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Title: **COST EFFECTIVENESS ANALYSIS OF LOW EMISSION IRON AND STEEL PRODUCTION: A CASE STUDY OF GREATER ACCRA REGION OF GHANA**

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COST EFFECTIVENESS ANALYSIS OF LOW EMISSION IRON AND STEEL PRODUCTION: A CASE STUDY OF GREATER ACCRA REGION OF GHANA

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Summary

The iron and steel sector is the largest industrial energy consumer and largest emission source of greenhouse gases (GHGs) and primary air pollutants. With the growing concern over climate change, steel makers are faced with the challenge of finding ways of lowering CO_2 emissions without seriously undermining process efficiency or considerably adding to costs. Steel is central to Ghana's current infrastructure, housing, manufacturing, agriculture, water and energy supply hence the backbone of economic development. As an emerging economy whose population continues to increase, the demand for steel in the next decade will also increase leading to the use of more fossil fuel and emissions of GHGs and primary air pollutants. In order to minimize these impacts and to deliver a manufacturing strategy based around "low emission", iron and steel industries in Ghana need to adopt a number of innovative and new technological measures that is cost-effective and has the potential to reduce emissions of GHG and unintentionally produced primary air pollutants.

In the following research, assessment of the most cost effectiveness of different measures that will reduce the emission of CO_2 and primary air pollutants in iron and steel industries was conducted. This was conducted by: estimating the annual CO_2 reduction capacity of each measure; estimation of the total operational costs or investment for each pollution abatement measure and calculating and ranking of possible pollution abatement measures based on their cost-effectiveness ($ per year reduced kg CO_2). The result was used to construct marginal abatement cost curves (MACCs). Near net shape casting thin slab was the most cost effective alternative climate and air pollution abatement measure. For the assessment of the current cost effective CO_2 abatement measures, IMF was found to be the most cost-effective production route compared to EAF. Hence, the implementation of these measures will be critical to reach the environmental objectives of low emission iron and steel production.

A comparative assessment of the two major iron and steelmaking route available in Ghana namely electric arc furnace (EAF) and induction melting furnace (IMF) was conducted against a selection of energy consumption and emission (CO_2 eq and priority air pollutants) indicators. The results showed that, EAF has higher energy consumption requirements and emissions than the IMF route. Thus EAF production route has the most significant low emission reduction challenges.

The study also incorporates investigation of barriers that account for the adoption and implementation of low emission measures in Ghanaian iron and steel industries. Results from the barriers interviews revealed that, "lack of budget funding", "access to capital/investment", "high cost of energy", "cost of raw materials and production", "inefficient technology" and "lack of technical skills" are considered to be of high importance. This result provides a good insight for future industrial policies towards low emission manufacturing.

The study recommends further studies into energy efficiency measures, which is among one of the most cost-effective investments that the iron and steel industries could make in improving efficiency and productivity, and reducing CO_2 and local air pollutant emissions. Again further studies into the barriers for adoption and implementation of low emission measures should incorporate views of external stakeholders to give a more comprehensive view of the subject studied and facilitates broad base knowledge suitable for policy implementation.

Keywords

Low emission, Iron and steel industry, Cost-effectiveness, Barriers, Ghana

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Juliana Bempah (September, 2015)
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Abbreviations

AFDB	African Development Bank
AISI	American Iron and Steel Institute
AUSC	Advanced Ultra-Super Critical
BAT	Best Available Technology
BF/BOF	Blast Furnace/Blast Oxygen Furnace
CO_2	Carbon dioxide
CO	Carbon monoxide
CFL	Compact Fluorescent Lamp
DFID	Department for International Development
DRI	Direct Reduced Iron
DSTI	Directorate for Science, Technology and Innovation Steel Committee
DWD	Dagme West District
EAF	Electric Arc Furnace
EIPCCB	European Intergovernmental Panel on Climate Change Bureau
EMS	Environmental Management Systems
G-CAP	Greenhouse Gas Abatement Process
GDP	Gross Domestic Product
GEMA	Ga East Municipal Assembly
GHG	Greenhouse gas
GSS	Ghana Statistical Service
H_2S	Hydrogen Sulphide
HBI	Hot Briquette Iron
HELE	High-Efficiency, Low Emissions
ICT	Information and Communication Technology
IEA	International Energy Agency
IHS	Institute for Housing and Urban Development
IMF	Electric Arc Furnace
IPCC	Intergovernmental Panel on Climate Change
LCI	Life Cycle Inventory
LCD	Low Carbon Development
MACC	Marginal Abatement Cost Curve

