. The research question for this criterion is provided below.

Research question 3:

Does PAT promote cost-effective improvement in energy efficiency in the industry?

As discussed in the previous section, the economic efficiency of an environmental policy is dependent on the structure of the policy to facilitate the convergence of the socially optimum and private optimum level of operation of an economic activity. Theoretically if the marginal external cost to the society is known with certainty an environmental tax equal to the amount of negative externality would result in the desired convergence of social and private optimum and hence economic efficiency will be achieved. However in practice an exact estimation of such externalities is very difficult to obtain.

In absence of such exact estimation of an environmental tax, a "second best" approach to account for or internalize the negative externalities is through cost-effective means to achieve environmental improvements (Kumar *et.al.,* 1996). The cost-effective means of pollution control aims for equalization of maximum marginal cost of pollution abatement across all polluters.

Indeed, the NMEEE proclaims that, the primary objective of the PAT scheme is to enable industries to improve energy efficiency in a cost effective way (Ministry of Power and Bureau of Energy Efficiency 2008). In PAT each individual plant has the three options of compliance; (a) by investing in energy efficient technologies, (b) by buying the energy efficiency certificates and (c) by a combination of both investing and buying of certificates. From financial perspective the specific strategy of compliance chosen by each plant would be guided by their respective marginal cost of energy efficiency improvement. The marginal cost of energy efficiency improvement varies between different industrial sectors as well as between different plants within a sector. This difference is due to the variation of number of parameters that affects energy efficiency within each plant; such factors include variation in product mix, variation in raw materials, variation in age of the plant, variation in technologies etc[9]. It is envisaged that, the opportunity to trade would equalize the maximum marginal cost of energy efficiency improvement across the participating plants, thereby ensuring cost effective energy efficiency improvement across the targeted industrial sectors. Newell and Stavins (1999)

[9] Please see table 2-4 for an estimated variation of energy efficiency both between and within each sector covered under PAT.

argues that where the potential for energy efficiency improvements varies widely across sectors and thus results in heterogeneity of abatement cost, the success potential for a market based instruments are better. Heterogeneity of abatement cost has been identified as one of crucial success factor for the SO_2 trading scheme in U.S. (Stavins 2001).

In this section an attempt has been made to construct an indicative marginal cost curve for energy efficiency improvement for thermal power and steel sector. The difference in slope of marginal cost curve of energy efficiency improvement will provide some indication of which sector has the potential to be net buyer and who has the potential to be net seller. The steeper the marginal cost curve, the more likely is the scenario to be of a net buyer and vice versa.

The equalization of marginal cost will also largely depend on the level of trading activity. For example, in UK's energy efficiency trading scheme, this equalization of marginal cost does not occur due to limited trading activity (Mundaca and Neij 2009). Easily achievable targets have been identified as one of the key reason for low demand of energy efficiency certificates and hence the resultant low trading activity for the UK scheme.

With these factors in mind, the following two guiding questions are formulated to evaluate the potential cost – effectiveness of the PAT scheme.

What is the difference between the target energy efficiency and the average annual energy efficiency improvement for thermal power plants and iron and steel sector under the PAT scheme?

What are the indicative marginal cost curves of energy efficiency improvement for thermal power sector and iron and steel sector in India?

3.4 Criterion 4: Technology penetration

This criterion is selected to assess what role will PAT play in implementation of the energy efficient technologies. The research question for this criterion is presented below.

Research question 4:

What are the potential barriers that can prohibit PAT in facilitating penetration of energy efficient technologies?

The role of technology is important for successful implementation of PAT. In order to achieve the targets and to generate EScerts, industries need to implement energy efficient technologies. Two parameters are selected for evaluation of this criterion; (i) potential for energy efficiency improvement in the selected sectors; and; (ii) barriers to implementation of energy efficiency technologies. Further justification on the choice of these criteria is provided below.

(i) Potential for energy efficiency improvement:

The improvement of energy efficiency is possible to the extent where there exist potential for improvement in energy efficiency. Thus this criterion is chosen to assess how much potential of energy efficiency exists in the selected sectors. An assessment of the potential and its comparison with respect to the target for energy efficiency improvement under PAT will help to understand how important the role of PAT would be in realising the energy efficiency improvements in the selected sectors. Following guiding question is formulated to evaluate this criterion.

What is the potential for energy efficiency improvement for thermal power and iron and steel sectors in India?

(ii) Barriers to implementation of energy efficiency improvement

Despite a number of potential benefits of energy efficiency improvements, they are not always implemented by energy consumers. Researchers have identified a multitude of barriers, which prohibits the implementation of energy efficient technologies, despite its apparent technological and economic viability. Literature on barrier to energy efficiency improvement is extensive. Some key barriers to energy efficiency include, (1) Financial (e.g., Taylor *et.al.,* 2008; Painuly & Reddy, 1996; Painuly , 2009), (2) Technical (e.g., Painuly & Reddy ,1996; Nagesha & Balachandra, 2006; Reddy A.K.N, 1991), (3) Institutional (e.g., Taylor *et.al.,* 2008; Weber, 1997; Reddy A.K.N, 1991), (4) Informational (e.g., Taylor *et.al.,* 2008; Decanio, 1993; Painuly & Reddy, 1996).

An assessment of the four barriers as mentioned above is envisaged to be carried out in this section, particularly to analyse their potential impact on PAT with respect to its potential for penetration of energy efficient technologies. Following guiding question is formulated to guide the assessment.

What are the potential impacts of the barriers to penetration of energy efficient technologies under PAT?

3.5 The framework

Table 3-1 below presents the consolidated analytical framework as elaborated above.

Table 3-1 The Analytical framework

Sl No	Name of criterion	Research question	Guiding questions
1	Design of PAT	Does the design of PAT incorporate the key elements of a well-functioning market based regulatory instrument?	1. How flexible PAT is with respect to compliance options to obliged DCs?
			2. Do the rules of target setting and compliance assessment in PAT follow simple methodologies?
			3. Does PAT design provide a robust monitoring and verification protocol?
			4. Would the level of penalty under PAT scheme provide sufficient deterrent to non-compliance?
2	Economic efficiency	What is the potential economic efficiency of the PAT scheme?	1. What is the estimated proportion of transaction cost with respect to the total cost of energy efficiency improvement investment under the PAT scheme?
			2. At what potential industrial efficiency will the thermal power and iron and steel sectors comply with the sectorial target under PAT?
			3. At what potential socio-economic efficiency will the thermal power and iron and steel sectors comply with the sectorial target under PAT?

Sl No	Name of criterion	Research question	Guiding questions
3	Cost-effectiveness	Does PAT promote cost-effective improvement in energy efficiency in the industry?	1. What is the difference between the target energy efficiency and the average annual energy efficiency improvement for thermal power plants and iron and steel sector under the PAT scheme?
			2. What are the indicative marginal cost curves of energy efficiency improvement for thermal power sector and iron and steel sector in India?
4	Technology penetration	What are the potential barriers that can prohibit PAT in facilitating penetration of energy efficient technologies?	1. What is the potential for energy efficiency improvement for thermal power and iron and steel sectors in India?
			2. What are the potential impacts of the barriers to penetration of energy efficient technologies under PAT?

4 PAT Assessment

This chapter presents the assessment of PAT using the analytical framework developed in the previous Chapter. The assessment is carried out primarily through information obtained from literature review, information from government agencies and audited reports of stock listed companies. In addition inputs from interviews conducted are used both as a means to substantiate the assessment and to conduct a reality check of the findings of the assessment. The assessments of each of the four criteria followed by a discussion on the results of the assessments for each criterion are presented below.

4.1 Design assessment of PAT:

As explained in previous sections, the design assessment of PAT will constitute answering the following research question of the thesis.

Research question 1:

Does the design of PAT incorporate the key elements of a well-functioning market based regulatory instrument?

To answer the above question, four key design elements has been identified for assessment, these include flexibility, simplicity, monitoring and verification protocol and quantum of penalty. These were explained in detail in Section 3.1 above. Assessment of these four design element of PAT are guided by specific guiding questions for each element. Below presented is the assessment of this criterion with respect to each of the guiding questions. Unless specified otherwise, the primary source of all the information presented in this section is the "PAT consultation document" prepared by BEE (2011). This document, till date is the most comprehensive source of information on the design of PAT.

4.1.1 Flexibility assessment

Flexibility assessment is guided by the following question.

How flexible PAT is with respect to compliance options to obliged designated consumers?

The design of PAT does provide the flexible option of compliance to the designated consumers. Designated consumers have three options of compliance under the scheme. These are, (i) Invest in energy efficiency technologies; (ii) buy energy efficiency certificates; and; (iii) a combination of both of the first and the second option. In addition, the PAT does not mandate any technology standards for the designated consumers. Thus industry has the freedom to choose the technology in meeting the target. Further, there is a provision of banking in the PAT design. DCs can bank up to 30% of their additional savings certificates for two consecutive PAT cycles, that is, for a period of 6 years. In addition PAT makes EScerts fungible with renewable energy certificate scheme, which was recently launched by Government of India. During the interviews conducted with representatives of the industries, it is revealed that industry consider banking a welcome decision for two reasons. One is the ability to bank certificates and trade at a later period of time in a situation where the price of certificates becomes too low for the current trading cycle. Secondly for energy efficiency improvement certain investments have a payback period of more than 3 years, provision for banking allows for the incentivizing of such investments which goes beyond the one single PAT cycle of 3 years. The fungibility of EScerts is also welcomed by the industries and it is expressed this fungibility will allow industry more flexibility with respect to compliance of PAT under scenarios where the owner of the plant is also in the business of renewable energy generation.

4.1.2 Simplicity assessment

The guiding question for the simplicity assessment is the following.

Do the rules of target setting and compliance assessment in PAT follow simple methodologies?

As discussed in Section 3.1, simple rule for target setting and compliance assessment method are considered essential to reduce contestability and chances of manipulation of the system. The salient features of the rules for establishing the (i) baseline SEC, (ii) target setting, (iii) compliance assessment and; (iv) normalization process are briefly described below.

(i) Baseline specific energy consumption:

The baseline specific energy consumption will be calculated as per the following formula.

$$SEC = \frac{Total\ energy\ input\ to\ the\ plant\ boundary}{Quantity\ of\ the\ product} \qquad (1)$$

In addition following guidance is provided for the estimation of the baseline energy efficiency.

(a) The total energy input would be the normalized average of the baseline period 2007-2010

(b) All forms of energy except renewables will be considered as energy input

(c) What constitute product is clearly defined in the methodology. For power sector it is electricity measured in Million kWh. For integrated steel sector it is crude steel measured tons.

(ii) Target setting:

As explained before in Chapter 2, first of all PAT has a broad sector specific targets. Further these broad targets are disaggregated at each individual plant level within a sector, such that the total savings from all the plants within a sector is equal to the sector wide target. The decision to set plant specific target has been taken to avoid complexity of adjustment with respect to individual plant specific characteristics, such as, age of plants and machinery, technologies, raw materials, product mix, which might have been required in case a common sector specific target was to be mandated. Further it is believed that plant specific target would also minimize any intrinsic technological barriers that might prohibit achievement of the targets. The basic philosophy for target setting is to give the lowest target to the best performing plant and highest target to the worst performing plant with respect to energy efficiency. The methodology for target setting is same for all sectors except for power plants. Both of these methodologies are presented below.

(a) The methodology for target setting other than the power sector:

The target for each individual plant will be fixed according the following formula.

$$Target\ for\ reduction = \frac{Plant\ SEC}{Best\ SEC} * X \qquad (2)$$

Where,

X = reduction target in % for the best performing plant

The "PAT consultation document" provides detailed illustrative examples of target setting procedures.

(b) Methodology for target setting of power sector:

For power sector the principle of target setting is based on the deviation from operating efficiency from the design efficiency. For plants which are operating at much lower operational efficiency than the design efficiency, the target is higher and for plants operating close to the design efficiency the target is lower. The range of target depending upon the variation of operational heat rate from design heat rate is provided in table 4-1 below. As mentioned before heat rate is the chosen parameter for energy efficiency in power plant under the PAT mechanism.

Table 4-1 PAT target setting for thermal power plant (BEE 2011)

Variation in net station heat rate from design heat rate	Reduction target for %deviation in the net station heat rate	% reduction target in net station heat rate
Up to 5%	10%	0.5
More than 5% and up to 10%	15%	0.75 to 1.5
More than 10% and up to 20%	20%	2 to 4
More than 20%	25%	5 and above

Source: BEE (2011)

(iii) Compliance assessment: The formula for compliance assessment under PAT scheme is the following.

$$Energy\ savings = P_{base year}\,(SEC_{base year} - SEC_{target\ year}) \qquad (3)$$

Where,

$P_{base\ year}$: Production in base year

$SEC_{base\ year}$: Specific energy consumption in the base year

$SEC_{target\ year}$: Specific energy consumption in the target year

The base year has been fixed at 2009-2010[10]. If the energy savings as per the above formula becomes negative, then the respective designated consumers have to meet the shortfall either by buying the certificates or by paying the penalty.

(iv) Normalization procedure:

[10] It is important to distinguish between base year and baseline period. Baseline period is 2007-2010; baseline data is used to fix the target. The base year is fixed at 2009-10, for the purpose of compliance assessment.

The PAT mechanism provides for normalization of data before they are used for both target setting as well as for compliance assessment. The normalization option is provided to avoid penalizing DCs under circumstances where the specific energy consumptions are affected by factors which are beyond the control of the DCs. As of now the normalization process for each sector is yet to be finalized. The consultation document mentions that a scientific methodology is currently being developed to provide detailed rules for normalization process for each sector covered under the PAT scheme. The consultation document provides the following factors will determine the normalization procedures (BEE 2011).

(a) Natural disaster

(b) Rioting or social unrest

(c) Acute shortage of raw materials

(d) Major change in government policy

During the interviews conducted with the designated consumers, representatives of both thermal power sector and iron and steel sector have generally expressed their satisfaction with respect to methodology related to baseline fixation, target setting and compliance assessment procedure. They particularly appreciated BEE for setting plant specific targets, instead of a common sector specific target. However, they expressed concern about the methodology for normalization process, which is yet to be finalized.

4.1.3 Monitoring and verification protocol assessment

Monitoring and verification protocol assessment has been guided by the following question.

Does PAT design provide a robust monitoring and verification protocol?

The PAT consultation document acknowledges the importance of monitoring and verification, and lays out the basic system of monitoring and verification. The basic structure of monitoring and verification can be seen in Figure 2-1. The report detailing the energy consumption figures and the resultant specific energy consumptions has been designated as the PAT assessment document (PAD). EScerts will only be issued to DCs, if the audited PAT assessment document by an accredited designated energy auditor reports overachievement of the targets by the respective designated consumer. The PAT consultation document provides the principles to be used for of validation and verification. These include the following; (i) consistency, (ii) transparency, (iii) impartiality, and, (iv) confidentiality. BEE is yet to publish a detailed monitoring and verification protocol. Further during the interviews with the representative of the BEE it is learnt, that BEE is currently in the process of producing a detailed monitoring and verification protocol. Since the detailed monitoring and verification protocol is yet to be developed, it is difficult to comment on its robustness at this stage.

4.1.4 Penalty assessment

Guiding question for the penalty assessment is the following.

Would the level of penalty under PAT scheme provide sufficient deterrent to non-compliance?

As discussed in Chapter 3, strict penalties are considered to be an important element in providing sufficient disincentive for non-compliance. The penalties under PAT scheme as of now consist of a onetime lump sum fine of INR 1,000,000 (USD 22,000 equivalent) and a daily fine of INR 10,000 (USD 220 equivalent) till the offence remains. During the interview few designated consumers have expressed that this penalty is indeed very low and might not be enough to discourage non-compliance. Others, while acknowledging that the penalty is low, have stressed on the point that for the first cycle when industry does not have any experience in such a tradable scheme a very high penalty might be disadvantageous for the industry. However the general consensus remains that the level of penalty is low and hence this might be a problematic area with respect to compliance attainment under PAT scheme. Dube *et.al* (2011) in a discussion paper on PAT also reiterates the same. During the interview with the representatives of BEE, it is learnt that BEE has taken cognizance of this issue and is in the process of revising the penalty clause.

4.1.5 Discussion on PAT design assessment

From the above assessment of PAT design, it can be said, that PAT scores well in terms of flexibility and simplicity aspect of the design. However, within the element of simplicity of design, ambiguity remains with respect to normalization process, since it is yet to be fully developed. With respect to monitoring and verification protocol no judgment could be passed at this moment, since, the same is still under the process of development. On the level of penalty it can be said, that it can't be considered as a significant deterrent to compliance in its present form, hopefully the revised penalty will be more effective.

In conclusion it may be said that, concerns remains with respect to design aspects of PAT particularly with respect to monitoring and verification protocol and penalty amount and to some extent with the methodology of normalization. The success of PAT will be dependent upon alleviation of these concerns by careful design of these aspects of PAT by BEE.

4.2 Economic efficiency assessment of PAT

The assessment of economic efficiency of PAT will constitute answering the following research question of the thesis.

Research question 2:

What is the potential economic efficiency of the PAT scheme?

As discussed in Section 3.2, the economic efficiency assessment of PAT will be conducted by analyzing the following three parameters.

1. Transaction cost
2. Industrial efficiency
3. Socio-economic efficiency

Internal rate of return (IRR) has been chosen as a tool to estimate both industrial and socio-economic efficiencies. Transaction cost will be an input variable in the assessment of the respective IRR.

Following formula will be used to measure the sector specific IRR for iron and steel and thermal power plants. The calculation is carried out using standard excel function IRR ( ).

$$\sum_{n=0}^{N} \frac{C_n}{(1+r)^n} = 0 \qquad (4)$$

Where,

n : Number of years varying from 0 to N

N : N is assumed to be 6 years

Cn : Net cash flow for the year n[11]

r : IRR

The assessment of transaction cost, industrial efficiency and socio-economic efficiency are guided by specific guiding questions. In the following sections first the guiding questions are presented, followed by the assessment.

4.2.1 Transaction cost assessment

The transaction cost assessment is guided by the following question.

What is the estimated proportion of transaction cost in the total cost of energy efficiency improvement investment for thermal power plants and integrated iron and steel sector under the PAT scheme?

As explained in Section 3.2, the transaction cost constitutes all the indirect cost associated with the actual production of goods and services. For PAT following cost heads are considered as part of the transaction cost[12].

1. Cost of information search and assessment for identification of energy efficient technologies.
2. Cost of due diligence and negotiation for finalization of contracts.
3. Cost of baseline energy efficiency audit.
4. Cost of monitoring and verification during the compliance assessment period.
5. Cost of setting up the trading platform for PAT
6. Administrative expenses for governance of PAT
7. Financial provision for partial risk guarantee fund and venture capital fund for PAT

The first two components of transaction costs, as mentioned above are in general valid for any energy efficiency improvement investment scheme. Studies on energy efficiency improvement potential in Indian economy however only provide qualitative assessment of the first two component of the transaction cost. In general the assessments states that the transaction cost related to information search and due diligence with respect to contract negotiation is higher

[11] Net cash flow is the difference between total cost and total revenue or benefit in a given year.

[12] Another form of transaction cost that impact the investment in energy efficient technologies is the transaction cost borne by financial institutions such as banks, donor funds etc. This transaction cost is not considered within the estimation of economic efficiency assessments, since this transaction cost would be dependent on the estimated quantum of debt financing requirement for PAT and such estimation is not performed in the thesis. However, a discussion on this form of transaction cost is presented in the barrier assessment in Section 4.4.2.1.

for household sector and small and medium size industries and is much lower for large scale industries (e.g., Banerjee, 2005; Painuly, 2009; Taylor *et.al.,* 2008). Considering PAT is applicable at its current form only for the large scale energy intensive industries (BEE 2011), the transaction cost with respect to information search and due diligence for contract negotiation is expected to be small. This assumption is further supported during the interviews conducted with the representatives of the thermal power and iron and steel sectors. Considering the same, the transaction cost for the information search and contract negotiation is considered negligible and is not taken into account in estimation of economic efficiency[13].

The estimation of the cost of the components 3 to 7 for PAT cycle 1 has been provided in the NMEEE mission document (Ministry of Power & Bureau of Energy Efficiency 2008). These values are provided in the Table 4-2 below.

Table 4-2 Transaction cost of PAT

Item No	Cost head	Value (USD equivalent)[14]
1	Mandatory baseline survey for all designated consumers (non- recurring cost)	10,195,556
2	Setting up of trading platform for PAT mechanism (non-recurring cost)	1,111,111
3	Provision of partial risk guarantee fund and venture capital fund for enhancing energy efficiency (non-recurring cost)	37,777,778
4	Monitoring and verification of DCs for ensuring credibility of PAT mechanism (annual cost)	1,022,222
5	Other administrative expenses (annual cost)	666,667

Source: Ministry of Power &Bureau of Energy Efficiency (2008)

The transaction cost is not separately estimated for thermal power and steel sector. Instead total transaction cost of the PAT scheme is estimated as a percentage of the total estimated investment in PAT scheme. The same percentage of transaction cost is used for the estimation of respective economic efficiencies for both thermal power and steel sector.