MEF	Major Economies Forum
MT	Metric Tonnes
NCCAS	National Climate Change Adaptation Strategy
NOx	Nitrous oxide
OECD	Organization for Economic Co-operation and Development
SO_2	Sulphur dioxide
CSTEP	Center for study of Science, Technology and Policy
TMA	Tema Metropolitan Area
UNDP	United Nations Development Programme
UNIDO	United Nations Industrial Development Organization
UNFCCC	United Nations Framework Convention on Climate Change
UN-Habitat	United Nations Human Settlements Programme
USC	Ultra-Super Critical
VALCO	Volta Aluminium Company
VSD	Viable Speed Drive
WEC	World Energy Council
WEMPA	Water Economic Modelling for Policy Analysis
WRI	WorldSteel Association
WEO	World Energy Organization

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Chapter 1: Introduction

1.1 Background

Globally, there has been a substantial growth of environmental and climate change issues over the past decade with scientific evidence as well as policy attention on most political agendas and Ghana is no exception. Climate change impacts are manifesting on the entire globe and this make developing countries such as Ghana very vulnerable (National Climate Change Adaptation Strategy, 2009). Issues of air quality has been a problem recognized for several decades and its impact has led to a number of strategies which include goals to minimize the risk to public health, improve visual air quality and minimize the region's contribution to climate change (Sustainable Region Initiative, 2011).

The major contributor of environmental health issues is the release of air pollutants including oxides of sulphur, nitrogen dioxide, carbon monoxide and particulates whiles climate change is the increase in greenhouse gases, which cause an increase in the temperature of planet earth. It is equally well established from many scientific investigations that one of the prime culprits of climate change and environmental health problems is carbon dioxide and primary air pollutants. In recognition of the strong connections between climate change and air quality, recent years have seen increasing legislation to manage air quality with actions to manage greenhouse gases (Potgieter, 2012).

For the first time as of 2008, humanity crossed a milestone when the global urban population exceeded the rural population (Seto, Sánchez-Rodríguez, et al., 2010). More than half of the world's 7 billion population is currently living in urban areas (Beall, 2008, UN-Habitat., 2008, UN-Habitat., 2014). Many urban centers are seeing rapid and largely uncontrolled population growth, creating a pattern of rapid urbanization and this is very pronounced in developing countries such as Africa (UN-Habitat., 2011).

The population of Ghana is 24,658,823 million while that of Greater Accra region now stands at 4,010,054 (Ghana Statistical Service, 2014). The Greater Accra region now has a high concentration of population, industries and infrastructure. Studies by Bai (2007) indicate that some cities own or steer key industries relevant to greenhouse gas emissions or other air pollutants such as oxides of sulphur, nitrogen dioxide, carbon monoxide as well as particulates such as soot, flying ash and dust which may contain iron oxides. Information gathered from the Environmental Protection Agency, Accra (Manufacturing Industry Department) indicates there are over 600 manufacturing companies located within the Accra Metropolitan Area. This concentration of industries increases the level of greenhouse gases and other air pollutants being emitted into the environment.

The country's economy is highly dependent on climate sensitive sectors hence the climate change vulnerability assessment conducted indicates that key economic sectors of the country are bound to be affected by the impacts of climate change (Stanturf, Warren, et al., 2011). There are however, acute air pollution episodes being experienced in Greater Accra region (industrial hub of Ghana) as a result of the release of other harmful air pollutants.

Ghana's economy has maintained commendable growth trajectory with an average annual growth of about 6.0 % over the past six years. The economy is expected to maintain robust growth which has been broad-based, driven largely by service-oriented sectors and industry, which on average have been growing at a rate of 9.0 % over five years up to 2013 (AfDB, OECD, et al., 2014). Ghana's total greenhouse gas emission was 30.8 million tonnes (Mt) carbon dioxide-equivalent (CO_2e) in 2012. This represents an increase of 6.9 % on net emissions recorded in 2010, and an increase of 49.3 % and 54 % above 2000 and 1990 levels respectively. Nevertheless, there are emissions of other local air pollutants including oxides of sulphur, nitrogen dioxide, carbon monoxide and particulates that are not accounted for.

The key productive sector (economic activities) that contributes to gaseous emissions in Ghana and the share of total national emissions by sectors includes energy (44 %) of which iron and steel production forms part. Iron and steel industry, like other "heavy" industries has the potential of having a significant impact on the environment and the population of nearby communities. It is also the largest industrial source of air pollutants and CO_2 emissions due to the energy intensity of steel production, its reliance on fossil fuels and reductants, and the large volume of steel produced – over 1414 million tonnes (Mt) in 2010 (Carpenter, 2012).

According to the International Energy Agency (2007), the iron and steel industry accounts for the largest share, approximately 27 % of CO_2 emissions from the global manufacturing sector (IEA, 2007). The industry's combustion process of oxidation produces emits some poison gases such as carbon monoxide, carbon dioxide, sulfur dioxide and sulfur trioxide etc. This stems from the vast amounts of energy required for iron and steel smelting (purifying iron or steel from iron ore) and from several chemical reactions that directly generate CO_2 and other local air pollutants (Bloom, A., 2012).

Annual world steel demand is expected to grow from approximately 1,410 Mt of crude steel in 2010 to approximately 2,200 Mt in 2050 (Hasanbeigi, Morrow, et al., 2012). The bulk of this growth is however, expected to take place in China, India, and other developing countries in Asia and Africa and Ghana is no exception. Today, the world steel industry accounts for between 4 % and 5 % of total man-made greenhouse gases. The average CO_2 intensity for the steel industry is about 1.9 tons of CO_2 per ton of steel produced. Taking into consideration the global steel production of more than 1.3 billion tons, the steel industry produces over two billion tons of CO_2 and major primary air pollutants including SO_2, NOx, CO, H_2S as well as particulate matter (Doushanov, 2009).

This significant increase in steel consumption and production will drive a significant increase in the industry's absolute energy use and CO_2 emissions (Hasanbeigi, Arens, et al., 2014). With the growing concern over climate change, steel makers are faced with the challenge of finding ways of lowering CO_2 emissions without seriously undermining process efficiency or considerably adding to costs (Carpenter, 2012). Again its combustion process of burning heavy oil and natural gas in industrial furnaces for steel production releases the bulk of local gases into the atmosphere and this contributes effectively to environmental damage (Sasi, 2013).

Growing concerns about local air pollutants and GHG emissions from the accelerated growth of iron and steel production pattern and increased awareness of a potential future climate crisis and environmental health issues have made it clear that the environment and the economy can no longer be considered in isolation. Without a global shift to a low-carbon, resource-efficient economy, the world is on track for pushing in the direction of the use of advanced technologies in the wide areas of iron and steel production as well as increasing greenhouse gas (GHG) emissions by 70 % by 2050, and temperature increases of 4-6 °C by the end of the century. China's Beijing and some other big cities environmental problems are among the most severe of any major country, and are mostly getting worse as it is now the 'world's factory'. This pollution spills over into other countries, while other countries affect China's environment through globalization and pollution (Liu and Diamond, 2005).

In addition, several studies conducted in southern and south east Asia (Meng, Fan, et al., , 2012, Sarker, Corradetti, et al., 2012, Zhang, Worrell, et al., 2014, Colenbrander, Gouldson, et al., 2015), Europe (Kundak, Lazić, et al., 2009), USA (Williams, 2005, Bhattacharjee, Drescher, et al., 1999), Australia (Strezov, Evans, et al., 2013) have indicated various environmental impacts of iron and steel industries to cities/urban areas. This is as a result of rapid industrialization and infrastructure development leading to higher steel consumption and consequently increased production requirement in industrialized nations. Although production has increased mainly due to extended plant capacities and introduction of new factories, little attention had been paid to efficient energy utilization and environmental pollution control (Ahmad and Patel, 2012). Hence, successful mitigation in these rapidly developing cities is key to achieving worldwide stabilization in the emissions of GHGs and primary air pollutants emissions (Colenbrander, Gouldson, et al., 2015). These concerns therefore point to the need for a substantial transformation of low emission production technologies (OECD, 2008a).