Following formula has been used to estimate the percentage of transaction cost.

$$Pt = \frac{C_N + C_R \, x \, n}{I_T} \qquad (5)$$

Where,

Pt : Transaction cost expressed as a percentage of total investment in the first cycle of PAT

C_N : Total non - recurring transaction cost for first cycle of PAT (summation of item 1 to 3 in Table 4-2

[13] This form of transaction cost is particularly sensitive with respect to informational barrier. Please see Section 4.4.2.4 for a more detailed discussion.

[14] Original values were in INR. They were converted to USD equivalent with the current exchange rate of approximately @ INR 45/USD.

C_R : Total annual transaction cost for the first cycle of PAT (summation of item 4 and 5 in Table 4-2)

n : Duration of first cycle of PAT in years. The value of "n" is 3

I_T : The total estimated investment for PAT in its first cycle

The total estimated investment in PAT cycle 1 is 6.8 billion USD equivalents (Ministry of Power & Bureau of Energy Efficiency 2008)[15]. The estimated transaction cost using the formula (5) works out to be around **0.80%** of the total estimated investment under PAT scheme in its first cycle.

4.2.2 Industrial efficiency assessment

The guiding question for the industrial efficiency assessment is the following.

At what potential industrial efficiency will the thermal power and iron and steel sectors would comply with the sectorial target under PAT?

As discussed in Section 1.3, the scope of this assessment is limited to the thermal power and iron and steel sectors. First the assessment with respect to thermal power sector and then the assessment with respect to the iron and steel sector are presented below.

4.2.2.1 Industrial efficiency of thermal power sector:

In estimation of industrial efficiency of the thermal power sector under the PAT scheme, IRR of the entire thermal power sector is estimated from a cost-revenue perspective. That is, no economic benefit of potential positive externality is accounted for.

The total installed capacity of thermal power sector in India is 110 GW, which corresponds to about 65% of the total generation capacities in India. Within the thermal power sector coal is the predominant fuel, with 92 GW of installed capacities, contributing about 83% of the total thermal power generation. The fuel mix of energy generation in India is presented in Figure 4-1 below.

[15] Singh *et.al* (2011) estimates annual investment under PAT at about USD 2.6 billion, which translates to about 7.8 billion USD for the first cycle under PAT. However, this figure is not considered for estimation, since the Government estimate provides more detailed sector specific cost estimates and thus the same is taken into consideration.

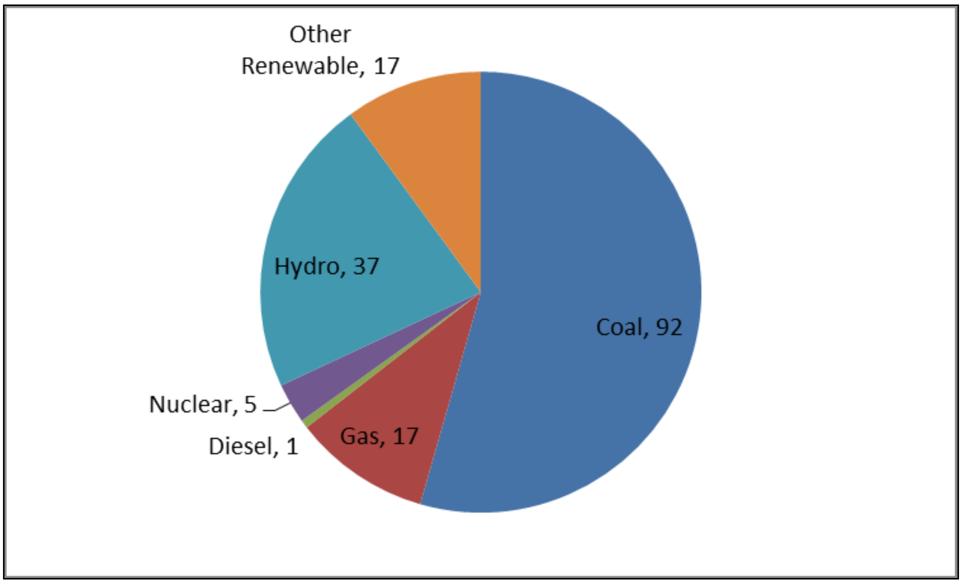

Figure 4-1 Fuel mix of installed power generation capacities of India (figures are in GW)

Source: Central Electricity Authority of India (2010)

In the estimation of IRR the cost of generation has been considered for coal fired power plants only. Considering coal fired power plants constitute the most dominant source of fossil based power generation in India and also since the largest scope of energy efficiency improvement is also within the coal fired power plants in India (Sinha & Kumar 2009).

The key input parameters for the estimation of IRR as per the formula (4) for the thermal power sector are given in Table 4-3 below.

Table 4-3 Key input parameters for IRR (industrial efficiency) estimation of thermal power sector under PAT

Item No	Description	Value	Source
1	Estimated total investment under PAT	5,057 Million USD equivalent	Ministry of Power and Bureau of Energy Efficiency (2008)
2	Transaction cost as a percentage of the total investment	0.8%	Estimated
3	Annual operation and maintenance cost as percentage of total investment	5%	Central Electricity Regulatory Commission of India (2009)
4	Total energy savings target in thermal power sector	6.92 Million tons of oil equivalent	BEE (2011)
5	Conversion factor of mtoe to GWh	11,630	IEA (2009)
6	Exchange rate of USD to INR	45	Reserve Bank of India (2011)
7	Weighted average cost of coal fired power plants in India	3.1 US Cents/kWh	Sathaye & Phadke (2004)
8	The number of years	6	Assumed[16]

[16] The IRR is estimated by considering cash flows for 6 years, since the savings generated under PAT can be banked for two consecutive cycles, which equals to 6 years.

The IRR for the thermal power plants under PAT has been estimated to be **37%** in the base case. A sensitivity analysis is performed by varying both the investment amount and the cost of generation independently of each other by ±10%, to assess their impact on IRR. It is found that the IRR is marginally more sensitive to variation in investment amount than the cost of power generation. The result of the sensitivity analysis is presented in Figure 4-2 below.

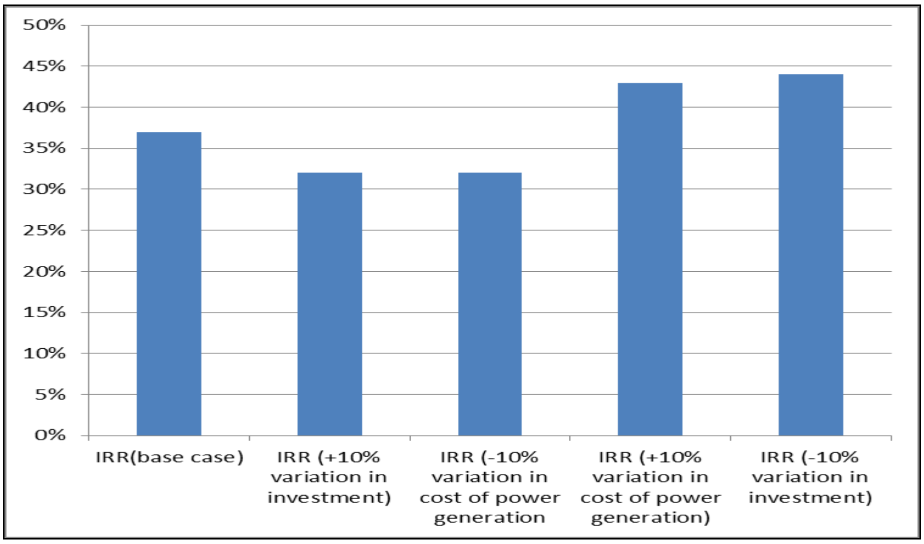

Figure 4-2 Results of sensitivity analysis of IRR (industrial efficiency) for thermal power sector under PAT

4.2.2.2 Industrial efficiency of iron and steel sector:

In estimation of industrial efficiency of the iron and steel sector under the PAT scheme, the same approach of cost-revenue analysis as in the case of thermal power plant is adopted. IRR of the entire iron and steel sector is estimated without accounting for the potential economic benefit of positive externality.

Indian iron and steel sector can be broadly divided in two parts. One is the integrated iron and steel sector, which has complete integration of steel making process from iron making up to finished steel production. The other segment consist of secondary producers who produces sponge iron and supplies to small and medium scale steel producers which uses these sponge iron and other scrap metals to produces steel (Dutta & Mukherjee 2010). The average share of integrated steel plant's production for the period 2006-2009 was 58%. The production figure for the period 2006-2009 is presented in Figure 4-3 below.

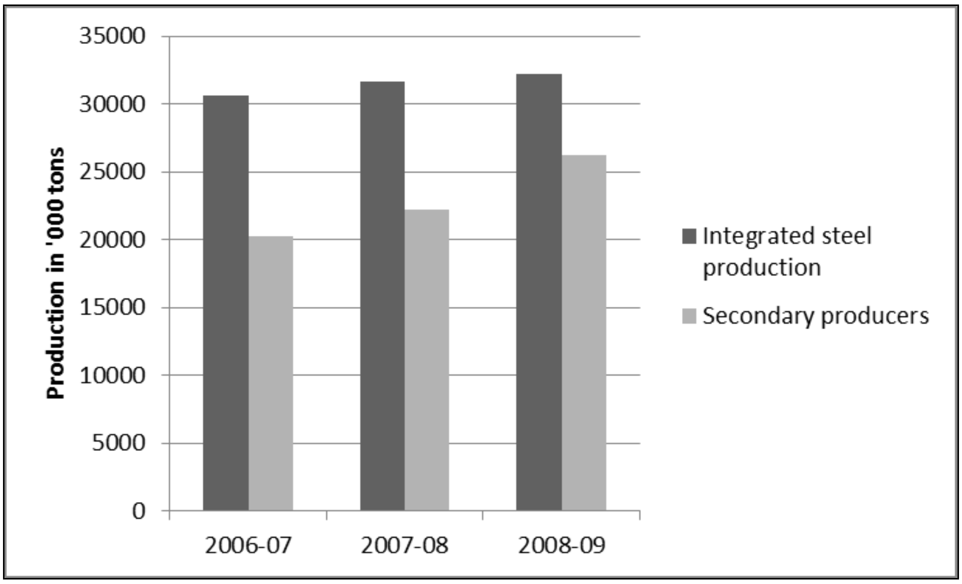

Figure 4-3 Annual production of steel segregated between integrated and secondary producers

Source: Ministry of Steel, Government of India (2010)

One of the key input parameters for the estimation of IRR is the cost of energy for steel production in India. This figure is estimated based on the information provided in the audited annual reports of the three main integrated steel producers of India. These three integrated steel producers include Tata Iron and Steel Company (TISCO), Steel Authority of India Limited (SAIL) and Jindal Steel Works Limited (JSW). Together these three companies represents on an average 41% of the total steel production and about 71% of the total integrated steel production in India based on production figures available from Ministry of Steel, Government of India (2010). The energy cost data for the secondary producers could not be obtained. Hence the cost of energy for the entire steel sector has been assumed to be equal to the weighted cost of energy of the three companies mentioned. This will in all likelihood give a conservative IRR estimates, since the energy cost for small and medium scale secondary steel producer would tend to be higher than the cost of major integrated steel producers due to economies of scale.

The key input parameters for the estimation of IRR to calculate the industrial efficiency of iron and steel sector under the PAT scheme are presented in Table 4-4 below.

Table 4-4 Key input parameters for IRR (industrial efficiency) estimation of iron and steel sector under PAT

Item No	Description	Value	Source
1	Estimated total investment under PAT	242 Million USD equivalent	Ministry of Power and Bureau of Energy Efficiency (2008)
2	Transaction cost as a percentage of the total investment	0.8%	Estimated
3	Total energy savings target in iron and steel sector	1.56 Million tons of oil equivalent	BEE (2011)

Item No	Description	Value	Source
4	Annual operation and maintenance cost as a percentage of the total investment	5%	Assumed[17]
5	Conversion factor of toe to kCal	10^7	IEA (2009)
6	Exchange rate of USD to INR	45	Reserve Bank of India (2011)
7	Weighted average cost of energy in integrated steel plants in India	28 USD equivalent/GCal	Calculated[18]
8	The number of years	6	Assumed[19]

The IRR for the iron and steel sector under PAT has been estimated to be **171%** in the base case. A sensitivity analysis is performed by varying both the investment amount and the cost of energy independently of each other by ±10%, to assess their impact on IRR. It is found that the IRR is marginally more sensitive to variation in investment amount than the cost of energy. The result of the sensitivity analysis is presented in Figure 4-4 below.

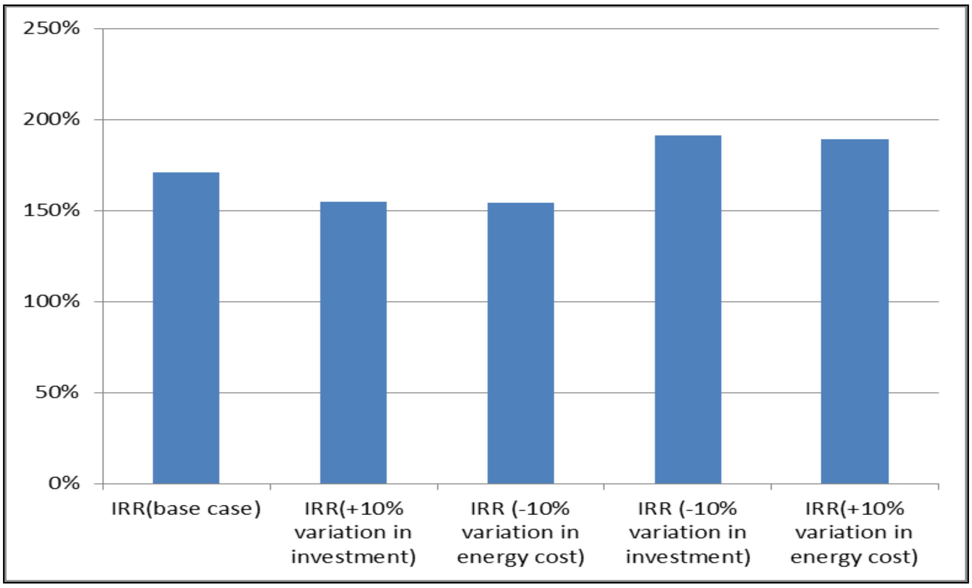

Figure 4-4 Results of sensitivity analysis of IRR (industrial efficiency) for iron and steel sector under PAT

4.2.3 Socio-economic efficiency assessment

The socio-economic efficiency assessment is guided by the following question.

At what potential socio-economic efficiency will the thermal power and iron and steel sectors would comply with the sectorial target under PAT?

---

[17] In absence of any regulatory guidelines for O&M cost in iron and steel sector, the annual rate of depreciation as specified under The Companies Act (1956) for plants and machinery has been assumed as a proxy to annual O&M cost.

[18] Please see table 0-3 in appendix for the calculation

[19] The IRR is estimated for 6 years, since the savings generated under PAT can be banked for two consecutive cycles, which equals 6 years.

For socio economic efficiency assessment the economic benefit of positive externalities associated with the avoided fossil based power generation owing to the savings of energy under the PAT scheme are accounted for.

The negative externalities of the fossil based power generation can be broadly divided into two components. One is local externality and the other is global externality.

Local externality is associated with the negative impact of SOx, NOx and particulate matter emission of fossil fuel burning. The negative impacts include impact on health such as asthma/bronchitis, increased morbidity and mortality and the associated loss of economic productivity of the affected persons. Other negative impacts include loss of value of property in close proximity of the power plants due to higher load of pollution (Bhattacharyya 1997).

Whereas global externality is associated with the negative impact of the climate change due to GHG emissions from fossil based energy generation (Rafaj & Kypreos 2007). An ex-ante estimation of avoided GHG emission due to the implementation of PAT scheme from thermal and iron and steel sectors is presented below.

Following formula is used to estimate the potential reduction in greenhouse gas emission in the thermal power plant and iron and steel sector covered under the PAT scheme.

$$ER_{PAT1} = E_{Aj} \times \gamma_j \times 11630 \times GEF_{India} \tag{6}$$

Where,

ER_{PAT1} : Emission reduction from PAT cycle 1 in tons of CO_2 equivalent

E_{Aj} : Estimated annual average electricity consumption in sector j in mtoe

γ_j : Sectorial energy consumption reduction target for sector j under PAT in %

GEF_{India} : Grid emission factor of India in tons of CO_2/GWh[20]

The Tables 4-5 and 4-6 represent the estimation of GHG emission reduction for thermal power plants and integrated iron and steel sector under the PAT scheme respectively.

Table 4-5 Estimated GHG emission reduction from thermal power plants under PAT cycle 1

Item number	Description	Value	Unit	Source of Information
1	Estimated annual average energy consumption (A)	160.3	mtoe	BEE(2011)
2	Sector wide reduction target for the first PAT cycle(B)	4.32	%	BEE(2011)
3	Sector wide total energy reduction target(C=AxB)	6.92	mtoe	Estimated
4	Conversion factor from mtoe to GWh (D)	11630	NA	IEA (2009)
5	Sector wide reduction target in GWh	80,537	GWh	Estimated

[20] Grid emission factor of India represents the carbon intensity of electricity production in India. The term grid refers to electricity supply and distribution grid.

	equivalent (E= C x D)			
6	Grid Emission Factor of India (F)	890	Tons of CO_2/GWH	Central Electricity Authority (2011)
7	Total estimated emission reduction from thermal power plants under the PAT cycle 1 (G = E x F)	71,678,183	Tons of CO_2	Estimated

Table 4-6 Estimated GHG emission reduction from iron and steel sector under PAT cycle 1

Item No	Description	Value	Unit	Source of Information
1	Estimated annual average energy consumption (A)	36.08	mtoe	BEE(2011)
2	Sector wide reduction target for the first PAT cycle(B)	4.32	%	BEE(2011)
3	Sector wide total energy reduction target(C=AxB)	1.56	mtoe	Estimated
4	Conversion factor from mtoe to GWh (D)	11630	NA	IEA (2009)
5	Sector wide reduction target in GWh equivalent (E= C x D)	17,456	GWh	Estimated
6	Grid Emission Factor of India (F)	890	Tons of CO_2/GWH	Central Electricity Authority (2011)
7	Total estimated emission reduction from iron and steel sector under the PAT cycle 1 (G = E x F)	16,133,181	Tons of CO_2	Estimated

Figure 4-5 below gives a graphical representation of the estimated GHG emission reduction from both the sector.

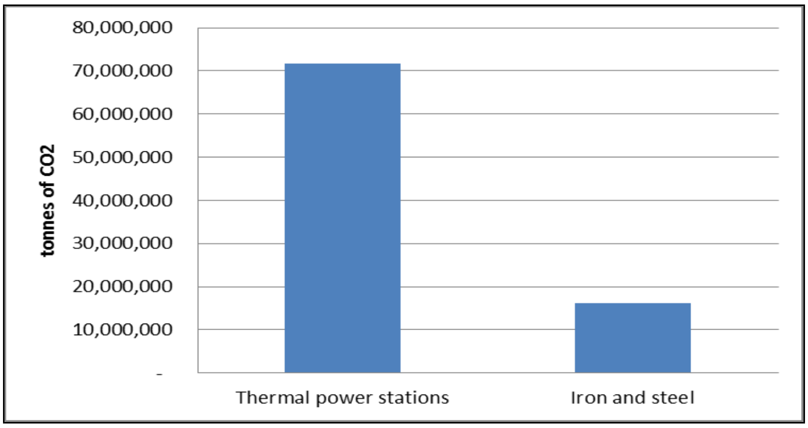

Figure 4-5 Estimated GHG emission reduction in thermal power plants and integrated iron and steel manufacturing sector under PAT scheme

A fundamental economic estimation of both local and global externalities in the context of India is beyond the scope of this thesis. The same is accounted for from peer reviewed published material in this thesis.

Two sources are consulted for the estimation of externalities. These are an India specific study by Bhattacharyya (1997) and another global region specific study by Rafaj & Kypreos (2007).

Bhattacharyya (1997) has estimated the local externalities associated with Indian coal fired power plants. The methodology adopted for the estimation of the local externality is of an "impact pathways", where the impact pathway for each pollutant from the source to the receptor is evaluated and the damage both in physical and monetary unit has been estimated. The result of the same is presented below in Table 4-7 below.