Presently, Ghana is under the grip of extreme pressure to meet the growing demand for iron and steel for society's technological everyday needs – now and in the future. Steel is central to our current transport systems, infrastructure, housing, manufacturing, agriculture, water and energy supply. It is also critical to the sectors and technologies that will enable and drive a green economy. As an emerging economy, the iron and steel sector is the backbone of economic development and there are several challenges for this sector. However, as the country's population increases, it is expected that emissions of several key air contaminants from the iron and steel production will also rise in the region over the next decade to meet its growing demand. According to the Ghana Statistics Services, industry including iron and steel production sector contributes to 28.6 % to the shares of the economic sectors in 2013 GDP.

Iron and steel industries in the Greater Accra region of Ghana use fossil fuel to generate energy for their production processes. These fuel types consumed by these industries emit CO_2 and local air pollutants. Emissions from CO_2 enhances greenhouse effect and global warming which leads to impacts of climate change while air pollutants are associated with significant health problems including acute respiratory symptoms. Fine particulate matter can impair visual air quality, making it difficult to see and breath. Poor visual air quality can also have a negative impact on the well-being of residents in urban areas (Sustainable Region Initiative, 2011). Again, photochemical pollution/ high concentration of ozone in the atmosphere and acid rain can result from emissions from industries including iron and steel production and this can also have effect on respiratory system, the climate and ecosystems respectively (Williams, 2005, Hao and Guowen, 2009).

Furthermore, Kyoto protocol, an international agreement which is linked to the United Nations Framework on Climate Change (UNFCCC) has been ratified by 183 parties in 2008 and has set legally binding targets for cutting the emissions of six greenhouse gases, mostly pollutants caused by burning coal, oil, and other hydro-carbon fuels by an aggregate 5.2 % from the 1990 levels between the years 2008 and 2012 (Leggett, 2011). Ghana is a signatory to the Kyoto Protocol and has to reduce its GHG emissions even though has no legally binding targets for reducing CO_2 and other gaseous emissions.

CO_2 emissions targets from various sectors including iron and steel are still under development. Energy used by iron and steel industries is highly carbon intensive (about 95 %). This makes it very difficult to meet climate stabilization goals outlined by IPCC without significantly reducing CO_2 emissions (IEA, 2011). Measures are provided by institutions such as permit to regulate emissions and air pollutants. In terms of conscious strategies to enable industries to move along a low carbon manufacturing path is not clearly defined. There are guidelines and few strategies available at the institutional level to ensure low carbon manufacturing but enforcement is still not deeply rooted and there are no policies geared towards that effect.

In order to minimize the impact of all the above mentioned issues and to deliver a manufacturing strategy based around "low emission" iron and steel industries in Ghana, it is clear that those industries will have to adopt a number of innovative and new practices as well as switching to fuels that result in less air pollutants and CO_2 emissions but the same amount of energy, when combusted. It should be fairly obvious that a holistic sustainable fuel type approach and strategies are being called for to ensure survival and prosperity for iron and steel as well as other Ghanaian industries in future, and that it is unlikely that simply addressing one or a few of the challenges ahead whiles leaving behind sustainable fuel technology options will accomplish long term sustainability.

In light of the importance of the iron and steel manufacturing sector as an emitter of GHGs, local air pollutants and in the face of the growing concern about health impacts of air pollution and climate change, analysts have been evaluating long-term manufacturing and energy policies for their potential impact on global climate change. Consequently, the pollution of the environment resulting from the production of steel is closely linked to energy consumption; it has therefore become essential to take care of reducing energy consumption, reducing fuel burning to a minimum and searching for alternative resources, and to protect the environment from air pollution (Sasi, 2013).

Earlier studies by several scientists (Worrell, Laitner, et al., 2003, IEA, 2007, Hasanbeigi, Morrow, et al., 2012) have documented the potential for the worldwide iron and steel industry to save energy by adopting commercially available energy-efficiency technologies and measures. However, in view of the projected continuing increase in absolute steel production, future reductions (e.g., by 2030 or 2050) in absolute energy use, primary air pollutants and CO_2 emissions will require innovation beyond technologies that are available today (Hasanbeigi, Arens, et al., 2014).

Meanwhile, stringent measures and studies to ensure better developments and technologies critical to the industry's climate change mitigation strategies for the mid and long term, as well as the identification of sector-specific and commercially available cross-cutting energy-efficiency technologies for the iron and steel industry have already been initiated in developed states including United States of America, European Union, Asia (American Iron and Steel Institute (AISI), 2010, Worrell, 2011, Hasanbeigi, Arens, et al., 2014).

In the case of third world nations, information regarding energy-efficiency and low-carbon measures for the iron and steel industry as well as other manufacturing industries is limited and not easily accessible. In countries where they exist, measures are poorly developed or non-existent. This may be due to (i) lack of financial support for scientific research; (ii) the limited number of governmental and non-governmental agencies that will raise concerns about environmental quality; and (iii) the lack of environmental policy and regulations.

Iron and steel making technologies and fuels are described as a key supply-side strategy to reducing GHG emissions and primary air pollutants; hence this research will also seek to comparatively assess the two major iron and steel making routes available in Ghana (electric arc furnace and induction melting furnace) and their climate abatement measures.

1.2 Problem Statement

The iron and steel industry is the largest industrial energy consumer and largest emission source of GHG and air pollutants. The industry is highly dependent on fossil fuels use for production of steel. The principal GHG and primary air pollutants emitted from iron and steel production is CO_2, CO, HC, SOx, NOx with specific air-borne particulates (dust, flying ash, smoke, fog, soot and fumes) emissions depending on the production process. Yet little is known about the relative contributions of these sources to pollution levels in Greater Accra region, where the urban population is growing faster than any other region; neither is it known how the source diversity affects pollution chemistry, which may in turn affect both health hazards and impacts on anthropogenic climate change.

Accelerated deployment of energy-efficient and low emission iron and steel manufacturing measures has significant potential to reduce primary air pollutants and GHG emissions, while also diminishing other adverse environmental consequences associated with industrial operations. Unlocking energy efficiency and low emission manufacturing in this sector involves unique challenges including developing and implementing air quality management actions that reduce primary air pollutants leading to meet health-based air quality objectives. Most energy used in the iron and steel production sector is predominately derived from fossil fuels and expanding supply increases greenhouse gas emissions and primary air pollutants. These primary air pollutants have adverse health effects given the number of people that live in close proximity to the industry (Halsnæs and Garg, 2011).

A low emission iron and steel industry is an alternative to minimize the output of GHG and primary air pollutants emissions, which specifically refers to gaseous pollutants (CO, HC, SOx, NOx) and solid air-borne particulates (dust, flying ash, smoke, fog, soot and fumes) into the environment. However, in many settings, low carbon energy has been expensive than high carbon energy (Halsnæs and Garg, 2011, Jacobs, 2012) and faces high risks due to relative capital intensity, technical unfamiliarity and complicated permit process (Schmidt, 2014).

Iron and steel manufacturers are under increasing pressure from stakeholders and stricter regulations to reduce the environmental impact of their activities. The basic approaches to reduce GHG emissions and primary air pollutants from the iron and steel making processes normally involves the introduction of low emission measures such as upgrading the efficiency of fuel consuming equipment/machinery and low-emission technologies.

Nevertheless, this depends on innovations or adoption of commercially available energy-efficiency measures to save energy and reduce GHG as well as primary air pollutants emissions in iron and steel production sector. New developments that will include different technologies that can economically capture and store the industry's CO_2 emissions and reduce environmental impacts of primary air pollutants will be critical to the industry's climate change mitigation strategies and public health issues (Metz, Davidson, et al., 2005).

Alternative form of iron and steel production routes will also reduce emissions from this sector and this is driven by economic viability, raw materials availability, energy type used, energy cost and regulatory regime as well as the willingness of individual industries to appreciate the need to reduce emissions and air pollutants. Low emission iron and steel manufacturing has been proposed globally as a means to avoid catastrophic climate change, adverse health effects resulting from primary air pollutants in urban centers and as a precursor to the more advanced, zero-carbon society and a renewable-energy economy (Colenbrander, Gouldson, et al., 2015).