Table 4-7 Externality of Indian coal based power plants

Pollutants	**Type of effect**	**Physical impacts**	**Monetary value (INR/kWh)**
Particulates	Morbidity	Respiratory problems	0.042
	Building	Loss of rent	0.012
SO_2	Mortality	1.885×10^{-10} deaths	6.5×10^{-4}
	Morbidity	Respiratory problems	0.334
NOx	Mortality	-	Not evaluated
	Morbidity	-	Not evaluated
Total			**0.388**
Equivalent value in USD @ of current exchange rate of INR 45/USD			**0.86 US Cents/kWh**

Source: Bhattacharyya (1997)

The value for the above estimation is more than a decade old and thus may not be representative of the current estimation of local externality of coal based power generation in India. A yearly inflation adjusted value is presented in the Table 4-8 below. The Wholesale price index figures were taken from figures published by Reserve Bank of India (2010).

Table 4-8 Inflation adjusted value of externality of coal based electricity in India

Year	**WPI**	**Inflation (%)**	**Inflation adjusted value of local externality of coal based electricity of India (INR/kWh)**
1996-97	127.2	-	0.388
1997-98	132.8	4.40%	0.405
1998-99	140.7	5.95%	0.429
1999-00	145.3	3.27%	0.443
2000-01	155.7	7.16%	0.474
2001-02	161.3	3.60%	0.492
2002-03	166.8	3.41%	0.508
2003-04	175.9	5.46%	0.536
2004-05	187.3	6.48%	0.571
2005-06	195.5	4.38%	0.596
2006-07	206.1	5.42%	0.628
2007-08	215.9	4.75%	0.658
2008-09	233.9	8.34%	0.713
2009-10	242.7	3.76%	**0.740**
Equivalent value in USD @ of current exchange rate of INR 45/USD			**1.64 US Cents/kWh**

Rafaj & Kypreos (2007) presents the local as well as the global externality for North American region (NAME), Organisation for Economic Cooperation and Development (OECD), Eastern Europe and Former Soviet Union (EEFSU), Asia and Latin America, Africa and Middle Eastern (LAFM) region based on multi-regional MARKAL model. The study presents the values of the negative externality for different time periods, ranging from 2010 to 2050. The values for 2010 are given in Figure 4-6 below.

The report explains that the coal dominated electricity generation in India and China is the reason for the highest externality figures for Asia. The difference is particularly significant with respect to global externality between Asia and the rest of the world.

For estimation of socio-economic efficiency of thermal power and iron and steel sectors in India under PAT the Asia specific figures of externality by Rafaj & Kypreos (2007) is taken into consideration. The estimation by Bhattacharyya (1997) is not considered primarily for two reasons. Firstly Bhattacharyya (1997) does not provide an estimation of global externality for India. Secondly a simple inflation adjusted figure of externality might be less reliable than a more recent study of the same by Rafaj & Kypreos (2007). However, in choosing the externality values by Rafaj & Kypreos (2007) it is assumed that the Asia specific figures would be more or less representative for India. The uncertainty with respect to this assumption could not be validated and thus the results will be only of an indicative nature. Using India specific values of externality will provide a more accurate socio-economic efficiency than presented in this thesis.

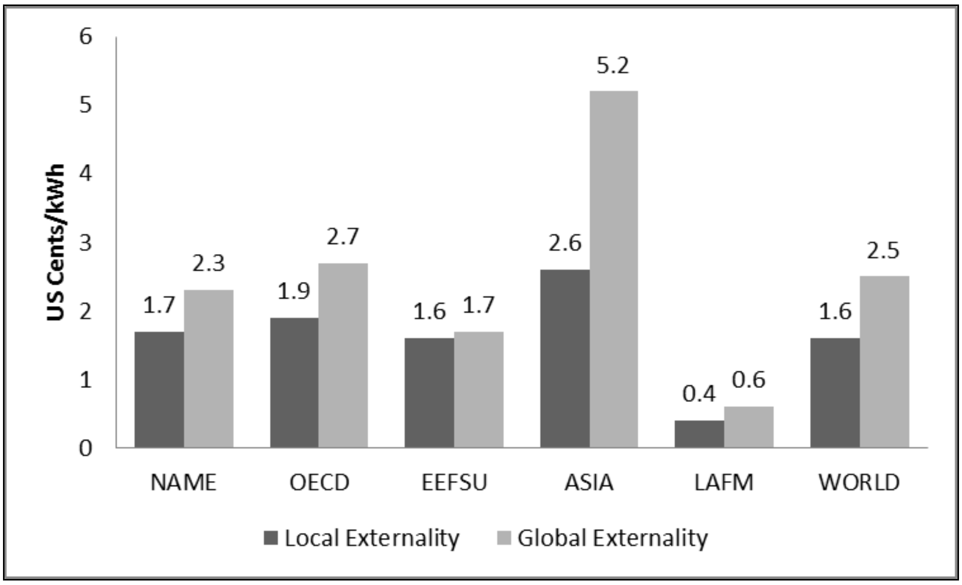

Figure 4-6 Local and global externality of fossil fuel based electricity in the world

Source: Rafaj & Kypreos (2007)

The IRR which has been chosen as a measure of socio-economic efficiency for both the thermal and the iron and steel sectors are presented in the following sections.

4.2.3.1 Socio-economic efficiency of thermal power sector

In estimation of socio-economic efficiency of the thermal power sector under the PAT scheme, IRR of the entire thermal power sector is estimated from a cost-benefit perspective. That is, economic benefit of potential positive externality is accounted for. The estimation of externality with respect to fossil based electricity generation in India has been taken from the peer reviewed publication as explained in the above section.

The key input figures for the estimation IRR for the thermal power sector is the same as given in Table 4-3 above, except for the values of local and global externalities. As mentioned in the above section, these values are 2.6 US Cents/kWh and 5.2 US Cents/kWh for local and global externalities respectively.

The IRR representing socio-economic efficiency of PAT scheme for thermal power sector is estimated to be **167%.** A sensitivity analysis is performed by varying the monetary value of both local and global externality independently of each other by ±10%, to assess their impact on IRR. It is found the IRR with positive externality is more sensitive to global externality as compared to the local externality. The result of the same is presented in Figure 4-7 below.

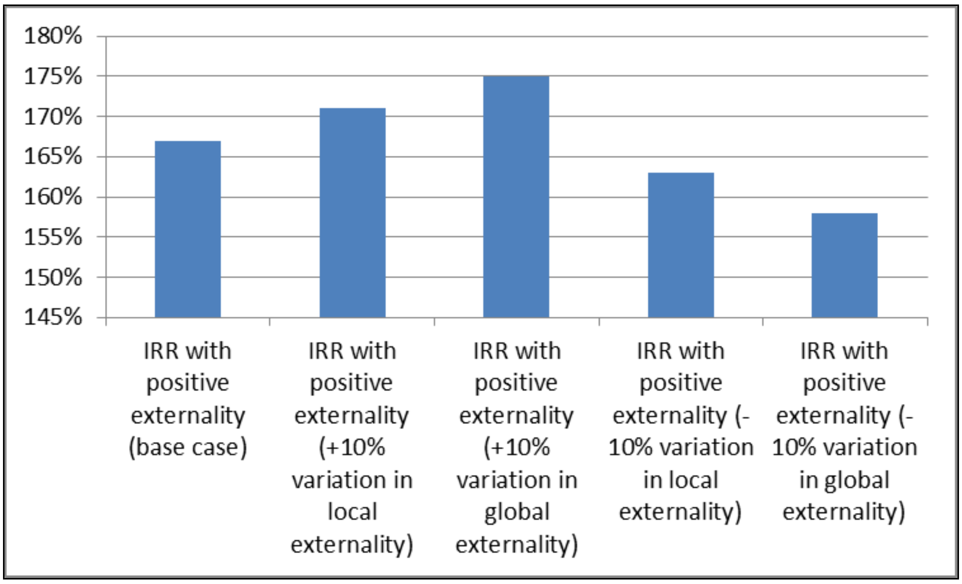

Figure 4-7 Results of sensitivity analysis of IRR (socio-economic efficiency) for thermal power sector under PAT

4.2.3.2 Socio-economic efficiency of iron and steel sector

In estimation of socio-economic efficiency of the iron and steel sector under the PAT scheme, IRR of the entire iron and steel sector is estimated from a cost-benefit perspective. That is, economic benefit of potential positive externality is accounted for. The estimation of externality with respect to fossil based electricity generation in India has been taken from the peer reviewed publication as explained in the beginning of Section 4.2.3.

The key input figure for the estimation IRR for the iron and steel sector is same as given in Table 4-4 above, except for the values of local and global externalities. The values local and global externalities are 2.6 US Cents/kWh and 5.2 US Cents/kWh respectively. The basis of choice for these values is given above in Section 4.2.3. The estimation of positive externality for the iron and steel sector is calculated by converting the energy savings in mtoe to equivalent electrical energy expressed in terms of GWh using the standard conversion factor of 11,630 (IEA 2009).

The IRR representing socio-economic efficiency of the PAT scheme for iron and steel sector is estimated to be **753%.** A sensitivity analysis is performed by varying the monetary value of both local and global externality independently of each other by ±10%, to assess their impact on IRR. It is found the IRR with positive externality is more sensitive to global externality as compared to the local externality. The result of the same is presented in Figure 4-8 below.

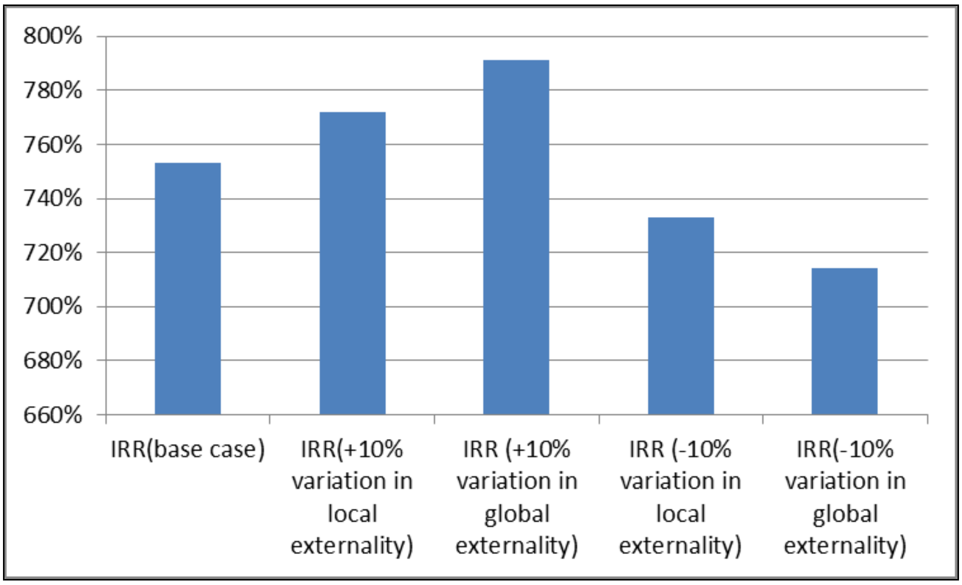

Figure 4-8 Results of sensitivity analysis of IRR (socio-economic efficiency) for iron and steel sector under PAT

4.2.4 Discussion on economic efficiency

In this section an overall discussion on the results of the economic efficiency assessment of thermal power and iron and steel sectors under the PAT scheme is presented.

The transaction cost is estimated to be around 0.8% of the total investment cost under PAT. The estimated transaction cost under PAT is significantly lower as compared to energy efficiency trading scheme in U.K, where the transaction cost has been estimated to be 10%-30% of the total investment cost (Mundaca 2007). However, it must be mentioned no qualitative judgment can be inferred between these two scheme based on the quantum of transaction cost alone. The U.K scheme was targeted towards the household sector, where the transaction cost for energy efficiency is traditionally higher as compared industrial sector. However, it can be inferred that compared to similar scheme, the transaction cost does not appear to be a major cost burden to the participants of the PAT scheme at least during the first cycle of its operation and hence its impact on the overall economic efficiency of the PAT scheme for the selected two sectors can be considered to be negligible.

The IRR figures representing the industrial and socio-economic efficiencies of the thermal power and the iron and steel sector is presented together in Figure 4-9 below, to facilitate the comparison of the economic efficiencies between the two sectors. It can be seen in the Figure 4-9, that the economic efficiencies of iron and steel sector are significantly higher than thermal power sector. From this result it can be inferred that energy efficiency improvement in the iron and steel sector is not only more profitable than the thermal power sector from an investment perspective, but also the social benefits from the avoided fossil based energy generation is more as compared to the thermal power sector. When compared to other energy efficiency trading schemes, the potential economic efficiency under PAT appears to be significantly higher. The IRR for British energy efficiency trading schemes representing the socio-economic efficiencies are in the range of 33% to 36% (Mundaca & Neij 2009).

Thus overall it can be concluded that PAT promises to achieve economically efficient energy efficiency improvement in the thermal power and the iron and steel sectors, due to its dual benefit of robust financial return to the industry and substantial net positive benefits to the society.

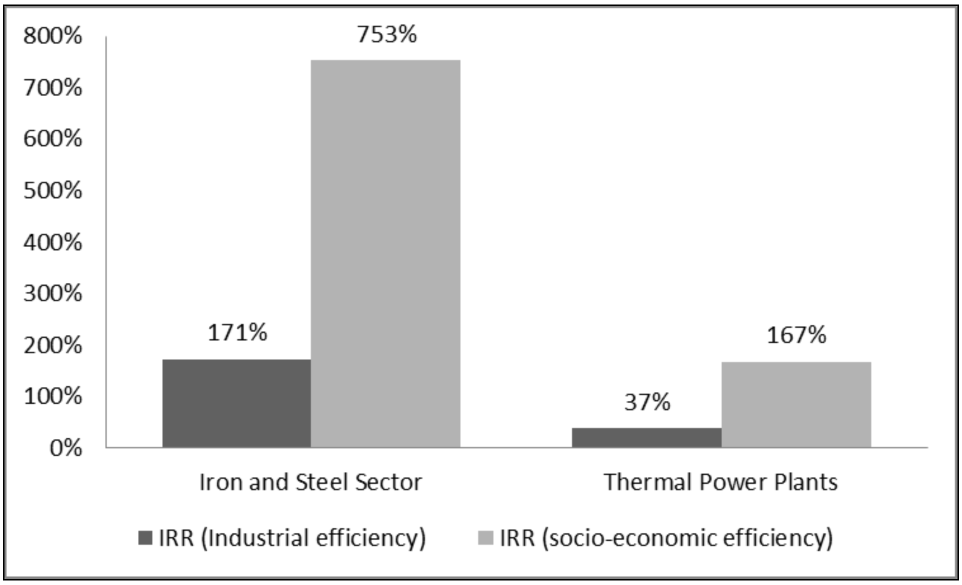

Figure 4-9 Economic efficiencies of iron and steel and thermal power sectors under PAT[21]

4.3 Cost-effectiveness assessment:

The assessment of cost-effectiveness of PAT will constitute answering the following research question of the thesis.

Research question 3:

Does PAT promote cost-effective improvement in energy efficiency in the industry?

As discussed in Section 3.3, the cost effectiveness assessment of PAT will be conducted by analyzing the following two criteria.

1. Assessment of the quantum of target
2. Assessment of the variation of marginal cost between iron and steel and thermal power sectors

Assessments of each of the two criteria as mentioned above are presented in the following sections.

4.3.1 Target assessment

The guiding question which defines the scope of the target assessment is presented below.

What is the difference between the target energy efficiency and the average annual energy efficiency improvement for thermal power plants and iron and steel sector under the PAT scheme?

The assessment of the target for both thermal power and the iron and steel sectors is presented in the following sections.

[21] Please see table 0-8 and 0-9 in the Appendix for the calculation details.

4.3.1.1 Target assessment for thermal power sector

As mentioned in Section 2, heat rate is the chosen parameter for measuring the efficiency of thermal power plants under PAT.

Central Electricity Authority (CEA) of India publishes annually the weighted average heat rate of thermal power stations in India in its annual "Performance review of thermal power stations" report. Figure 4-10 below represents the trends in heat rate in thermal power plants in India for the period 2005-2009. The rate of improvement in heat rate for the period 2005-2009 has been estimated to be around 1.51%. This improvement is marginally higher than the average annual target for thermal power sector under PAT, which is 1.44%.

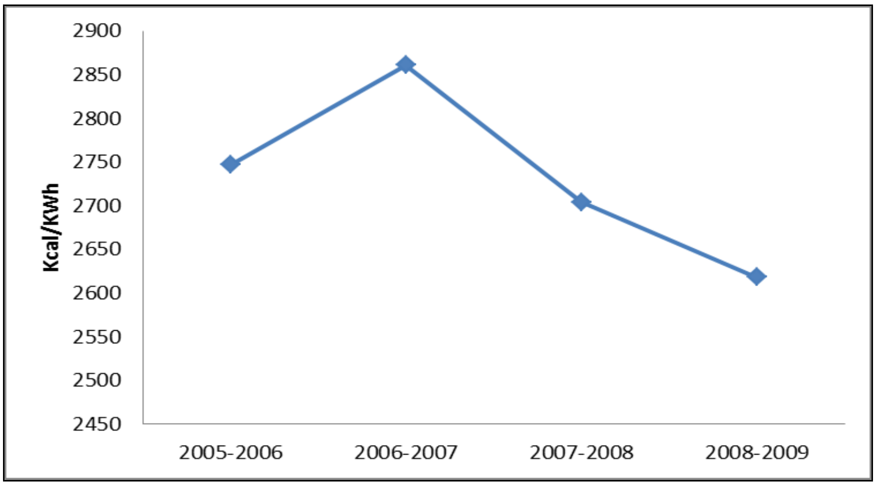

Figure 4-10 Historical trend in heat rate of Indian thermal power plants

Source: Central Electricity Authority (2006, 2007, 2008 and 2009)

4.3.1.2 Target assessment for iron and steel sector

As discussed in the industrial efficiency assessment for iron and steel sector in Section 4.2.1.2, the information of the secondary steel producers in India is not readily available. Thus the target assessment for the iron and steel sector is done for the integrated steel sector. Further, the secondary steel producing sector is highly fragmented and constituted by a number of small and medium scale steel plants (Dutta & Mukherjee 2010). Considering the fact that PAT in its current form is only targeting large scale industries, this approximation can be justified from the assumption that most of the secondary steel producers will not fall under the PAT at least in the first cycle of its operation.

As mentioned in Section 2, the specific energy consumption for iron and steel sector under PAT will be measured in terms of GCal/ton of crude steel production. Unlike the thermal power sector, where the weighted average heat rate figures are available at the national level, no such aggregated data exist for the iron and steel sector. Thus a number of sources were consulted to construct a representative sample for weighted average figure of specific energy consumption in integrated steel plants of India. These include the annual reports published by Ministry of Steel, Government of India and audited annual reports of listed Indian steel making companies.

There are seven integrated iron and steel companies in India. These are Steel Authority of India Limited (SAIL), Rashtriya Ispat Nigam Limited (RINL), Tata Iron and Steel Company (TISCO), JSW Steel Limited, Jindal Steel and Power Limited, Essar steel and Ispat Industries

Limited (Ministry of Steel, Government of India 2010). Of these seven companies only for four companies data of specific energy consumption is available for 5 consecutive years starting from 2005 to 2010. These four companies are SAIL, TISCO, JSW Steel Limited and RINL. The share of production of these four companies in the integrated iron and steel sector for the period 2005-2010 is 82% (Ministry of Steel, Government of India 2010). The Figure 4-11 below represents the share of production of these four companies in the Indian integrated steel sector[22].

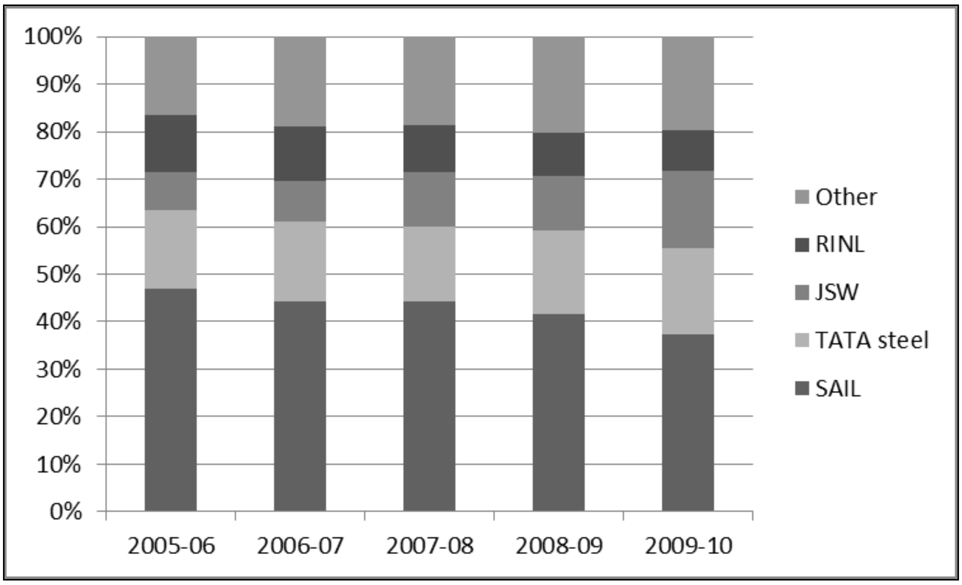

Figure 4-11 Percentage breakup of production in integrated iron and steel sector of India

Source: Ministry of Steel, Government of India (2010)

Considering these four companies represents more than 80% of the total steel production integrated steel sector in India, the specific energy consumption figures of these companies can be considered to be fairly representative of the integrated steel sector of India.