1.3 Research Objective

The main objective of this thesis is to assess the cost effectiveness of different measures that will reduce CO_2 emission and primary air pollutants levels in iron and steel industry in the Greater Accra Region of Ghana.

1.4 Research Question

- What is the cost effectiveness of alternative climate and air pollution abatement measures at the iron and steel industry in the Greater Accra region in Ghana and the barriers for adoption and implementation of low emission measures by the iron and steel production industry in Greater Accra?

1.5 Sub-Questions

- What are the iron and steel production routes used in Greater Accra Region of Ghana and which one is the most cost effective?
- What is the cost effectiveness of the current low emission measures used in iron and steel industry in the Greater Accra Region of Ghana?
- What is the cost effectiveness of the best available technologies (BAT) for low emission iron and steel production in the Greater Accra Region of Ghana?

- What barriers account for the adoption and implementation of low emission measures by the iron and steel production industry in Greater Accra Region of Ghana?

1.6 Significance of the Study

The main arguments for conducting this research in low emission manufacturing in iron and steelmaking industries, is that iron and steel industry is the largest industrial source of global CO_2 and primary air pollutants emissions due to the energy intensity of steel production, its reliance on fossil fuels and reductants (IEA CCC Report, 2014). With the growing concern over climate change, steel makers are faced with the challenge of finding ways of lowering CO_2 and its associated primary air pollutants emissions without seriously undermining process efficiency or considerably adding to costs. In many cases, implementing the best available climate abatement measures is among one of the most cost-effective investments that the industry could make in improving efficiency and productivity, whiles reducing CO_2 and unintentionally produced primary air pollutants emissions.

In addition, a comparative assessment of the two major iron and steelmaking production routes (electric arc furnace and induction melting furnace) used in Ghanaian iron and steelmaking industries against a selection of energy consumption and emission (CO_2 eq and priority air pollutants) parameters will contribute to a better understanding of emission reduction and facilitate the adoption of the most cost effective alternative climate and air pollution abatement measures at the iron and steel making industries in Ghana.

Further, the most cost-effectiveness analysis of alternative climate and air pollution abatement measures was conducted in steelmaking industries and the results used to construct marginal abatement cost (MAC) curves. The curves showed the relationship between the marginal costs (the cost of the last unit/extra cost) of emission abatement for the identified pollution abatement measures. The results of the cost-effectiveness analysis provided important directions for the future prioritization of best available technologies within the economic sectors towards low emission iron and steel manufacturing. Again, the selection of the most cost effective climate and air pollution abatement technologies and measures by the iron and steel production industries were critical to reach the reduction of emissions emanating from iron and steel production as well as serving as a key economic input into the preparation of the low emission iron and steelmaking management plans.

The research on barriers for adoption and implementation of low emission iron and steel technologies was important for exploring why climate and air pollution abatement technologies and measures failed to be implemented. The results on the barriers issues revealed factors inhibiting low emission manufacturing in Ghanaian steel industries and provided a good insight for future industrial policies towards low emission manufacturing.

1.7 Scope and Limitations

This thesis is based on quantitative and qualitative studies of low emission measures in the Ghanaian iron and steelmaking industry. The main focus of the thesis is in two folds: First, the assessment of the most cost effectiveness of different alternative climate abatement measures that would not only reduce GHG and primary air pollutants emission but also decrease the energy consumption and extra energy consumed by end-of-pipe options in iron and steelmaking industries and secondly, the barriers that account for the adoption of climate and air pollution abatement technologies and measures by the iron and steel production industry in Greater Accra.

In the assessment of the most cost effective alternative climate and air pollution abatement measures studies, one main limitation in the analysis is the availability of cost data. In many cases the evaluation of costs and effects is based on expert judgment as widely applies in Europe (van Soesbergen, Brouwer, et al., 2008) and other secondary sources (Worrell, Bernstein, et al., 2009, American Iron and Steel Institute (AISI), 2010, Galama, 2013). However, this thesis carried out the cost-effectiveness analysis based on some available data and information acquired through interviews and discussions with managers and engineering staffs of the respective steelmaking firms which was subsequently confirmed from government records (EPA-Akoben Report, 2014).