The times series data for specific energy consumption for each of the four companies for the period 2005-2010 were converted to weighted averaged specific energy consumption for each individual year using the following formula.

$$SEC_y = \sum_n w_n \times SEC_{n,y} \qquad (7)$$

Where,

SEC y	:	Weighted average specific energy consumption for year y
w_n	:	Weights equal to the percentage share of the company n in total crude steel production among n companies
n	:	Number of companies, n varies from 1 to 4

[22] For detailed production figures please refer to table 0-4 in the appendix

$SEC_{n,y}$: specific energy consumption of company n in year y

Figure 4-12 below represents the weighted average SEC figures for the selected four companies in the iron and steel sector covered under the PAT scheme for the period 2005-2010. The average annual rate of improvement in specific energy consumption for the period 2005-2010 for the iron and steel sector has been estimated to be around 1.56%. This improvement is marginally higher than the average annual target for iron and steel sector under PAT, which is 1.44%.

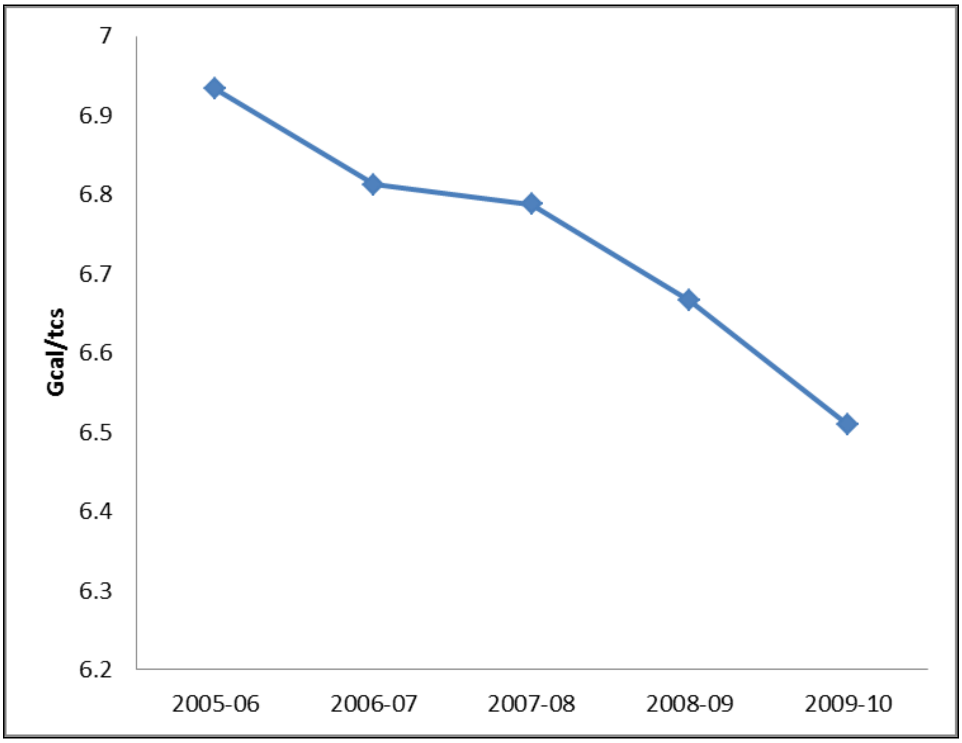

Figure 4-12 Weighted average specific energy consumptions in selected companies in integrated iron and steel companies

Source: Ministry of Steel, Government of India (2010), SAIL (2006, 2007, 2008, 2009 and 2010), TISCO (2006, 2007, 2008, 2009 and 2010), RINL (2006, 2007, 2008, 2009 and 2010) and JSW Steel (2006, 2007, 2008, 2009 and 2010)[23]

4.3.2 Marginal cost assessment

The guiding question which defines the scope of the marginal cost assessment is presented below.

What are the indicative marginal cost curves of energy efficiency improvement for thermal power sector and iron and steel sector in India?

At the outset it needs to be mentioned, the actual marginal cost curve for a specific plant in both thermal power and the iron and steel sector in all likelihood will be different from the cost curve as presented below. Since, the actual cost would be determined by the specific technological characteristics of the plant in question. In addition it also important to note, the

[23] Please see table 0-10 in the Appendix for the individual specific energy consumption figures of these companies.

different energy efficient technologies mentioned during the estimation is also not exhaustive in nature. The costs as presented below is only indicative in nature and is presented to understand the potential variation of marginal cost of energy efficiency improvement between thermal power and iron and steel sectors to assess potential cross-sectorial trading pattern between these two sectors.

The assessment of the marginal cost curves for both thermal power and the iron and steel sector is presented in the following sections.

4.3.2.1 Marginal cost assessment for thermal power sector

Marginal cost assessment for thermal power sector is done for the coal fired power plants only. The main justification for the choice of coal power plants has been provided in the economic efficiency assessment in Section 4.2.2.1. The same is not repeated in this section.

The estimation of the marginal cost for coal power plants is done based on literature review. The key technology related input for capital cost, O&M cost and net heat rate improvement figures were taken from Hasler (2009). These values are available for three different capacities of coal fired power plants, namely 200 MW, 500 MW and 900 MW. This report was commissioned by US EPA.

Another important input parameter which is the cost of coal based electricity generation is taken from Sathaye & Phadke (2004) from their paper titled "Cost and carbon emissions of coal and combined cycle power plants of India", published by Ernest Orlando Lawrence Berkeley National Laboratory.

The calculation procedure for estimation of the marginal cost for thermal power plant is given below.

Step 1: Estimation of annual energy savings

The energy saving estimation has been carried out using the following formula.

$$E_S = \frac{Q\,x\,365\,x\,24\,x\,PLF\;x\,NHRR\,x\,10^3}{AHR} \tag{8}$$

Where:

Es	:	Energy saved expressed in kWh
Q	:	Capacity of the plant
PLF	:	Plant Load Factor
NHRR	:	Net heat rate reduction in kCal/kWh
AHR	:	Average heat rate in kCal/kWh

Step 2: Estimation of net annual cost

The estimation of net annual cost has been estimated using the following formula.

$$NAC = \left(Capital\ Cost\,x\,d + O\,\&\,M_f + O\,\&\,M_v\right) - \left(E_s\;x\,C_g\right) \tag{9}$$

Where,

NAC : Net annual cost in USD

Capital cost : Capital cost of the energy efficient technology

d : Annual rate of depreciation of plant and machinery

$O\&M_f$: Fixed annual operation & maintenance cost

$O\&M_v$: Variable annual operation and maintenance cost

Cg : Cost of generation

Step 3: Estimation of annual energy savings in toe

The estimation of energy savings in toe is conducted using the following formula.

$$E_t = \frac{Q\, x\, 365\, x\, 24\, x\, PLF\ x\ NHRR}{10^4} \quad (10)$$

Where,

Et : Annual energy saved expressed in toe

Step 4: Estimation of marginal cost of energy efficiency improvement for a specific measure

The marginal cost of energy efficiency improvement for a specific measure is estimated using the following formula.

$$MC = \frac{NAC}{E_t} \quad (11)$$

Where,

MC : Marginal cost of energy efficiency improvement in USD/toe

Table 4-9 below provides various source of information consulted to estimate the marginal cost curve of energy efficiency improvement for coal fired thermal power plants in India.

Table 4-9 Input parameters for marginal cost calculation of coal fired thermal power plants in India

Sl No	Description	Value	Reference
1.	Net heat rate reduction	Various, please see Table 0-1 in Appendix for specific values of each energy efficient technologies	Hasler (2009)
2.	Average heat rate	2728 kCal/kWh[24]	Central Electricity

[24] Weighted average heat rate of coal fired power plants of India for the period 2006-209. Please see table 0-5 in appendix

			Authority (2007, 2008 and 2009)
3.	Plant Load Factor	77.67%[25]	Central Electricity Authority (2007,2008 and 2009)
4	Capital cost	Various, please see Table 0-1 in Appendix for specific values of each energy efficient technologies	Hasler (2009)
5	Annual rate of depreciation of plant and machinery	5.28%	The Companies Act of India (1956)
6	Fixed annual O&M cost	Various, please see Table 0-1 in Appendix for specific values of each energy efficient technologies	Hasler (2009)
7	Variable annual O&M cost	Various, please see Table 0-1 in Appendix for specific values of each energy efficient technologies	Hasler (2009)
8	Weighted average cost of coal fired power plants in India	3.1 US cents/kWh	Sathaye & Phadke (2004)

The results of the same for each of 200 MW, 500 MW and 900 MW capacity of power plant are presented in Figures 4-13, 4-14 and 4-15 below. There are total 16 different energy efficient technologies which are being assessed. In the figures they are designated as A to P[26]. It can be observed from these graphs that for larger power plants the energy efficiency improvement is relatively more cost effective than smaller power plants.

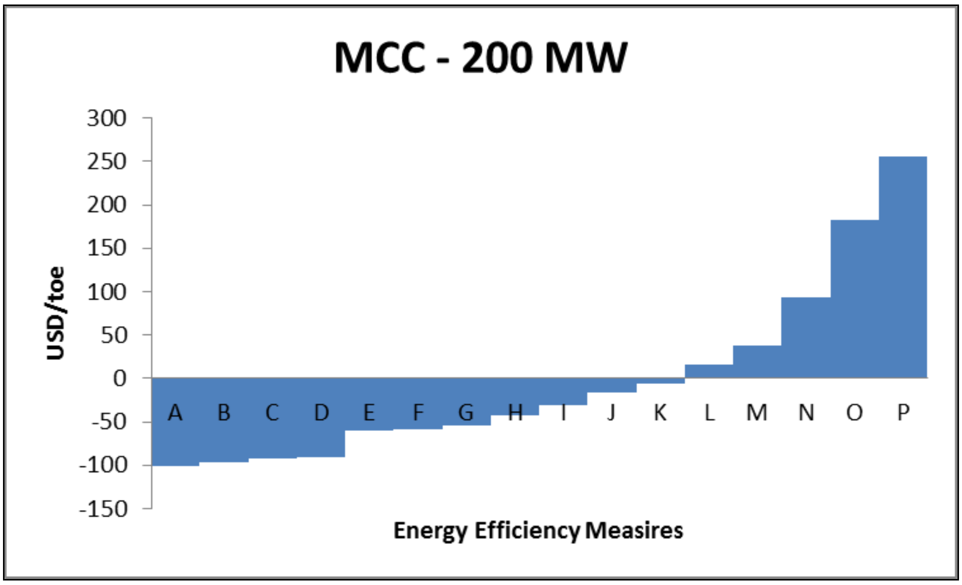

Figure 4-13 Marginal Cost Curve (MCC) of energy efficiency improvement for 200 MW coal fired power plant in India

[25] Weighted average plant load factor of coal fired power plants of India for the period 2006-2009. Please see table 0-5 in Appendix

[26] Please see table 0-1 in Appendix for the details of these technologies

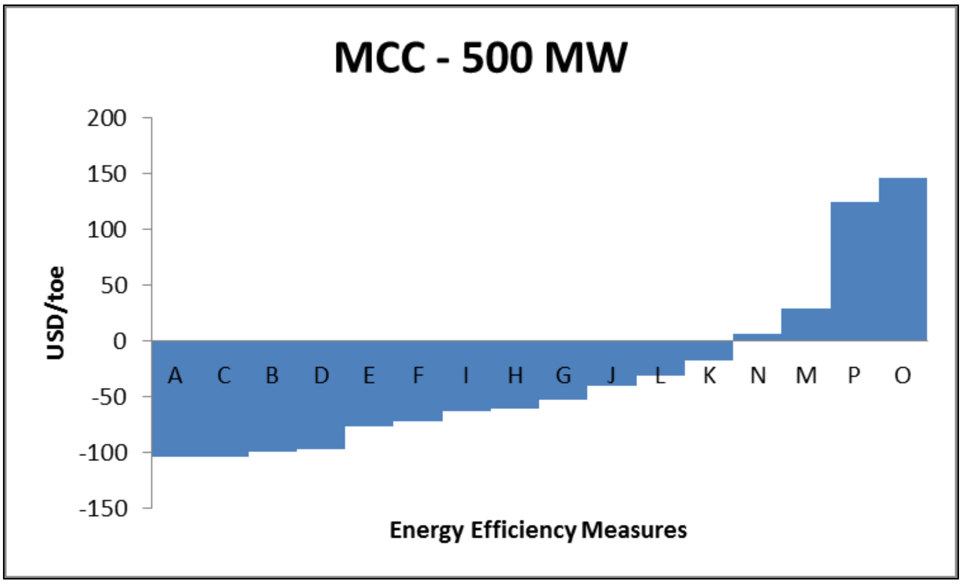

Figure 4-14 Marginal Cost Curve (MCC) of energy efficiency improvement for 500 MW coal fired power plant in India

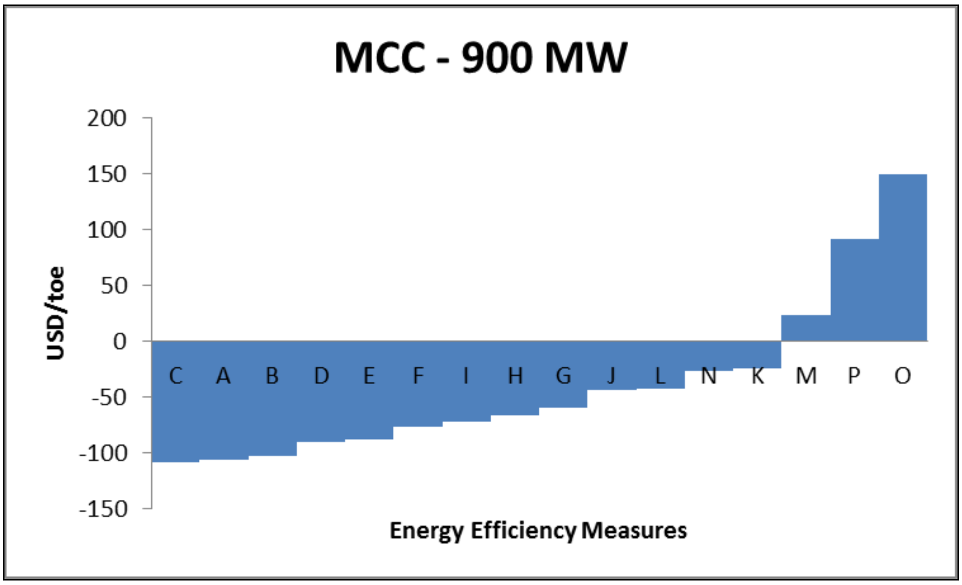

Figure 4-15 Marginal Cost Curve (MCC) of energy efficiency improvement for 900 MW coal fired power plant in India

4.3.2.2 Marginal cost assessment for iron and steel sector

The estimation of the marginal cost for iron and steel plant is done based on literature review. The key technology related input for capital cost, and energy savings estimates were taken from Petroleum Conservation Research Association of India's guidebook on energy conservation (2009).

The basis for estimation of cost of energy for steel making is the same as explained in economic efficiency estimation for iron and steel sector in Section 4.2.2.2.

The estimation of the marginal cost for iron and steel sector is calculated using the following formula.

$$MC = \frac{CC\,x\,(d + O\,\&\,M) - E_S\,x\,C_E}{E_S\,x\,10^{-7}} \tag{12}$$

Where,

MC : Marginal cost of energy efficiency improvement in USD/toe

CC : Capital cost of energy efficient technology expressed in USD equivalent

d : Annual depreciation expressed as % of the CC

O&M : Annual O&M cost expressed as a % of the CC

Es : Annual savings in energy in kCal/kWh equivalent

Cs : Cost of energy in USD/kCal

The steel making has two main processes. One is the iron making and the other is the steel making. Each process requires the input of both heat as well as electrical energy. The iron making process is the more energy intensive and consumes 64% of the total energy consumed in making 1 ton of crude steel. The rest 34% is spent on the steel making process (PCRA 2009)[27]. The marginal cost of energy efficiency improvement is calculated for 24 different energy efficient technologies[28]. In calculating the marginal cost for specific energy efficient technologies, energy cost has been apportioned depending on the application of the relevant technology in either in the iron making or in the steel making process.

Table 4-10 below provides the various input parameters and their respective sources used to estimate the marginal cost curve of energy efficiency improvement for iron and steel making in India.

Table 4-10 Input parameters for marginal cost calculation of iron and steel sector in India

Sl No	Description	Value	Reference
1.	Energy savings	Various, please see Table 0-2 in Appendix for specific values of each energy efficient technologies	PCRA (2009)
2.	Capital cost	Various, please see Table 0-2 in Appendix for specific values of each energy efficient technologies	Hasler (2009)
3.	Annual rate of depreciation of plant and machinery	5.28%	The Companies Act of India (1956)
4.	Annual O&M cost	5%	Assumed[29]
5.	Cost of energy	28 USD equivalent/Gcal	Calculated[30]

[27] Please refer to table 0-6 in the Appendix for typical energy balance estimation for steel manufacturing process.

[28] Please refer to table 0-2 in the Appendix for the description of these technologies.

[29] In absence of technology specific O&M cost data, the annual rate of depreciation has been assumed as a proxy to annual O&M cost. Thus O&M cost has been assumed approximately 5%.

The marginal cost curve for the 24 different energy efficient technologies for the iron and steel sector calculated as per the formula 12 is presented in Figure 4-16 below. The 24 different technologies are designated from A to X[31]. The impact of the scale of operation in the cost-effectiveness of energy efficiency improvement is not revealed through MCC constructed for the iron and steel sector due to unavailability of suitable data. However, the author of this thesis is of the view that economies of scale will make energy efficiency improvement relatively more cost effective in case of big steel manufacturing plants as compared to smaller steel making facilities.

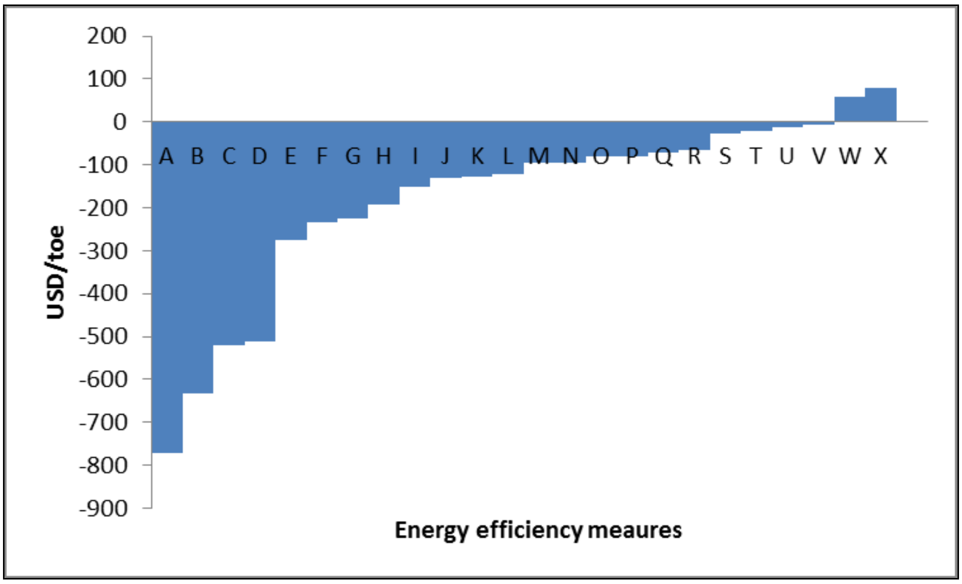

Figure 4-16 Marginal Cost Curve (MCC) of energy efficiency improvement for iron and steel sector in India

4.3.3 Discussion on cost-effectiveness

This section presents an overall discussion on the results of the cost-effective assessment.

The annual average target for improvements in the thermal power sector and the iron and steel sector is 1.44%. This target is higher than other energy efficiency trading schemes in the world. This can be seen from the Table 4-11 below, which presents the corresponding targets from energy efficiency trading schemes in France, Italy and Great Britain. However, when the targets are compared with respect to sector specific historical improvements in energy efficiency in recent past, it is observed that, for both thermal power and iron and steel sectors, the historical rate of improvement in energy efficiency is marginally higher than the their sector specific targets under PAT cycle 1. For thermal power plant the rate of improvement is 1.51% and for iron and steel it is 1.56%. The potential implication of this finding is the prospect of a thin trading of energy efficiency certificates for PAT cycle 1. Lower targets will mean that plants from the thermal power and the iron and steel sector will find it easier to meet their targets, without any need for buying certificates from the market. This will result in lower demand and lower price for energy efficiency certificates in the first cycle of the PAT. Under such a scenario, one of the main objectives of PAT, that is, equalization of maximum

[30] Please see table 0-3 in appendix for the calculation

[31] The details of these technologies are presented in table 0-2 in Appendix

marginal cost across these two sectors will not be achieved. In other words achieving cost effective improvement in energy efficiency between the thermal power and the steel sector will be compromised.