Due to time limitations, driving forces and factors that motivate or promote the adoption of the most cost effective low emission investments as well as investments for auxiliary equipment, such as energy efficient and distribution systems, were not included in the analysis.

Ethical issues such as trust were one of the limitations encountered throughout the whole investigation process (interviews) in barriers for low emission manufacturing implementation. Low emission is a sensitive issue to the energy intensive industries, especially when industries think exposing certain details of their company may bring negative impact for the development of their respective companies.

Externalities such as detailed health and safety issues and other environmental impact besides CO_2 and primary air pollutants emissions were beyond the scope of this study.

CHAPTER 2: Literature Review

2.0 State of the Art and Literature Review

[Keywords: Low emission, Sustainable development, Energy use in iron and steel industry, Abatement and mitigation options and Assessment methods,]

This paper will answer four questions: What are the iron and steel production routes used in the Greater Accra Region of Ghana and which one is the most cost effective?; What is the cost effectiveness of the current low emission measures used in iron and steel industry in the Greater Accra Region of Ghana? What is the cost effectiveness of the best available technologies (BAT) for low emission iron and steel production in the Greater Accra Region of Ghana?; What barriers account for the adoption of the low emission technologies and measures by the iron and steel production industry in Greater Accra of Ghana?

These questions are based on the foundation of exploring the cost effectiveness of different climate abatement measures on choice of technologies that will reduce CO_2 emission levels in iron and steel industry in Greater Accra region of Ghana. I will therefore apply five bodies of literature, one discussing the concept of low emission manufacturing, two, discussing technologies for sustainable development, three, discussing energy technology use in iron and steel production, four, discussing cost- effectiveness and abatement potential of possible alternative measures and technologies for GHGs reduction for the iron and steel making industry and five discussing barriers that account for the adoption and implementation of low emission measures by the iron and steel production industry.

2.1 Basic Concepts and Measurements of Low Emission

Increased production rates of iron and steel promote economic wealth; however they impose challenges to emissions associated with iron and steelmaking processing. Low emissions in iron and steel industry refer to measures for mitigating air pollution and CO_2 emissions associated with steel production. A key emphasis is to accelerate the uptake of low emission fuels and measures. There are range of indicators that defines emissions of air pollutants and greenhouse gases. Worldsteel Association (2012) for example provides a list of indicators which are based on environmental sustainability (greenhouse gas emissions, energy intensity, material efficiency and environmental management systems), social sustainability (lost time injury frequency rate and employee training) and economic sustainability (investment in new processes and products and economic value distributed). Strezov et. al., 2013, also defines sustainability indicators based on economic parameters, greenhouse gas emissions, freshwater consumption, land use requirements and air pollution. In this study, three low emission indicators will be used which are directly linked to these literature. Therefore low emission related indicators are defined as energy efficiency, greenhouse gas emissions and air pollutants. These indicators take care of emission reductions in iron and steel production industry.

2.1.1 Greenhouse-Gas Emissions

The greenhouse gas of most relevance to the world steel industry is carbon dioxide (CO_2), as it makes up approximately 93 % of all steel industry greenhouse gas emissions. On average, 1.8 tonnes of carbon dioxide are emitted for every tonne of steel produced (World Steel Association, 2014).

Technological advancements over the past 25 years have enabled substantial reductions in CO_2 emissions from steel production. These advancements include: energy efficiency in the steelmaking process; improved steel recycling rates; increased recycling and utilization of by-products from steelmaking and extensive process automation for precise control of steelmaking processes (World Steel Association, 2014).

2.1.2 Energy Efficiency

The efficient use of energy has always been one of the steel industry's key priorities. Cost is a key incentive for this, considering that energy purchases account for 20-40% of the total input costs for steel producers (World Steel Association, 2014). Lowering these costs has therefore become one of the most important priorities for steel producers (Horvath L., 2012). Energy efficiency which can be defined as using less energy for the same or even increased output is increasingly being recognized as one of the most important and cost-effective solutions to reduce greenhouse gas (GHG) emissions. Along with the benefits to the environment, successful energy efficiency projects also typically improve a company's overall efficiency, including by increasing productivity and competiveness (DSTI, 2015). Compared to energy conservation implying a change in consumers' behaviour, energy efficiency focuses 13 more on adoption of measures to reduce the energy consumption without change of relevant behaviour and in other words, reducing energy consumption through applying effective measures rather than produce or consume fewer products in production or daily life (Ou, 2013).