Table 4-11 Target levels in energy efficiency trading schemes expressed in percentage of average annual energy consumption of end use sector under the coverage

France	Italy	Great Britain
0.14%	0.3%	0.6%

Source: Mundaca & Neij (2009)

Marginal cost curves of thermal power and iron and steel sectors provide evidence of large variation of marginal cost of energy efficiency improvements between these two sectors. Marginal cost curve indicates number of measures with net negative cost for implementation is higher for iron and steel sectors as compared to the thermal power sector. This essentially mean in the iron and steel sector energy efficiency improvement can be achieved in a more cost-effective way as compared to thermal power sector. This finding also corroborates the finding in the economic efficiency section, where it is seen that energy efficiency improvements are more profitable in the iron and steel sector as compared to the thermal power sector.

However, if there is no net demand of energy efficiency certificates in the market[32], due to low level of target, the prices of energy efficiency certificates will be low and thus there will be no or very limited incentive for the iron and steel sector to go beyond their target level of energy efficiency improvement despite their ability to achieve higher level of energy efficiency improvement in a more cost effective way than the thermal power sector. This situation will prevent the potential for a least cost equilibrium outcome at the end of the PAT cycle 1. In addition generally low price of energy efficiency certificates will prohibit implementation of those energy efficiency measures, which has net positive marginal costs for its implementation.

Thus it can be concluded that although there is a substantial variation in marginal cost of energy efficiency improvement between the iron and steel and the thermal power sector, the lower level of target set in PAT cycle 1 might prohibit the equalization of maximum marginal cost of energy efficiency improvement across thermal power and the iron and steel sector. Hence in the first cycle, PAT does not appear to be promoting cost-effective improvements in energy efficiency in the thermal power and the iron and steel sector.

4.4 Technology penetration assessment

The role of technology is very important in the success of PAT. To meet the energy efficiency targets industries need to implement energy efficient technologies. The following research question is formulated to assess the role of PAT in facilitating the implementation of energy efficient technologies in the selected sectors.

Research question 4:

[32] Although this analysis does not assess the target for other 6 sectors covered under the PAT, it is assumed that if the demand for energy efficiency certificates are low for the thermal power and steel sector which together accounts for 85% of the total energy reduction target under PAT scheme, the overall demand of energy efficiency certificates for the entire PAT scheme will also be low.

What are the potential barriers that can prohibit PAT in facilitating penetration of energy efficient technologies?

As discussed in Section 3.4, the assessment of the role of PAT in facilitation of the implementation of the energy efficient technologies will be conducted for the following two criteria.

1. Potential for energy efficiency improvement in selected sectors

2. Barrier to implementation of energy efficiency improvement

The assessments of these two criteria are presented in the following sections.

4.4.1 Energy efficiency improvement potential assessment

The potential for energy efficiency improvement is a key pre-condition for the implementation of the energy efficient technology. From a theoretical perspective, the higher the scope of improvement in energy efficiency the higher will be the scope of adoption of energy efficient technologies. Although the actual uptake of energy efficient technologies to realize their full potential will depend on mitigation of barriers for adoption of energy efficient technologies and their marginal cost, but the knowledge of theoretical potential for improvement is an important starting point in any energy efficiency policy discourse.

As discussed in Section 1.3, the main focus of this thesis is on power and steel sector, the theoretical potential for energy efficiency improvement is assessed for these two sectors only. The potential has been assessed from a top-down approach to assess the sector wide potential. The assessment is based on archival research.

The assessment of energy efficiency improvement potential for thermal power and iron and steel sectors is guided by the following guiding question.

What is the potential for energy efficiency improvement for thermal power and iron and steel sectors in India?

In the following sections the energy efficiency potential assessment for thermal power and iron and steel sectors in India is presented.

4.4.1.1 Energy efficiency improvement potential in thermal power sector

Graus *et al* (2007) have conducted a detailed analysis of fossil based power generation across 14 countries, including Australia, China, France, Germany, India, Japan, Nordic countries (Denmark, Finland, Sweden and Norway integrated), South Korea, United Kingdom, Ireland and United States. The potential for energy efficiency improvement across these countries as estimated in this study is presented in Figure 4-17 below. This potential has been estimated by comparing the best efficiencies with country specific efficiencies of thermal power generation among the select group of countries.

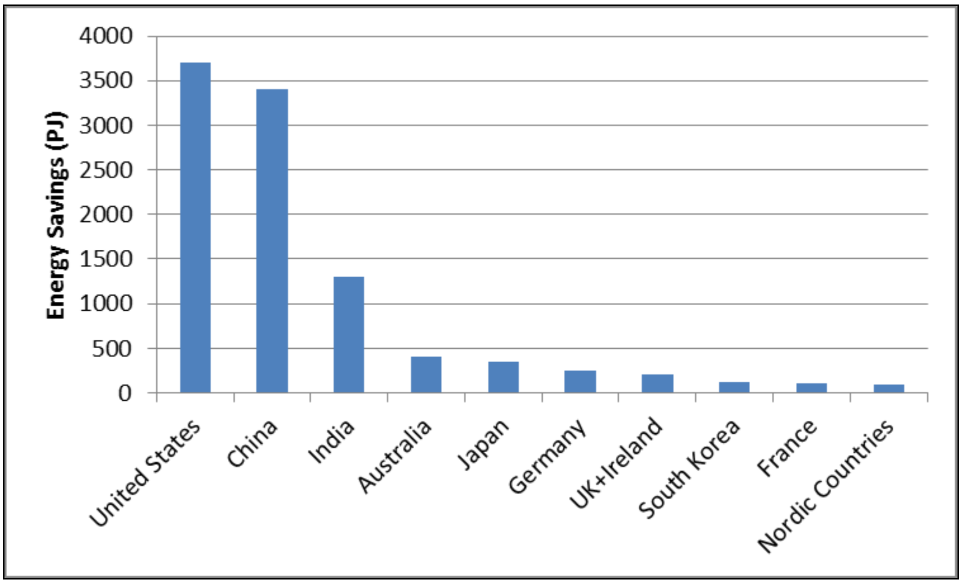

Figure 4-17 Energy savings potentials across countries

Source: Graus et.al.,(2007)

The total energy savings potential for India in the thermal power sector is about 1300 PJ. Thus the Figure 4-17 indicates a substantial scope of improvement in energy efficiency in Indian thermal power sector. Hence correspondingly it can be argued that theoretically there exists a substantial scope for implementation of energy efficient technology in the Indian thermal power sector. The PAT target for energy efficiency improvement in its 1st cycle is expressed as percentage of total energy savings potential in Table 4-12 below.

Table 4-12 PAT cycle 1 energy efficiency target as % of total energy savings potential in Indian thermal power sector

Description	Value	Unit
Total energy savings potential in Indian thermal power sector	1300	PJ
Conversion factor of J to toe	2.388×10^{-11}	
Total energy savings potential in Indian thermal power sector	31	Million toe
Target of energy savings for Indian thermal power sector for PAT cycle 1	6.92	Million toe
Target energy savings of PAT cycle 1 as a percentage of total energy saving potential	22.32	%

Thus Table 4-12 indicates that the target of energy efficiency improvement for thermal power plants in PAT cycle 1 approximately corresponds to 22% of the total savings potential in the sector. As elaborated in the PAT design document for subsequent compliance period, this target will be further increased (BEE 2011). Hence PAT will play an important role in making thermal power plants in India more energy efficient in the coming years.

4.4.1.2 Energy efficiency improvement potential in iron and steel sector in India:

The energy efficiency improvement potential in Indian Iron and steel sector is estimated using the following formula.

$$EE_P = \frac{P_T \, x \, (SEC_I - SEC_W)}{10^7} \qquad (13)$$

Where,

EE_P : Energy efficiency improvement potential in Indian iron and steel sector at current production capacity expressed in mtoe

P_T : Total production capacity in India for the year 2009-10 expressed tons

SEC_I : Average specific energy consumption in iron and steel making in India, expressed in GCal/tcs

SEC_W : World's best average specific energy consumption in iron and steel sector, expressed in GCal/tcs

The result and the various input parameters used for the estimation of the energy efficiency potential improvement in Indian iron and steel by formula 13 is presented in Table 4-13 below. The Table 4-13 also presents the target of PAT cycle 1 for the iron and steel sector as a percentage of the total potential for energy efficiency improvement in the iron and steel sector.

Table 4-13 Input parameters for estimation of energy efficiency improvement potential in the iron and steel sector of India

Sl No	Description	Value	Source
1.	Total production capacity in India for the year 2009-10	72,763,000 tons	Ministry of Steel, Government of India (2010)
2.	Average specific energy consumption in Indian iron and steel sector	7.17 GCal/tcs	BEE (2011)
3.	World's best average specific energy consumption in iron and steel sector	5 Gcal/tcs	Ministry of Steel, Government of India (2010)
4	Energy efficiency improvement potential in Indian iron and steel sector at production capacity of 2009-10	15.75 mtoe	Calculated using formula (13)
5	Target for energy efficiency improvement for iron and steel sector under PAT cycle 1	1.56 mtoe	BEE (2011)
6	Target energy savings of PAT cycle 1 for iron and steel sector as a percentage of total energy saving potential	9.9%	Calculated

Thus Table 4-13 indicates that the target of energy efficiency improvement for iron and steel sector in PAT cycle 1 approximately corresponds to 10% of the total savings potential in the sector. As elaborated in the PAT design document for subsequent compliance period, this target will be further increased (BEE 2011). Hence role of PAT will be crucial in making iron and steel production plants in India more energy efficient in the coming years.

4.4.2 Barrier assessment

From the previous section it follows that there exist substantial potential for energy efficiency improvement both in the thermal power and in the iron and steel sector. However despite the potential, historical rate of improvement in energy efficiency in the above sectors are modest, as discussed in Section 4.3.1.2. As discussed in Section 3.4, this lack of significant energy efficiency improvement is attributed to the existence of a number of barriers to energy efficiency improvement. As elaborated in Section 3.4, four key barriers to energy efficiency improvement are identified for assessment to analyze their potential impact on the performance of PAT. These include, (1) Financial, (2) Technical, (3) Institutional, and (4) Informational. The following guiding question is formulated to guide the barrier assessment.

What are the potential impacts of the barriers to penetration of energy efficient technologies under PAT?

Below presented are the assessments of each of these barriers and their potential impact on performance of PAT. The assessments are not separately presented for thermal power and iron and steel sectors, since many of these barriers are generic in nature, however, efforts are being made to present sector specific discussions to the extent possible.

4.4.2.1 Financial barrier assessment

Financial barrier has been identified as one of the key barriers to energy efficiency improvements in India by a number of studies (e.g., Sathaye *et.al.,* 2006; Painuly, 2009; Taylor *et.al.,* 2008). However the impact of financial barriers is different across various energy consuming sectors. The financial barrier is particularly a major bottleneck among the small and medium scale industries (Painuly 2009) and in the household sectors (Nix *et.al.,* 2011).

For small and medium scale industries there is a general lack of awareness about the performance of energy efficient technologies, thus despite of potential high financial returns, the chosen benchmark of discount rate in taking decision to invest in energy efficiency improvement projects are kept at significantly higher level than any other projects (Taylor *et.al.,* 2008). For this reason a number of energy efficiency projects do not qualify for self-financing among the small and medium scale industries. In addition, there is a general lack of interest among the banking community to finance energy efficiency projects in small scale industries due to their perceived high transaction cost associated in conducting the due diligence necessary for the risk assessment of energy efficiency projects. The transaction cost for banks to conduct the loan assessment of energy efficiency improvement projects tend to be high due to their lack of awareness about the energy efficient technologies. Further, transaction cost for such energy efficiency projects in terms of percentage of the total loan amount also becomes significant due to their relatively small size (e.g., Painuly, 2009 and Taylor *et.al.,* 2008).

For large scale industries the financial barrier is not considered a significant factor. The general level of awareness about the importance of energy efficiency among the large scale industries is much higher as compared to small scale industries (Taylor *et.al.,* 2008). This notion is also validated during the sector specific interviews conducted as a part of the thesis. The interviewees without any exception have mentioned energy efficiency as an important aspect of their operation, since improvement in energy efficiency reduces their fuel cost and thus improves their bottom line and hence provides higher profitability. Except for one company, representatives of all the companies from both thermal power and the iron and steel sector have mentioned the existence of a specific energy management division in their companies. The energy management cell conducts, regular internal audits, identifies energy efficiency improvement potential within their plants and often has internal targets for energy efficiency improvements. Interviewees have also mentioned, energy efficiency improvement projects are often self-financed if the payback period is within the range of 3-5 years. Availing loans for energy efficiency improvement in large scale sector also does not face any significant problems, since they generally have an existing credit line with some banks and loan request for energy efficiency projects are generally submitted as a part of modernization and renovation projects and not as standalone projects (Painuly 2009).

Considering PAT in its current form is only targeting large scale energy intensive industries (BEE 2011), the financial barrier is not expected to have any significant impact on the performance of PAT.

4.4.2.2 Technological barrier assessment

At the outset it needs to be mentioned that an exhaustive assessment of the technological barrier for energy efficiency improvement in the thermal power and iron and steel sectors is beyond the scope of this thesis. Instead, focus of this assessment is to identify the key generic elements of technological barriers both for the thermal power and the iron and steel sector from a macro perspective. Literature reviews and interviews have revealed the following four elements of technological barriers to energy efficiency improvement with respect to India. These include, (1) availability of technology, (2) raw materials, (3) age of plant and machinery and (4) plant layout. Brief discussions on each of these four elements are presented below.

(1) Availability of technology

The National Mission for Enhanced Energy Efficiency document mentions that the achievement of the targets under PAT cycle 1 is possible through implementation of the existing technologies in each sector (Ministry of Power and Bureau of Energy Efficiency 2008). Taylor *et.al.,* (2008) in their report on financing of energy efficiency measures in India, China and Brazil also mentions that technology for energy efficiency improvement are available in India. However, one important aspect of technological barrier has been revealed during the interviews. Particularly the respondents from the thermal power sector have mentioned that often they find it difficult to find technology supplier who will provide services for energy efficiency improvements through retrofitting measures. Typically the big power plant technology suppliers are not interested in engaging themselves in the retrofitting exercise; instead they push for replacement of the old equipment. The interviewees have mentioned that cost of achieving the same amount of energy efficiency improvement by retrofitting is often 5 to 6 times less as compared to replacement of the entire equipment. Interviewees felt that promotion of energy service companies (ESCO) can potentially remove this barrier. The interviewees from the iron and steel sector mentioned that they do not see any major problem with respect to availability of energy efficiency technologies.

(2) Raw materials

There are mainly two issues pertaining to raw materials that can impact the energy efficiency performance of both thermal power and iron and steel sectors. These are availability and quality. Shortage of raw material restricts the capacity utilization and thus increases the energy intensity of production. Quality of raw material can make specific processes of production more energy intensive.

Availability of raw material has been found to be a particular problem for the natural gas based power plants in India (Press Trust of India 2011). During the interviews the respondents associated with the natural gas based power plants have mentioned, that their specific energy consumption has been very high in the past due to acute shortage of raw materials. The interviewees have mentioned that the gas availability is as low as 60%-70% of the total requirement. The respondents have mentioned when the gas is available the energy efficiency of natural gas based power plants improve significantly and operates within 5% of the net design efficiency.

Quality of raw materials impact the energy efficiency performance of both coal fired power plant and iron and steel making. For coal fired power plant the problem is with respect to ash content and moisture content of the coal (BEE 2011). The higher the ash and moisture content, the lower the specific energy consumption of power generation. Indian coals generally have high ash content and thus restricts the power producer to achieve improvement in energy efficiency of operation (Sinha & Kumar 2009). A number of power producer in India also imports high quality coal with low ash content from abroad (BEE 2011) to mitigate this problem but this again adds to the cost of power generation, since imported coal is costlier than the domestically produced coal.

For iron and steel making, the raw material quality of coking coal and iron ore impact the energy efficiency performance of steel making. High ash content of Indian coking coal and higher percentage of impurities in iron ore such as alumina and silica to some extent restricts the energy efficiency performance of iron and steel plants in India (Singhal 2009).

(3) Age of plants and machinery:

The age of plants and machineries is an important factor affecting the energy efficiency performance of both thermal power plants and iron and steel sector. Ageing of equipment results in wear and tear and reduces its original design efficiency of operation. The ageing of plants and machinery at times prohibits improvement of energy efficiency improvements. This problem is particularly important for public sector steel companies in India, which has a relatively old capital stock of plants and machineries commissioned during 1960s and 1970s, as compared to new more efficient private steel making companies (e.g., Schumacher & Sathaye 1998 and Jain 2010). The problem is similar in public sector coal fired power plants in India, most of which has a capital stock of more than 20 years old as compared to the newly built more efficient power plants in India (Shanmugam & Kulshreshtha 2005).

(4) Plant layout

The plant layout at times can be an impediment for energy efficiency improvement. This problem is found to be particularly important within the iron and steel sector as compared to the thermal power sector. The reason may be attributed to the more complex process of iron and steel making as compared to the power generation. One aspect of plant layout is with respect to the choice of existing technology. During the interviews it is revealed that in the iron and steel sector the plant layout is guided by the choice of technology, this creates bottlenecks for implementation of new energy efficient technologies due to lack of space or incompatibility of the new energy efficient technology with respect to the existing technologies. For example, steel making through electric arc furnace is more efficient than steel making through basic oxygen furnace/ blast furnace route (American Iron and Steel Institute 2005). However, conversion of basic oxygen furnace/blast furnace route of steelmaking to electric arc furnace route is not possible unless the complete plant layout is changed to facilitate this improvement in energy efficiency. Lack of space at times also prohibits the realization of energy efficiency improvements. One of the interviewees in the iron and steel sector mentioned a potential 20 MW worth of waste heat recovery plant could not be commissioned due to lack of space in the existing plant layout.

4.4.2.3 Institutional barrier assessment

Institution is in a broad sense an over encompassing concept. It can mean, inter alia, economic, political, social, cultural and legal institutional structures. However with respect to the institutional barrier assessment for this thesis, the narrow definition as proposed by Weber (1997) is taken into consideration. Weber (1997) defines "public administration" as the relevant institution in his essay on barriers to energy efficiency improvement. For PAT, BEE is the principal public administrative body responsible for the functioning of PAT. Thus in this section the institutional barrier assessment is presented with respect to institutional capacity of BEE.

BEE was created to facilitate implementation of The Energy Conservation Act (2001). The roles and responsibility of BEE is very extensive and wide ranging. These include all matters related to energy conservation and energy efficiency improvements in India both at the national and sub-national level. Nandi & Basu (2008) have listed 20 different functions that are presently being carried out by BEE. These include, inter alia, preparation of building codes, labeling schemes for energy consuming appliances; administration of the accreditation procedures for energy auditors, promotion of energy efficiency and energy conservation initiatives among all sectors of energy consumers, formulation of policies and launching of schemes to develop market for energy efficient technologies, development of market for energy service companies.

Performance assessment of BEE in the past has resulted in mixed responses. On the one hand, BEE has been credited for creating awareness of energy efficiency among the industries by making energy audit a mandatory activity, through introduction of energy labelling schemes and through an extensive publication of energy efficiency related literature (Balachandra *et .al* 2010). On the other hand BEE has been criticised for failing to catalyse any significant energy efficiency improvements among the industries (Nandi & Basu 2008). Nandi & Basu (2008) attribute this relative failure to catalyse energy efficiency improvement to BEE's extensive administrative responsibilities which impedes effective co-ordination with the designated consumers in the industrial sectors.

Administering PAT would be in addition to all the existing roles and responsibility already performed by BEE. Considering the vast scope and extent of PAT, the performance of BEE would be extremely crucial in successful implementation of PAT. BEE has been extremely active in the past year and a half in preparation to launch of PAT. BEE has been conducting series of consultation across India with industry representatives and various sector specific expert groups to finalise the design of PAT. Despite the valiant effort by BEE, the launch of PAT has been delayed. During the interviews, all five designated consumers have mentioned that the baseline audit and individual target fixation is still pending. Climate Connect, UK (2011), an independent news and research agency in the field of energy and climate change reported that the delay is due to certain regulatory approval procedures from the law ministry and some pending fine tuning of the design of PAT. Robins *et.al.,* (2011) from Hong Kong and Shanghai Bank Corporation in their climate investment update have indicated that implementation of PAT is now expected to be delayed by about 4 months from its scheduled implementation date of 1st of April, 2011. Representative of BEE has further mentioned during the interview that due to this delay BEE might be considering revision of the compliance period from its earlier 1st April 2011- 31st of March of 2014. Some commentators indicate that the reason for this delay can also be attributed to the fact, that BEE has not been given adequate time to prepare the launch of an ambitious scheme like PAT that covers nearly 60% of India's total energy conservation (Umashankar 2010).

Thus it can be seen that the institutional barrier due to constrained capacity of overstressed BEE might prove to be a significant barrier unless rectification measures are adopted in future.

4.4.2.4 Informational barrier assessment

Lack of information on energy efficient technologies can significantly prohibit the uptake of energy efficiency improvement projects. The informational barrier can manifest itself, inter alia, in lack of motivation among the industries due to lack of awareness about the importance of energy efficiency improvement, by driving up the financial return expectation due to perceived higher risk association with the energy efficient technologies and by increasing the transaction cost in realizing the benefits of energy efficiency improvements (e.g., Decanio ,1993; Reddy A.K.N, 1991; Nagesha & Balachandra, 2006).

In general, the significance of information barrier can be more for small and medium scale industries (Painuly 2009) and in the household sector (Nix *et.al.,* 2011). But for large scale industries which concerns PAT, informational barrier does not seem to be major factor. The introduction of the Energy Conservation Act (2001) was an important factor for easing the information barrier particularly related to the large scale industries. Two most important provisions of The Energy Conservation Act (2001) that has helped easing of information barrier in the large scale industries are (i) mandatory energy audit and reporting requirement for the large industries, and, (ii) mandatory appointment of in-house energy managers at the large scale industries (Dutta & Mukherjee 2010). Mandatory energy audit and mandatory appointment of energy managers in large industries have helped to raise the profile of energy efficiency related issues among the top management and thus have made them more aware of the importance of the energy efficiency and energy conservation measures. In addition the role of BEE has been all along very crucial in raising awareness on issues pertaining to energy efficiency and in easing the information barrier related to the same. BEE has worked closely with industries to build their capacities and raise their awareness in matters related to energy efficiency (Balachandra *et.al.,* 2010). BEE has constituted an accreditation process for certification of energy auditors and energy managers. The total number of BEE certified energy managers and energy auditors in India are currently around 3000[33] and this number is growing each year. Influx of these trained energy professionals in Indian industry has helped raise the awareness as well as the capacity with respect to energy efficiency related issues in the large scale industrial sectors. In addition BEE has been playing a crucial role in knowledge creation in the field of energy conservation through publication and dissemination of information among the concerned stakeholders.

4.4.2.5 Other barrier assessment

In addition to the barriers mentioned above literature on barrier to energy efficiency improvements also mention certain other barriers related to energy efficiency improvement. These barriers are related to behavioral, managerial and organizational barriers. Some of the key barriers in these categories include, (i) the inability of the firms to behave as individuals although often for the sake of simplification economic analysis assumes them to do so, (ii) lack of focus and attention, and, (iii) the principal-agent problem, which is manifested through divergence of owners' objective from the manager's objectives (Decanio 1993). Although these barriers do have an impact on energy efficiency improvements initiatives taken up by firms, their potential impact with respect to PAT is not assessed as a part of the thesis. Since, literature on the impact of these barriers on energy efficiency improvement in Indian context

[33] This information is obtained from BEE website: http://www.bee-india.nic.in/content.php?page=energy_managers_auditors/ema.php?id=1

is not available and the impact of these barriers could not be assessed with the limited number of interviews conducted as a part of this thesis. A fundamental analysis of these barriers for the selected sectors under PAT is beyond the scope of the thesis.

4.4.3 Discussion on technology penetration assessment

The assessment indicates that both in the thermal power and in the iron and steel sector there is substantial scope of improvement of energy efficiency. PAT, which is the first of its market based scheme in improving the energy efficiency in the energy intensive industrial sectors in India, will thus have a major role to play in catalyzing the growth of energy efficiency in India. Analysis also reveals that between thermal power and the iron and steel sector, the focus of improvement in energy efficiency is more on thermal power sector than in iron and steel sector in the first cycle of PAT. While the target for energy efficiency improvement in thermal power sector is about 22% of the total theoretical energy efficiency improvement potential, for iron and steel it is only about 10% during the first compliance period of PAT.

The analysis of the barrier to implementation of energy efficient technologies reveals the existence of certain important barrier, easing of which will be crucial for PAT to achieve its desired outcome. The most important barriers with respect to PAT are technological and institutional barriers.

Within the technological barrier the issues with respect to raw material quality, plant lay-out and ageing of equipment are expected to be taken care of while setting plant specific targets. These issues will be considered during the baseline survey at individual plants, and target will be set in a way that it does not prohibit the respective designated consumers to achieve the same due to the existence of any intrinsic technological barriers (BEE 2011). However, efforts need to be taken by BEE and other concerned government agencies to develop the market for ESCOs to increase the flexibility of the designated consumers in order to enable them to meet the target under PAT in a cost effective way. BEE is already taking certain steps to promote market for ESCOs. BEE has recently signed a Memorandum of Understanding (MoU) with Hong Kong and Shanghai Bank Corporation, India to facilitate financing of ESCO based projects in India (Construction update.com 2010). This MoU is a part of the Energy Efficiency Financing Platform (EEFP) scheme under National Mission on Enhanced Energy Efficiency that aims to reduce financial barrier to energy efficiency (Ministry of Power and Bureau of Energy Efficiency 2008).In India the ESCO market is still in a very niche stage and it is yet not in a position to provide a full range of services to the industrial sectors (Delio *et.al.,* 2009). The lack of ESCO model of service might not be a significant barrier for the first cycle of PAT. Since, in the first cycle, targets are relatively easier to achieve, considering the fact that the targets are lower than the average improvement in energy efficiency in the selected sectors. In addition, during the interviews the industry representatives expressed confidence of meeting the target in the first cycle of PAT through their in-house capabilities. However, for subsequent compliance period role of ESCO might be crucial for the success of PAT. Hopefully the introduction of PAT and schemes such as Energy Efficiency Financing Platform will give the necessary impetus for the growth of ESCO model of services in India.

The barrier with respect to availability of natural gas is of a macro nature and it will not only impact the natural gas based power plant but also the fertilizer sector which is also part of PAT. However, this problem is of national importance and solution to this problem largely rests with the national government. The performance of PAT due to lack of natural gas supply will be affected unless Government of India finds a solution to this problem in near future.

With respect to institutional barrier the main issue is the capacity of BEE in effective administration of PAT. The assessment shows that BEE is currently over-stressed and which is one of the important reasons for delays happening in launch of PAT. The proposed administrative system to govern the PAT promises to ease this pressure on BEE through formation of an integrated electronic platform called PATNET to facilitate seamless real time reporting and transaction under PAT. In addition, delegating the task of compliance assessment to independent energy auditors also will relive BEE from a carrying out a major activity within the PAT scheme. However, PATNET is yet to be launched and timely launch of PATNET together with the official commencement of the PAT scheme would be crucial to maintain the operational efficiency of the PAT scheme. With respect to efficient functioning of the independent energy auditors, development of a detailed monitoring and verification protocol will be crucial.

In addition consideration might be given by separating the role of regulator and scheme administrator. BEE can limit its role to only being a regulator of the PAT scheme and can delegate the responsibilities of scheme administration through formation of a separate entity by invoking the clause in Section 51 of The Energy Conservation Act (2001). This separation of role might provide better framework for an effective administration of the PAT mechanism.

The financial and informational barrier assessment reveals at this stage they are not significant barrier in PAT. Since, large scale companies do not face any major barrier with respect to the access to finance and the provision of mandatory energy audits, mandatory appointment of energy managers have eased the informational barrier significantly. In future PAT is expected to increase its sectorial scope and include other sectors such as residential and commercial buildings and small and medium scale industries. In that case, these barriers are expected to be significant unless efforts are taken to ease the barrier. The roles of schemes such as Energy Efficiency Financing Platform, as mentioned above will be crucial in easing financial barrier for these sectors. With respect to informational barrier the challenge for BEE is to reach out to energy consumers in the building and the small scale industries in a more effective way to ease the existence of informational barrier. Hopefully launch of PAT will provide greater impetus to all these initiatives and will help in removal of barriers to energy efficiency in India.

In conclusion it can be said that PAT is expected to play an important role in penetration of energy efficient technologies in the thermal power and the iron and steel sector. However, the extent of success of PAT will be particularly dependent on easing of certain technological and institutional barriers that are found to be more significant in the first compliance period of PAT.

4.5 Summary of the assessment of PAT

The assessment reveals that PAT promises to deliver significant net positive benefit to the society. However, the assessment also indicates a number of concerns that might hinder realization of the full potential net positive socio-economic benefit under the PAT scheme. Most important among these concerns include lack of potential for cost-effective improvement in energy efficiency under PAT cycle 1, lack of detailed monitoring and verification protocol, inadequate penalty for non-compliance, institutional and certain technological barriers. Success of PAT will be dependent upon the alleviation of these concerns in future.

Table 4-14 below presents the summary of the assessment in the form of answers to the research questions. .

Table 4-14 Summary of PAT assessment

Sl No	Name of criterion	Research question	Guiding questions	Answers to the guiding questions	Summary Response to the research question
1	Design of PAT	Does the design of PAT incorporate the key elements of a well-functioning market based regulatory instrument?	1. How flexible PAT is with respect to compliance options to obliged DCs?	PAT provides flexibility of compliance to designated consumers on three areas. The compliance can be achieved by investing in energy efficient technologies, by buying energy efficiency certificates generated within the PAT scheme and by a combination of both of the options as mentioned above. In addition PAT does not mandate any technology standards for the industry. Thus industry has the flexibility in terms of choice of the technology. Further provision of banking in PAT provides temporal flexibility with respect to compliance to the designated consumers. The fungibility of Renewable Energy Certificates with EScerts further adds to the flexibility of compliance to the designated consumers.	The design of PAT incorporates the key elements of a well-functioning market based instruments. However, concerns remains with respect to design aspects of PAT particularly with respect to monitoring and verification protocol, penalty amount and to some extent with the methodology of normalization. A well-functioning PAT will be dependent upon the alleviation of these concerns by careful design of these aspects of PAT by Bureau of Energy Efficiency.
			2. Do the rules of target setting and compliance assessment in PAT follow simple methodologies?	PAT provides simple methodologies for fixation of baseline specific energy consumption, target setting and for compliance assessment. However, concerns remains with respect to normalization process, which is still under process of development.	
			3. Does PAT design provide a robust monitoring and verification protocol?	PAT acknowledges the need for a robust monitoring and verification protocol. However the same is still not finalized and is one of the reasons for the delays in launch of the scheme. No judgment could be passed on the robustness of the monitoring and verification protocol, since the same is yet to be completed. However, it can be said that timely completion of a robust monitoring and verification protocol will be an important aspect to attain satisfactory performance of the PAT scheme.	

Sl No	Name of criterion	Research question	Guiding questions	Answers to the guiding questions	Summary Response to the research question
			4. Would the level of penalty under PAT scheme provide sufficient deterrent to non-compliance?	The level of penalty found to be inadequate in its present form. However, BEE has taken cognizance of this issue and is in the process of revising the same to make it more effective deterrent as compared to its present form.	
2	Economic efficiency	What is the potential economic efficiency of the PAT scheme?	1. What is the estimated proportion of transaction cost in the total cost of energy efficiency improvement investment for thermal power plants and integrated iron and steel sector under the PAT scheme?	The estimated proportion of transaction cost is found to nominal for the first cycle of the PAT scheme. It is estimated to be about 0.8% of the total estimated investment under the PAT scheme.	The assessment of economic efficiency shows that PAT promises to provide economically efficient improvement in energy efficiency improvement in the thermal power and the iron and steel sector, due to its dual benefit of robust financial return to the industry and substantial net positive benefits to the society.
			2. At what potential industrial efficiency will the thermal power and iron and steel sectors would comply with the sectorial target under PAT?	The estimated industrial efficiency for the PAT scheme for both thermal power and the iron and steel sector is found to robust. The industrial efficiency for iron and steel sector is substantially higher than the same for the thermal power sector. The estimated industrial efficiency for thermal power plants is about 37%. For iron and steel sector it is 171%.	
			3. At what potential socio-economic efficiency will the thermal power and iron and steel sectors would comply with the sectorial target under PAT?	PAT promises to yield significant net positive socio-economic benefit to the society. The socio-economic efficiency under the PAT scheme for thermal power sector has been estimated to be 167%. For iron and steel sector it is 753%.	
3	Cost-effectiveness	Does PAT promote cost-effective improvement in energy efficiency in	1. What is the difference between the target energy efficiency and the average annual energy efficiency improvement for thermal	The difference between target energy efficiency and the average annual improvement in energy efficiency before the commencement of PAT has been found to be marginal. The average annual target is found to be smaller than the average	The assessment indicates that although there is a substantial variation in marginal cost of energy efficiency improvement between the iron and steel and the thermal power sector, the lower level of target in PAT cycle 1 might prohibit the

Sl No	Name of criterion	Research question	Guiding questions	Answers to the guiding questions	Summary Response to the research question
		the industry?	power plants and iron and steel sector under the PAT scheme?	annual improvement in energy efficiency in both sectors in recent past. The average annual target for both iron and steel and the thermal power sector under PAT is 1.44%. Whereas the average annual rate of improvement of energy efficiency has been 1.51% and 1.56% for the thermal power and the iron and steel sector respectively.	equalization of maximum marginal cost of energy efficiency improvement across thermal power and the iron and steel sector. Hence in the first cycle, PAT does not appear to be promoting cost-effective improvements in energy efficiency in the thermal power and the iron and steel sector.
			2. What are the indicative marginal cost curves of energy efficiency improvement for thermal power sector and iron and steel sector in India?	Marginal cost curves of thermal power and iron and steel sectors provide evidence of large variation of marginal cost of energy efficiency improvements between these two sectors. For iron and steel marginal cost curve is much less steeper than for the thermal power plants. This indicates that in the iron and steel sector energy efficiency improvement can be achieved in a more cost-effective way as compared to thermal power sector.	
4	Technology	What are the potential barriers that can prohibit PAT in facilitating penetration of energy efficient technologies?	1. What is the potential for energy efficiency improvement for thermal power and iron and steel sectors in India?	The potential for energy efficiency improvement is substantial for both in the thermal power and the iron and steel sector. It is estimated to be 31 million tons of oil equivalents for the thermal power sector and about 16 million tons of oil equivalents for the iron and steel sector.	The assessment indicates that PAT is expected to play an important role in penetration of energy efficient technologies in the thermal power and the iron and steel sector. However, the extent of success of PAT will be particularly dependent on easing of certain technological and institutional barriers that are found to be more significant during the first compliance period of PAT.
			2. What are the potential impacts of the barriers to penetration of energy efficient technologies under PAT?	The barrier analysis indicates that the most important barriers with respect to PAT at present are the technological and institutional. The impact of these barriers on PAT can hamper the potential of PAT in catalyzing penetration of energy efficient technologies for thermal power and steel sectors covered under the PAT scheme.	

5 Conclusion

The objective of this research was to evaluate the first compliance period (2011-14) of Perform Achieve and Trade (PAT) scheme currently proposed in India against four criteria. These four criteria were; (i) design of PAT; (ii) economic efficiency; (iii) cost-effectiveness; and; (iv) assessment of barriers to energy efficiency improvement. The focus of the evaluation was on thermal power and the iron and steel sectors. These two sectors are the two most dominant sectors among all the eight industrial sectors covered under PAT, from the perspective of the share of annual energy consumption. To define the specific scope of assessment, a number of specific guiding questions were also formulated under each of the four criteria.

The design assessment of PAT reveals that PAT provides a number of flexibility to designated consumers with respect to compliance options. This aspect together with the formulation of simple methodological rules with respect to baseline and target setting and compliance assessment are the positive features of the design. The main concerns with respect to design are the lack of a detailed monitoring and verification protocol and low level of penalty which is not found to be a sufficient deterrent to non-compliance. It is learnt during the research that Bureau of Energy Efficiency is currently in the process of preparing a detailed monitoring and verification protocol and is also considering to revise the penalty amount. Addressing these two concerns is deemed to be important to achieve satisfactory performance of PAT.

The evaluation indicates that if the two sectors comply with the energy efficiency target assigned to them, the same would provide significant net positive benefit to the society. Thus it can be said that PAT promises to improve energy consumption behavior in the industry in an economically efficient way.

The cost-effectiveness assessment of PAT indicates that there exist wide variations in the marginal cost of energy efficiency improvement between the thermal power and the iron and steel sector. However, at least in the first cycle of PAT, equalization of maximum marginal cost of energy efficiency improvement is not expected, due to setting of apparently easier level of target for energy efficiency improvements in these sectors. Thus the first cycle of PAT does not promise to enable cost effective energy efficiency improvement in the chosen sectors.

The potential for improvement of energy efficiency has been found to be substantial in both thermal power and the iron and steel sector. The role of PAT is expected to be important, considering PAT is the first regulatory instrument which mandates energy efficiency improvement in the large scale industrial sectors. However certain barriers, particularly the institutional and technological barriers are found to be the most significant which can hamper the performance of the PAT in near future.

In general it can be said on the basis of the assessment, that PAT is a very promising instrument which has the potential to play a major role in providing momentum to the improvement of energy efficiency in Indian industrial sector. The most significant positive aspect of PAT is in its potential to provide substantial net positive socio-economic benefit to the society. However, this socio-economic benefit will be only realised if PAT achieves 100% compliance. Two most important issues which can hinder the 100% compliance level in near future are penalty for non-compliance and institutional barrier. The assessment reveals the present level of penalty does not appear to be a significant deterrent to non-compliance. In addition, institutional barrier with respect to capacity of the government agency in charge of PAT (Bureau of Energy Efficiency) to administer the scheme can be a major hindrance to achieve 100% compliance. Further in future beyond the first compliance period, informational, financial and technological barriers can be a major deterrent for full compliance, unless efforts are taken to alleviate these barriers. Another drawback of PAT at least in its first cycle is the lack of ambitious target. This reduces the cost-effectiveness of the scheme. In absence of cost-effective compliance of energy efficiency targets, the least cost equilibrium outcome of PAT will be prohibited. This in turn will reduce the net positive socio-economic benefits to the society by increasing the total cost of compliance. The transaction cost has been estimated to be nominal in the present format of PAT. However, in future when the scope of PAT is expected to have wider sectorial coverage, unless various barriers are eased, the transaction cost will tend to be higher and in turn will impact both economic efficiency as well as cost-effectiveness of the scheme.

The author of this thesis hopes, that this small research endeavor will provide some meaningful early insights to stakeholders of the PAT scheme, which will help in further improvement of the scheme. Hopefully the research will also help in providing some useful information on the application of market based instruments in Indian context.

A logical next step from this research is to assess the actual performance of the PAT scheme in its post-implementation phase. Hopefully this research can provide some foundation to the potential future research endeavors on PAT.

A number of other potential research areas have also been identified during the course of the thesis. These include; (i) quantification of transaction cost to energy efficiency improvement in various energy consuming sectors in India; (ii) quantification of local and global externality of Indian coal fired power plants; and; (iii) the impact of behavioural, managerial and organisational barrier to energy efficiency improvement in Indian corporations.

Bibliography

Agriculture Carbon Market Working Group. ("n.d"). *Critical mass: China, India and the United States are working together to mitigate climate change.* Retrieved from http://www.agcarbonmarkets.com/documents/ACMWG%20White%20Paper_China%20and%20India_Final.pdf

American Iron and Steel Institute. (2005). *Saving one barrel of oil per ton (SOBOT): A new roadmap for transformation of steel making process.* Retrieved from http://www.climatevision.gov/pdfs/Saving_1005.pdf

Babu, K.L., & Manasi, S. (2007). Evaluation of present pollution control regime in India. *Current Science, 93(4).* Retrieved from http://www.ias.ac.in/currsci/aug252007/443.pdf

Balachandra, P., Ravindranath, D., & Ravindranath, N.H. (2010). Energy efficiency in India: Assessing the policy regimes and their impacts. *Energy Policy, 38*, 6428-6438.

Bambawale, M.J., & Sovacool, B.K. (2011). India's energy security: A sample of business, government, civil society, and university perspectives. *Energy Policy, 39*, 1254-1264.

Banerjee, R. (2005). *Energy efficiency and demand side management: Background paper submitted to Integrated Energy Policy Committee, Government of India.* Retrieved from http://www.whrc.org/policy/pdf/India/EEDSMMay05%20%28sent%20by%20Rangan%20Banerjee%29.pdf

Bureau of Energy Efficiency (BEE). (2011). *PAT consultation document: 2010-11.* New Delhi: Bureau of Energy Efficiency

Bertoldi, P., & Rezessy, S., (2006). Tradable certificates for energy savings (white certificates). Theory and practice. (No. EUR 22196 EN), Institute for Environment and Sustainability. European Commission Joint Research Centre.

Bhattacharyya, S.C. (1997). An estimation of environmental costs of coal-based thermal power generation in India. *International Journal of Energy Research, 21*, 289-298.

Bohi, D., & Burtraw, D. (1997). SO_2 allowance trading: How do expectations and experience measure Up?. *The Electricity Journal, 10(7)*, 67-75.

Burtraw, D. (1996), The SO2 emissions trading program: Cost savings without allowance trades. *Contemporary Economic Policy, 14,* 79-94.

Central Electricity Authority. (2006). *Review of performance of thermal power stations 2005-06.* Retrieved from http://www.cea.nic.in/reports/yearly/thermal_perfm_review_rep/0506/COVER%20PAGE.pdf

Central Electricity Authority. (2007). *Review of performance of thermal power stations 2006-07.* Retrieved from http://www.cea.nic.in/reports/yearly/thermal_perfm_review_rep/0607/highlights.pdf

Central Electricity Authority. (2008). *Review of performance of thermal power stations 2007-08.* Retrieved from http://www.cea.nic.in/reports/yearly/thermal_perfm_review_rep/0708Final/0_Coverpage.pdf

Central Electricity Authority. (2009). *Review of performance of thermal power stations 2008-09.* Retrieved from http://www.cea.nic.in/reports/yearly/thermal_perfm_review_rep/0809/Highlights.pdf

Central Electricity Authority. (2010). *Review of performance of thermal power stations 2009-10.* Retrieved from http://www.cea.nic.in/reports/yearly/thermal_perfm_review_rep/0910/highlights.pdf

Central Electricity Authority. (2011). CO_2 baseline database for the Indian power sector: User guide, version 06. Retrieved from http://www.cea.nic.in/reports/planning/cdm_co2/user_guide_ver6.pdf

Central Electricity Regulatory Commission of India. (2009). *Terms and conditions of tariff, regulations for 2009-14.* Retrieved from http://www.cercind.gov.in/Current_reg.html

Climate Connect, UK. (2011 April 27). PAT list of target being approved by Ministry of Law, final scheme document to release soon. *Climate Connect, UK.* Retrieved from http://www.climate-connect.co.uk/Home/?q=node/571

Coase, R. (1960). The problem of social cost. *Journal of Law and Economics*, 3, 1–44.

Construction update.com. (2010 March). Partial risk guarantee fund is guarantee reserve account to pay participating banks in the event of default. *Construction update.com.* Retrieved from http://www.constructionupdate.com/News.aspx?nId=EHTQStRW9lONlpc/0tHPzw==&NewsType=PRGF-is-guarantee-reserve-account-to-pay-participating-banks-in-the-event-of-default-India-Sector

DeCanio, S.J. (1993). Barriers within firms to energy-efficient investments. *Energy Policy, 21(9)*, 906-914.

Delio, E.A., Lall, S., & Singh, C. (2009). *Powering up: The investment potential of energy service companies in India*. Retrieved from http://pdf.wri.org/powering_up_full_report.pdf

Doucet, J., & Strauss, T. (1994). On the bundling of coal and sulphur dioxide emissions allowances. *Energy Policy, 22(9)*, 764-770.

Dube, S., Awasthi, R., & Dhariwal, V. (2011). Can the learning's from international examples make the Perform Achieve and Trade (PAT) scheme perform better for India. Retrived from http://www.emergent-ventures.com/UploadedFiles/Videos/A%20Discussion%20Paper%20on%20India%27s%20Perform%20%20Achieve%20and%20Trade%20%28PAT%29%20Scheme.pdf

Dutta, M., & Mukherjee, S. (2010). An outlook into energy consumption in large scale industries in India: The case of steel, aluminium and cement. *Energy Policy, 38*, 7286-7298.

Ellerman, D., & Montero, J. (1998). The declining trend in sulfur dioxide emissions: Implications for allowance

Prices.*Journal of Environmental Economics and Management, 36*, 26-45.

Ellerman, D., Schmalensee, R., Joskow, P., Montero, J., & Bailey, E. (1997). *Emissions Trading Under the U.S. Acid Rain Program: Evaluation of Compliance Costs and Allowance Market Performance*. Cambridge: MIT Center for Energy and Environmental Policy Research.

European Commission. (2003). *External costs: Research results on socio-environmental damages due to electricity and transport.* Brussels: European Commission.

European Parliament. (2008). *Press release: European Parliament seals climate change package*. Retrieved from http://www.europarl.europa.eu/news/expert/infopress_page/064-44858-350-12-51-911-20081216IPR44857-15-12-2008-2008-false/default_en.htm

Government of India. (2008). *National action plan on climate change*. Retrieved from http://india.gov.in/allimpfrms/alldocs/15651.doc

Graus, W.H.J., Voogt, M., & Worell, E. (2007). International comparison of energy efficiency of fossil power generation. *Energy Policy, 35*, 3936-3951.

Gupta, S. (2002). *Environmental benefits and cost savings through market-based instruments: An application using state-level data from India, working paper number 111*. Retrieved from http://www.cdedse.org/pdf/work111.pdf

Gupta, S. (2003). *Implementing Kyoto-type flexibility mechanism for India: issues and prospects.* This paper was prepared for the OECD Global Forum on Sustainable Development: Emissions Trading and Concerted Action on Tradable Emissions Permits (CATEP) Country Forum held on March 17-18 at OECD Headquarters in Paris. Retrieved from http://www.ccsindia.org/ccsindia/policy/enviro/articles/sg_cde_working_paper.pdf

Hahn, R.W., & Hester, G.L. (1989a). Marketable permits: lessons for theory and practice. *Ecology Law Quarterly, 16*, 361-406.

Hahn, R.W., & Hester, G.L. (1989b).Where did all the markets go? An analysis of EPA's emissions trading program. *Yale Journal of Regulation, 6*, 109-153.

Hasler, D. (2009). Coal-fired power plant heat rate reductions. Retrieved from http://www.epa.gov/airmarkets/resource/docs/coalfired.pdf

International Energy Agency (IEA). (2009). *Key world energy statistics*. Paris: International Energy Agency

Jones, G.R., & Butler, J.E. (1988). Costs, revenue, and business-level strategy. *The academy of management review, 13(2)*, 202-213.

JSW Steel Limited. (2006). *Breaking barriers: Annual report 2005-2006*. Retrieved from http://www.jsw.in/investor_zone/pdf/Annual_Results/2006.pdf

JSW Steel Limited. (2007). *The spirit of challenge: 2006-2007 annual report*. Retrieved from http://www.jsw.in/investor_zone/pdf/Annual_Results/2007.pdf

JSW Steel Limited. (2008). *Annual report 2007-2008: Spreading the josh across the world*. Retrieved from http://www.jsw.in/investor_zone/pdf/Annual_Results/2008.pdf

JSW Steel Limited. (2009). *Annual report 2008-2009: The challengers*. Retrieved from http://www.jsw.in/investor_zone/pdf/Annual_Results/JSW%20Steel%20Full%202009.pdf

JSW Steel Limited. (2010). *Sustained growth through foresight: Annual report 2009-2010*. Retrieved from http://www.jsw.in/investor_zone/pdf/Annual_Results/JSW%20Steel%20Full%202010.pdf

Kerr, S., & Mare, D. (1998). *Efficient regulation through tradeable permit markets: The United States lead phasedown*. Retrieved from http://www.motu.org.nz/files/docs/MEL0259.pdf

Krishnan, S.S., Narang, N., Dolly, S.K., King, R., & Subrahmanian E. (2010). Proceedings from Infrastructure systems and services: Next generation infrastructure systems for eco-cities (INFRA), third international conference '2010. *Global mechanism to create energy efficient and low-carbon infrastructure: An Indian perspective.* Shenzhen: IEEE.

Kossoy, A., Ambrosi, P. (2010). State and trends of the carbon market 2010. Washington, DC: World Bank

Kumar, R., Robins, N., Chaturvedi, A.K., Srinivasan, R., & Gupta, J. (1996). *Incentives for eco-efficiency lessons from an evaluation of policy alternatives: A case study of the steel sector in India, working paper number 11*. Retrieved from http://www.uneptie.org/shared/publications/other/webx0072xpa/manual_cdrom/cplinks/pdfs/creed11e.pdf

Langniss, O., & Praetorius, B. (2006). How much market do market-based instruments create? An analysis for the case of white certificates. *Energy Policy, 34 (2)*, 200–211.

Lees, E. (2007). *European experience of white certificates*. Retrieved from http://www.worldenergy.org/documents/white_certificate.pdf

Mallah, S., & Bansal, N.K. (2009). Allocation of energy resources for power generation in India: Business as usual and energy efficiency. *Energy Policy, 38*, 1059-1066.

Menard, C. E., (Ed.) 2004a. *Transaction Costs and Property Rights*. Cheltenham, UK; Northampton, MA, USA: Elgar Reference Collection.

Ministry of Environment and Forest, Government of India. (2007). *India: Addressing energy security and climate change*. Retrieved from http://www.moef.nic.in/divisions/ccd/Addressing_CC_09-10-07.pdf

Ministry of Environment and Forest, Government of India. (2010). *India: Greenhouse gas emissions 2007*. Retrieved from http://moef.nic.in/downloads/public-information/Report_INCCA.pdf

Ministry of Power and Bureau of Energy Efficiency. (2008). National mission for enhanced energy efficiency. Retrieved from http://www.indiaenvironmentportal.org.in/files/National%20Mission%20for%20Enhanced%20Energy.pdf

Ministry of Steel, Government of India. (2010). Annual report 2009-2010. Retrieved from http://steel.nic.in/Annual%20Report%20%282009-10%29/English/Annual%20Report%20%282009-10%29.pdf

Monjon, S. (2006). The French energy savings certificate system, IEA-DSM Task XIV on markets mechanisms for 'White Certificates' trading. Trondheim, Norway.

Montero, J.P. (1997). Marketable pollution permits with uncertainty and transaction costs. *Resource and Energy Economics, 20*, 27–50.

Mundaca, L. (2007). Transaction costs of tradable white certificate schemes: The energy efficiency commitment as case study. *Energy Policy, 35*, 4340-4354.

Mundaca,L., & Neij, L. (2009). A multi-criteria evaluation framework for tradable white certificate schemes. *Energy Policy, 37*, 4557- 4573.

Nagesha,N., & Balachandra, P. (2006). Barriers to energy efficiency in small industry clusters: Multi-criteria-based prioritization using the analytic hierarchy process. *Energy*, 31, 1969-1983.

Nandi, P., & Basu, S. (2008). A review of energy conservation initiatives by the Government of India. *Renewable and Sustainable Energy Reviews, 12*, 518-530.

National Development and Reform Commission, People's Republic of China. (2007). China's National Climate Change Program. Retrieved from http://www.ccchina.gov.cn/WebSite/CCChina/UpFile/File188.pdf

Newell, R. and Stavins, R.N. (1999). Abatement cost heterogeneity and potential gains from market-based instruments, working paper, John F. Kennedy School of Government, Harvard University.

Nix,O., Layke,J., Supple, D., Montgomery, S.J., Wani, H., & Dharia, A. (2011). Unlocking energy performance contracting in India. Retrieved from http://www.institutebe.com/InstituteBE/media/Library/Resources/Energy%20and%20Climate%20Policy/IB_EPC-India_r1.pdf

Painuly, J.P., & Reddy, B.S. (1996). Electricity conservation programs—barriers to their implementations. *Energy Sources, 18*, 257–67.

Painuly, J.P. (2009). Financing energy efficiency: Lessons from experience in India and China. *International Journal of Energy Sector Management, 3(3)*, 293-307.

Parikh, K.S., Karandikar, V., Rana, A., & Dani, P. (2009). Projecting India's energy requirements for policy formulation. *Energy, 34,* 928-941.

Pavan, M., 2002. What's up in Italy? Market liberalization, tariff regulation and incentives to promote energy efficiency in end use. Paper presented at the American Council for an Energy Efficiency Economy—Summer study on energy efficiency in buildings, Pacific Grove, California. August 18–23, 2002.

Petroleum Conservation Research Association of India. (2009). Chapter 9 – Iron and steel industry. In, *A ready reckoner on energy conservation measures: Practical guide to energy conservation* (pp. 293-321). New Delhi: Petroleum Conservation Research Association of India.

PEW Center on Global Climate Change. ("nd"). At a glance: American Clean Energy and Security Act of 2009. Retrieved from http://www.pewclimate.org/docUploads/Waxman-Markey-short-summary-revised-June26.pdf

Planning Commission, Government of India (2005). Draft report of the expert committee on integrated energy policy. New Delhi: Planning Commission, Government of India.

Press Trust of India. (2011 May 26). DGH to summon RIL next month on falling KG-D6 output. *Livemint.com & The Wall Street Journal*. Retrieved from http://www.livemint.com/2011/04/22182909/DGH-to-summon-RIL-next-month-o.html?h=B

Priyadarshini, K., & Gupta, O.K. (2003). Compliance to environmental regulations: *The Indian context. International Journal of Business and Economics,* 2(1), 9-26.

Rafaj, P., & Kypreos, S. (2007). Internalisation of external cost in the power generation sector: Analysis with global multi-regional MARKAL model. *Energy Policy, 35*, 828-843.

Rashtriya Ispat Nigam Limited (RINL). (2006). 24th annual report 2005-06. Retrieved from http://www.vizagsteel.com/images/fin%20result%200506%20ENGLISH_PDF.PDF

Rashtriya Ispat Nigam Limited (RINL). (2007). 25th annual report 2006-07. Retrieved from http://www.vizagsteel.com/images/English%202006-07.PDF

Rashtriya Ispat Nigam Limited (RINL). (2008). 26th annual report 2007-08. Retrieved from http://www.vizagsteel.com/images/English%202007-08.PDF

Rashtriya Ispat Nigam Limited (RINL). (2009). 27th annual report 2008-09. Retrieved from http://www.vizagsteel.com/images/Annual%20Report%202008-09%20%28English%29.pdf

Rashtriya Ispat Nigam Limited (RINL). (2010). 28th annual report 2009-10. Retrieved from http://www.vizagsteel.com/images/Annual%20Report%202009-10%20%28English%29.pdf

Reddy, A.K.N. (1991). Barriers to improvement in energy efficiency. *Energy Policy, 19(10)*, 953-961.

Reddy, B.S. (2003). Overcoming the energy efficiency gap in India's household sector. *Energy Policy, 31*, 1117-1127.

Reserve Bank of India. (2010). *Table 39: Wholesale price index-annual average*. Retrieved from http://rbidocs.rbi.org.in/rdocs/Publications/PDFs/80219.pdf

Reserve Bank of India (2011). *Exchange rates*. Retrieved from http://www.rbi.org.in/home.aspx

Rico, R. (1995). The U.S. allowance trading system for sulfur dioxide: An update of market experience. *Environmental and Resource Economics*, *5(2)*, 115-129.

Robins,N., Knight, Z., & Saravanan, D. (2011 May 11). Top 10 catalysts for clean energy policy change. *Climate Spectator*. Retrieved from http://www.climatespectator.com.au/commentary/top-10-catalysts-clean-energy-policy-change

Rossi, P., Lipsey, M., Freeman, H. (Eds.), 2004. *Evaluation. A Systematic Approach* (Seventh ed.). Thousand Oaks: SAGE Publications

Sathaye,J., & Phadke, A. (2004). *Cost and carbon emissions of coal and combined cycle power plants in India: Implications for costs of climate mitigation projects in a nascent market*. Retrieved from http://eetd.lbl.gov/ea/IES/iespubs/52915.pdf

Sathaye, J.A., de la Rue du Can, S., Kumar, S., Iyer, M., Galitsky, C., Phadke, A., . . . Padmanabhan, S. (2006). *Implementing end-use efficiency improvements in India: Drawing from experience in the U.S. and other countries*. Retrieved from http://eetd.lbl.gov/ea/ies/iespubs/60035.pdf

Sawhney, A. (1997). *A review of market based instruments for pollution control: Implications for India*. This paper was prepared as a background paper for the Taskforce report of the Ministry of Environment and Forest, Government of India. Retrieved from http://www.nipfp.org.in/working_paper/wp_1997_02.pdf

Shanmugam, K.R., & Kulshreshtha, P. (2005). Efficiency analysis of coal- based thermal power generation in India during post reform era. *International Journal of Global Energy Issues*, 23(1), 15-28.

Singhal, K.K. (2009). *Energy efficiency in steel industry and Clean Development Mechanism (CDM)* [PDF document]. Retrieved from http://www.teamorissa.org/Convention_%20Presentations_%20Sessionwise/Session-1/Session1-2%20Energy_Efficiency%20_PPT_2.pdf

Sinha, N., & Kumar, N.V. (2009). Energy efficiency management in India: A supply side perspective. *International Journal of Energy Technology and Policy, 7(1)*, 63-77.

Stavins, R.N. (1998). What have we learned from the grand policy experiment: Lessons from SO_2 allowance trading. *Journal of Economic Perspectives, 12(3),* 69-88.

Stavins, R.N. (2001). Experience with market-based environmental policy instruments. In K.G Maler & J. Vincent (Eds.), *The handbook of environmental economics* (pp. 1-88). Amsterdam: Elsevier Science.

Stavins, R.N. (2004). Environmental Economics. In: Durlauf, S., Blume, L. (Eds.), *The New Palgrave Dictionary of Economics* (Second ed). Palgrave: Macmillan.

Steel Authority of India Limited. (2006). *Annual report 2005-06*. Retrieved from http://www.sail.co.in/SAIL-Annual%20Report-06.pdf

Steel Authority of India Limited. (2007). *Annual report 2006-07*. Retrieved from http://www.sail.co.in/SAIL-Annual%20Report-06-07.pdf

Steel Authority of India Limited. (2008). *Annual report 2007-08*. Retrieved from http://www.sail.co.in/report2007-08.zip

Steel Authority of India Limited. (2009). *Annual report 2008-09*. Retrieved from http://www.sail.co.in/pdf/report2008-09.zip

Steel Authority of India Limited. (2010). *Annual report 2009-10*. Retrieved from http://www.sail.co.in/pdf/report-2009-2010.zip

Tata Iron and Steel Company. (2006). 99th annual report 2005-2006. Retrieved from http://www.tatasteel.com/investors/pdf/annual05-06.pdf

Tata Iron and Steel Company. (2007). 100th annual report 2006-2007. Retrieved from http://www.tatasteel.com/investors/pdf/100-Annualreport.pdf

Tata Iron and Steel Company. (2008). 101st annual report 2007-2008. Retrieved from http://www.tatasteel.com/investors/annual-report-07-08/annual-report-07-08.pdf

Tata Iron and Steel Company. (2009). 102nd annual report 2008-2009. Retrieved from http://www.tatasteel.com/investors/annual-report-2008-09/annual-report-2008-09.pdf

Tata Iron and Steel Company. (2010). 103rd annual report 2009-2010. Retrieved from http://www.tatasteel.com/investors/annual-report-2009-10/annual-report-2009-10.pdf

Taylor, R.P., Govindarajalu, C., Levin, J., Meyer, A.S., & Ward, W.A. (2008). *Financing energy efficiency: Lessons from Brazil, China, India and beyond*. Washington DC: World Bank

The Companies Act. (1956). Bill number 1 of 1956. The Gazette of India.

The Energy and Resource Institute. (2008). Mitigation options for India: The role of the international community. New Delhi: The Energy and Resource Institute.

The Energy Conservation (Amendment) Bill. (2010). Bill number 18 of 2010. The Gazette of India.

The Energy Conservation Act. (2001). Bill number 52 of 2001. The Gazette of India.

U.S. Department of Agriculture Economic Research Service. (2009). India: Basic information. Retrieved from http://www.ers.usda.gov/Briefing/India/Basicinformation.htm

Umashankar, S. (2010 Dec 15). An unsteady first step. *Down to Earth*. Retrieved from http://www.downtoearth.org.in/node/2347

United Nations Statistics Division. (2010). *Carbon dioxide emissions (CO2), thousand metric tons of CO2 (CDIAC).*Retrieved from http://mdgs.un.org/unsd/mdg/SeriesDetail.aspx?srid=749&crid=

Weber, L. (1997). Some reflections on barriers to efficient use of energy. *Energy Policy, 25(10)*, 833-835.

Appendix

1. Details of energy efficient technologies assessed for the computation of indicative marginal coat curve of energy efficiency improvement for coal fired power plants in India are presented in Table 0-1 below.

Table 0-1 Details of energy efficient technologies for coal fired power plants

Technology Designation	Name of the technology	Net heat rate reduction (kCal/kWh)	Capital cost (USD)			Fixed annual operating cost (USD)			Variable annual operating cost (USD)		
			200 MW	**500 MW**	**900 MW**	**200 MW**	**500 MW**	**900 MW**	**200 MW**	**500 MW**	**900 MW**
A	Boiler feed pump heat rate reductions in turbine system	9.45	300,000	550,000	750,000	0	0	0	0	0	0
B	Condenser heat rate reductions in turbine system	12.6	0	0	0	30,000	60,000	80,000	0	0	0
C	Intelligent Soot Blowers and heat rate reduction in boiler system	22.68	300,000	500,000	500,000	50,000	50,000	50,000	0	0	0
D	Neural Network heat rate reduction in boiler system	25.2	500,000	750,000	750,000	50,000	50,000	50,000	0	0	0
E	Turbine overhaul heat rate reduction	50.4	7,000,000	12,000,000	15,000,000	0	0	0	0	0	0
F	Variable Frequency Drive (only) heat rate reductions in flue gas Systems	15.12	1,750,000	3,500,000	5,500,000	20,000	30,000	50,000	0	0	0
G	Flue Gas Desulferization (FGD) system modification heat rate reductions in emission control system	6.3	500,000	1,500,000	2,500,000	25,000	50,000	75,000	0	0	0
H	Economiser heat rate reduction in boiler system	18.9	2,500,000	4,500,000	7,500,000	50,000	100,000	150,000	0	0	0
I	Air heater and duct leakage	6.3	400,000	650,000	1,100,000	50,000	75,000	100,000	0	0	0

Technology Designation	Name of the technology	Net heat rate reduction (kCal/kWh)	Capital cost (USD)			Fixed annual operating cost (USD)			Variable annual operating cost (USD)		
			200 MW	500 MW	900 MW	200 MW	500 MW	900 MW	200 MW	500 MW	900 MW
	control heat rate reduction in boiler system										
J	Cooling tower advanced packing upgrade heat rate reductions in water treatment system	8.82	1,500,000	3,000,000	5,000,000	37,500	62,500	87,500	0	0	0
K	Combined environmental technology system modification	8.19	850,000	2,250,000	4,000,000	50,000	87,500	137,500	25,000	60,000	100,000
L	Combined variable frequency drive and fan heat rate reductions in flue gas systems	20.16	6,250,000	10,000,000	15,500,000	25,000	38,000	60,000	0	0	0
M	Acid dew point control heat rate reduction boiler system	21.42	2,500,000	6,250,000	10,750,000	50,000	75,000	100,000	260,000	637,500	1,125,000
N	Electro Static Precipitator (ESP) system modification heat rate reductions in emission control system	0.63	100,000	250,000	400,000	12,500	12,500	12,500	0	0	0
O	Selective Catalytic Reduction (SCR) system modification heat rate reductions in emission control system	1.26	250,000	500,000	1,000,000	12,500	25,000	50,000	25,000	60,000	100,000
P	Induced Draft (ID) axial fan (and motor) heat rate reductions in flue gas systems	7.56	6,250,000	10,000,000	15,500,000	50,000	85,000	130,000	0	0	0

Source: Hasler (2009)

2. Details of energy efficient technologies assessed for the computation of indicative marginal coat curve of energy efficiency improvement in iron and steel sector in India are presented in Table 0-2 below.

Table 0-2 Details of energy efficient technologies for iron and steel sector

Technology Designation	**Name of the technology**	**Energy Savings per year**[34]	**Capital Cost (USD equivalent)**	**Key assumptions**
A	Installation of appropriate/smaller capacity CW pumps in captive power plant of the steel plant (general utility)	936,000 kWh	35,000	Capacity of the captive power plant 14.25 MW
B	Use of variable frequency drives on FD fans and ID fans instead of existing inlet (general utility)	880,000 kWh	135,000	FD fan rating: 275 KW ID fan rating: 310 KW. Number of FD fans: 2 Number of ID fans: 2
C	High frequency melting machine (steel making process)	3,600,000 kWh	900,000	Rating of low frequency melting machine: 750 KW Rating of high frequency melting machine: 1,500 KW Melting speed of low frequency melting machine: 910 kg/h Melting speed of high frequency melting machine: 1,550 kg/h
D	DC arc furnace with with water cooled furnace oil (steel making process)	35,277,656 kWh	9,000,000	Capacity of the electric arc furnace: 140 ton/h
E	Control of excess air by installing O2 monitoring system in high pressure boiler of CPP in a steel plant (general utility)	1,363 toe	11,000	% of excess O2 reduction: 7% Excess air reduction: 150%

[34] Steel making is a complex process and often the energy savings are both in thermal as well as electrical. Excpet for the cases where the savings are purely electrical, energy savings are expressed in toe.

Technology Designation	Name of the technology	Energy Savings per year[34]	Capital Cost (USD equivalent)	Key assumptions
				Capacity of the boiler: 73.6 tons per hour Baseline boiler efficiency: 79.1% Improvement in efficiency: 4%
F	Automatic combustion control of coke oven (iron making process)	8,934 toe	3,555,000	Capacity of coke oven: 1500 k tons/annum
G	Sensible heat recovery from main exhaust gas of sintering machine (iron making process)	7,234 toe	3,555,000	Capacity of the waste heat boiler: 10 tons/ hour
H	Coke dry quenching (iron making process)	63,729 toe	51,100,000	Capacity of the coke oven: 150 tons/hour
I	Improvement in segregated charging of sintering materials (iron making process)	6,693 toe	1,700,000	Reduction in specific coke consumption: 2.8 kg/ton of sinter Reduction in coal addition rate: 0.54%
J	Blast furnace top pressure recovery turbine (iron making process)	29,176 toe	13,350,000	Capacity of top pressure recovery turbine is 18 MW
K	Blast furnace hot blast valve control system(iron making process)	3,690 toe	1,800,000	Hot metal production capacity: 3000 k tons/annum
L	Hot stove exhaust heat recovery equipment(iron making process)	8,324 toe	4,400,000	Heat recovery @ 30,000 kCal/tcs for a crude steel production capacity of 3,000 k tons/annum
M	Continuous casting machine (steel making process)	22,260 toe	720,000	Steel production capacity: 1,200,000 tons/year
N	Basic Oxygen Furnace Exhaust gas recovery device (steel making process)	411,720 toe	18,000,000	Capacity of basic Oxygen furnace: 250 tons/hour

Technology Designation	Name of the technology	Energy Savings per year[34]	Capital Cost (USD equivalent)	Key assumptions
O	Energy savings operation of electric arc furnaces (steel making process)	515 toe	90,000	Capacity of electric arc furnace: 123,000 tons/annum
P	Coal drying and humidity control equipment for coke oven (iron making process)	19,200 toe	17,700,000	Coal handling capacity: 3200 k tons/annum
Q	Raw Material Pre heater for electric arc furnace (steel making process)	17,914 toe	9,800,000	Capacity of the electric arc furnace is 150 tons/hour
R	Ladle heating apparatus with regenerative burners (steel making process)	659 toe	220,000	Reduction in fuel consumption during heating: 80 Nm3/hour Reduction in fuel consumption during soaking: Nm3/hour
S	Ferro alloy furnace for effective energy utilization (steel making process)	12,570 toe	8,800,000	Rating of electric furnace: 10,000 KVA
T	Hot charging and direct rolling mill (steel making process)	15,000 toe	4,440,000	Crude steel production: 3000 tons/annum
U	Recovery of sensible heat from skid cooling water in heating furnace (general utilities)	19,737 toe	17,000,000	Quantity of recovered steam: 9 tons/hour at a pressure of 12 kg/cm2
V	Pulverized coal injection system for blast furnace (iron making process)	16,699 toe	27,700,000	Pig iron production capacity of 3,000 k tons/year
W	Descaling pump (steel making process)	1,148 toe	1,700,000	Number of pump: 1 Reduction in power load: 1070 KW
X	Low temperature forge welded pipe production method (steel making process)	6,436	11,100,000	Production capacity of pipe: 50,000 tons/month

Source: Petroleum Conservation Research Association of India (2009)

3. The estimation of cost of energy for production for 1 ton of crude steel is presented in Table 0-3 below.

Table 0-3 Cost of energy estimation for 1 ton of crude steel (tcs) production in India

Electricity production cost									
	2007-2008			2008-2009			2009-2010		
	TISCO	SAIL	JSW	TISCO	SAIL	JSW	TISCO	SAIL	JSW
Production of crude steel (1000 tons)	5,013	13,962	3,626	5,646	13,409	3,724	6,560	13,500	5,987
Electricity purchase (Million KWh)	2,031.07	6,483	192.14	2,194.54	6,495	808.28	2,439.47	6,631	1,743.5
Average rate of electricity purchased (INR/KWh)	2.74	3.13	4.47	2.9	3.43	4.63	2.81	3.46	3.52
Own generation through diesel (Million KWh)	14.05	0	101.3	12.48	0	53.3	12.86	0	56.2
cost of electricity from diesel (INR/KWh)	12.27	0	4.29	15.91	0	4.83	15.74	0	5.32
Own generation through coal (Million KWh)	996.85	895	1,520.12	1,069.45	902	1,797.24	997.93	797	2,204.9
Cost of electricity from coal (INR/KWh)	1.88	3.67	1.99	2.05	4.15	3.05	2.08	4.67	2.62
own generation through top recovery turbine (Million KWh)	0	0	0	0	0	0	0	0	6.86
cost of generation through top recovery turbine (INR/KWh)	0	0	0	0	0	0	0	0	0.64
Weighted Average cost of electricity (INR/KWh)	2.50	3.20	2.38	2.67	3.52	3.57	2.65	3.59	3.04
Weighted average cost of electricity with respect of share of production (INR/KWh)	2.91			3.32			3.23		
Average Cost of electricity (INR/KWh)	3.15								

Unit cost of production for 1 tons of Crude Steel									
	2007-2008			2008-2009			2009-2010		
	TISCO	SAIL	JSW	TISCO	SAIL	JSW	TISCO	SAIL	JSW
Production of crude steel (1000 tonstons)	5,013	13,962	3,626	5,646	13,409	3,724	6,560	13,500	5,987
Electricity (KWh)	412.06	498	0	431.91	500	523	390	498	510
Price of electricity (INR/KWh)	2.50	3.20	2.38	2.67	3.52	3.57	2.65	3.59	3.04
LPG (kg)	0	0	0	0	0	1.3	0	0	1
Price of LPG (INR/kg)	35.23	0	33.914	41.99	0	38.116	34.35	0	33.405
Coking coal (tons)	0.66	1.087	0	0.66	1.108	0	0.62	1.083	0
Rate of coking coal (INR/Tonne)	2,929.54	5,907	5,028	6,055.07	10,181	9,872	5,731.88	8,786	7,996
Light diesel oil (litres)	1.21	0	0	0.83	0	0	0.58	0	0
Rate of light diesel oil (INR/litre)	28.97	0	0	38.481	0	0	34.713	0	0
Fuel oil (litres)	0	5		32.25	4	0	28.44	3	0
Price of fuel oil (INR/litre)	18.108	23.801	20.67	24.13	32.25	26.32	23.15	28.44	25.82
Coke (kgs)	0	50	0	0	20	0	0.00	6	0
Rate of Coke (INR/kg)	0	12.83	14.876	0	20.203	22.006	0.00	23.529	14.056
Non - coking coal (kgs)	0	76	0	0	76	0	0.00	56	0
Price of non-coking coal (INR/kgs)	3.08	1.81	5.03	5.66	1.98	0.00	8.41	2.27	0.00
Energy cost of 1 tonne of crude steel	3000	8910	0	5961	13723	1915	5265	11656	1586
Weighted average cost of energy with respect of share of production (INR/tcs)	7349			9869			7732		
Average cost of energy (INR/tcs)	8316								
Average cost of energy (USD/tcs)	**185**								
Specific Energy Consumption									
	2007-2008			2008-2009			2009-2010		
	TISCO	SAIL	JSW	TISCO	SAIL	JSW	TISCO	SAIL	JSW

Production of crude steel (1000 tons)	5,013	13,962	3,626		5,646	13,409	3,724		6,560	13,500	5,987
Specific Energy Consumption (Gcal/tcs)	6.655	6.95	6.847		6.587	6.74	6.704		6.125	6.72	6.495
Weighted average specific energy consumption	6.868				6.696				6.518		
Average specific energy consumption (Gcal/tcs)	6.69										
Unit cost of energy (INR/kCal)	0.001242323										
Unit cost of energy (USD/Gcal)	**28**										

Source: Tata Iron and Steel Company (TISCO) (2008, 2009, 2010), Steel Authority of India Limited (SAIL) (2008, 2009, 2010), JSW (2008, 2009, 2010)

4. Steel productions of selected companies in India are presented in Table 0-4 below.

*Table 0-4 Steel production of selected companies**

	2005-06	2006-07	2007-08	2008-09	2009-10**
SAIL	13,470	13,506	13,962	13,409	10,175
TATA steel	4,730	5174	5013	5,646	4,867
JSW	2,250	2,652	3,626	3,724	4,490
RINL	3,494	3,497	3,129	2,963	2,308
Other	4,718	5,758	5,912	6,494	5,345

**All figures are in ('000 tons)*
*** Data from April – December*
Source: Ministry of Steel, Government of India 2010

5. Weighted average heat rate and plant load factor for thermal power plants in India are presented in Figure 0-5 below.

Table 0-5 Weighted average heat rate and plant load factor of thermal power plants of India

Year	Weighted average heat rate (kCal/kWh)	Weighted average plant load factor (%)
2006-07	2,861	77.03
2007-08	2,704	78.75
2008-09	2,618	77.22

Source: Central Electricity Authority of India (2007, 2008, 2009)

6. Typical energy balance in Indian iron and steel production process is given in Table 0-6 below.

Table 0-6 Typical Energy balance in Indian iron and steel production for 1 ton of crude steel production

Description	**Quantity of energy**		**Energy in heat value (10^6 kCal)**	
	Consumed	**Produced**	**Consumed**	**Produced**
Coke Oven (per ton of coke)				
Coal (ton)	1.489	-	10.423	-
BF Coke (ton)	-	1.0	-	7.0
Electricity (kWh)	27	-	0.067	-
COG (m^3)	208	416	0.853	1.706
Steam (kg)	100	-	0.087	-
Coke breeze (kg)	-	150	-	1.050
Crude tar (kg)	-	40	-	0.034
Total			11.43	9.79
Net energy consumed per ton of BF coke			1.64	
Net energy consumed per ton of CS (at coke rate of 700 kg and HM ratio of 900 kg)			1.033	
Sinter plant (per ton of sinter)				
Coke breeze (kg)	100	-	0.70	-

Description	Quantity of energy		Energy in heat value (10^6 kCal)	
	Consumed	Produced	Consumed	Produced
Electricity (kWh)	100	-	0.25	-
COG (m^3)	20	-	0.082	-
BFG (m^3)	50	-	0.043	-
Total			1.075	-
Net energy consumed per ton of sinter			1.075	-
Net energy consumed per ton of CS (at sinter rate of 1,000 kg and HM ratio of 900 kg)			0.967	
Blast furnace (per ton of hot metal)				
Coke (kg)	700	-	4.900	
Electricity (kWh)	30	-	0.075	
BFG (m^3)	1,000	2500	0.870	2.075
Steam (kg)	160	-	0.140	-
Total			5.985	2.075
Net energy consumed per ton of hot metal			3.910	
Net energy consumed per ton of CS (at HM ratio of 900 kg)			3.519	
Steel melting shop (per ton of ingots)				
Electricity (kWh)	40	-	0.100	-
Steam (kg)	25	140	0.022	0.122
COG (m^3)	20	-	0.082	-
Oxygen (m^3)	70	-	0.120	-
Total			0.324	0.122
Net energy consumed per ton of CS			0.202	
Slabbing mill (per ton of ingots)				
Electricity (kWh)	45	-	0.112	-
BFG (m^3)	450	-	0.371	-
Total			0.483	
Net energy consumed per ton of CS			0.483	
Hot strip mill (per ton of slabs)				
Electricity (kWh)	150	-	0.375	-
COG (m^3)	140	-	0.574	-
BFG (m^3)	420	-	0.366	-
Steam (kg)	-	50	-	0.043
Total			1.315	0.043
Net energy consumed per ton of slab			1.272	
Net energy consumed per ton of crude steel			1.080	
Cold rolling mill (per ton of CR coils)				
Electricity (kWh)	250	-	0.625	-
Steam (kg)	250	-	0.219	-
COG (m^3)	70	-	0.287	-
BFG (m^3)	210	-	0.183	-
Total			1.314	-

Description	Quantity of energy		Energy in heat value (10^6 kCal)	
	Consumed	Produced	Consumed	Produced
Net energy consumed per ton of cold rolled coils			1.314	-
Net energy consumed per ton of crude steel			1.025	

Source: Petroleum Conservation Research Association of India (2009)

7. List of interviewees are presented below in the table 0-7.

Table 0-7 List of interviewees

Sl No	Name of the interviewees	Designation	Organization	Interview setting
1.	Dr Avinash Patkar	Chief Sustainability Officer	TATA Power	Tele-conference
2.	Mr Ashok S Sethi	Vice President		
3.	Mr. Pranab Mondal	Deputy General Manager	Essar Steel	Telephonic conversation
4.	Mr Aditya Kumar	Senior General Manager	Adhunik Metaliks Limited	Telephonic conversation
5.	Mr Ch Ankarao	Independent Energy Auditor for natural gas based power plants	Not Applicable	Telephonic conversation
6.	Mr. B Laxmi Prasad	Energy Manager	GVK Power and Infrastructure Limited	Telephonic conversation
7.	Mr Saurabh Diddi	Energy Economist	Bureau of Energy Efficiency	Skype chat

8. IRR estimation for quantification of industrial and economic efficiency of thermal power sector under the PAT scheme in presented in table 0-8 below.

Table 0-8 IRR estimation for thermal power sector

Input figures			
Total investment	227,550	INR Millions	
Transaction cost	0.80%	%	
Target efficiency improvement in thermal power sector	4.32%	%	
Total target in savings for the thermal power sector	6.92	mtoe	
Conversion factor from mtoe to GWh	11630		
Total estimated savings	80480	GWh	
Exchange rate of USD to INR	45	INR/USD	
Weighted average cost of coal fired power generattion in India	3.1	USCents/kWh	

Local externality	2.6	USCents/kWh					
Global externality	5.2	USCents/kWh					
IRR Estimation*							
Year	0	1	2	3	4	5	6
Investment	(5,057)**	0	0	0	0	0	0
Transaction cost	(40)	0	0	0	0	0	0
Annual O&M cost		(253)	(253)	(253)	(253)	(253)	(253)
Revenue from energy savings		2,495	2,495	2,495	2,495	2,495	2,495
Positive externality		6,277	6,277	6,277	6,277	6,277	6,277
Cash flow (without externality)	(5,097)	2,242	2,242	2,242	2,242	2,242	2,242
Cash flow (with positive externality)	(5,097)	8,519	8,519	8,519	8,519	8,519	8,519
IRR(industrial efficiency)	**37%**						
IRR (socio-economic efficiency)	**167%**						

** All figures are in million USD*
*** Figures in bracket are negative*

9. IRR estimation for quantification of industrial and economic efficiency of iron and steel sector under the PAT scheme in presented in table 0-9 below.

Table 0-9 IRR estimation for iron and steel sector

Input figures		
Total investment	10,877	INR Millions
Transaction cost	0.80%	%
Total target in savings for the iron and steel sector	1.56	mtoe
Conversion factor of toe to kCal	10000000.00	
Total estimated savings	1.56E+13	kCal
Cost of energy	0.001242323	INR/kCal
Cost of energy	2.76072E-05	USD/kCal

Local Externality	2.6	US Cents/kWh					
Global externality	5.2	US Cents/kWh					
IRR estimation*							
Year	0	1	2	3	4	5	6
Investment	(242)**	0	0	0	0	0	0
Transaction cost	(2)	0	0	0	0	0	0
Annual O&M cost		(12)	(12)	(12)	(12)	(12)	(12)
Savings from energy efficiency improvement		431	431	431	431	431	431
savings from positive externality		1,415	1,415	1,415	1,415	1,415	1,415
Cash flow (without externality)	(244)	419	419	419	419	419	419
Cash flow (with positive externality)	(244)	1,834	1,834	1,834	1,834	1,834	1,834
IRR (Industrial efficiency)	**171%**						
IRR (socio-economic efficiency)	**753%**						

** All figures are in million USD*
*** Figures in bracket are negative*

10. Specific energy consumptions figures of selected companies in the iron and steel sector of India.

Table 0-10 Specific energy consumption of selected companies in the iron and steel sector of India

Year	**Steel Authority of India Limited (SAIL)(GCal/tcs)**	**Rashtryia Ispat Nigam Limited (RINL) (GCal/tcs)**	**Tata Iron and Steel Company (TISCO) (GCal/tcs)**	**JSW Steel Limited (GCal/tcs)**
2005-06	7.24	6.08	6.959	6.37
2006-07	7.16	6.15	6.717	6.1
2007-08	6.95	6.21	6.655	6.847
2008-09	6.74	6.45	6.587	6.704
2009-10	6.72	6.44	6.125	6.495

Source: SAIL (2006, 2007, 2008, 2009 and 2010), TISCO (2006, 2007, 2008, 2009 and 2010), RINL (2006, 2007, 2008, 2009 and 2010) and JSW Steel (2006, 2007, 2008, 2009 and 2010)