Modern steel production processes are now very close to their theoretical minimum energy and CO_2 intensity per tonne of steel output. Technology transfer and spread of best practice can be made through medium-term improvements which can make a significant difference in energy and CO_2 intensity in the long-term, however, it requires new low-carbon breakthrough steelmaking technology (World Steel Association, 2014).

2.1.3 Material Efficiency

Material efficiency in industrial production, on the other hand, can be defined as the amount of a particular material needed to produce a particular product. Material efficiency can be improved either by reducing the amount of the material contained in the final product ("lightweighting"), or by reducing the amount of material that enters the production process but ends up in the waste stream (Peck and Chipman, 2007). Material efficiency is promoted through innovative design for reuse and the development of high-strength steels that allow for dematerialization.

Three components of material efficiency can therefore be identified: light-weighting in the production process; waste reduction in the production process; and recycling of material in the production-consumption cycle (Peck and Chipman, 2007). Recovered by-products can be recycled during the steelmaking process or sold for use by other industries and this supports the sustainability of the steel industry. It prevents landfill waste, reduces CO_2 and other primary air pollutants emissions and helps preserve natural resources. The sale of by-products is also economically sustainable. It generates revenues for steel producers, creates jobs, and forms the base of a lucrative worldwide industry (World Steel Association, 2014).

2.1.4 Environmental Management System (EMS)

An EMS helps iron and steel industries to monitor and improve its environmental performance and to increase its operating efficiency. Most iron and steel companies develop EMS with the aim to decrease the adverse environmental impacts of production, achieve compliance with environmental regulations, improve the company's competitive stance on the open market, reduce production costs, and improve public access to environmental information. Effective EMS results in significant reduction in energy and material consumption leading to environmental and economic benefits. Less consumption of resources and less waste means less impact on the environment and more economic savings.

2.2 Description of Iron and Steel Industry

Production of iron and steel can be categorized into two namely primary/ integrated iron and secondary (steel plant) production routes. Production of steel is accomplished using several interrelated processes which includes (1) coke production; (2) sinter production; (3) iron production; (4) raw steel production; (5) ladle metallurgy; (6) continuous casting; (7) hot and cold rolling; and (8) finished product preparation. The operations for secondary steelmaking, where ferrous scrap is recycled by melting and refining in electric arc furnaces (EAF) entails only (4) through (8) above (US-EPA., 2015). Steel production that occur at an integrated facility uses iron ore as its main raw material while secondary facilities uses recycled steel scrap as the sole feed. Raw steel is produced using a basic oxygen furnace from pig iron produced by the blast furnace and then processed into finished steel products. Secondary steel making most often occurs in electric arc furnaces (EAFs) (Yellishetty, Mudd, et al., 2011).

There are two major variants of steel making through electric technology and this includes Electrical Arc Furnace (EAF), Induction Melting Furnace (IMF) and submerged arc furnace (SAF) (Krishnan, Vunnam, et al., 2013). However, in Ghana, EAF and IMF routes are used for the production of steel. Electric furnaces are favoured over other types of furnaces for steel making. The factors for this being that electric furnaces produce high temperatures as compared to other furnaces allowing quick rise and control of temperatures, lower exhaust gas losses as compared to conventional furnaces as well as concentration of heating (Central Pollution Control Board, 2010). This study again indicates that several reasons such as less energy consumption, less environmental pollution, lesser quantity of refractory use makes IMF technology more popular as compared to EAF. Furthermore, expenditure on electrode is nil and the initial investment is less on plant and equipment in relation to EAF. Thus there are economic advantages in making steel through induction furnaces route compared to EAF (Central Pollution

Control Board, 2010). Figure 2.1 shows schematic drawing of the routes of production in iron and steel industry.

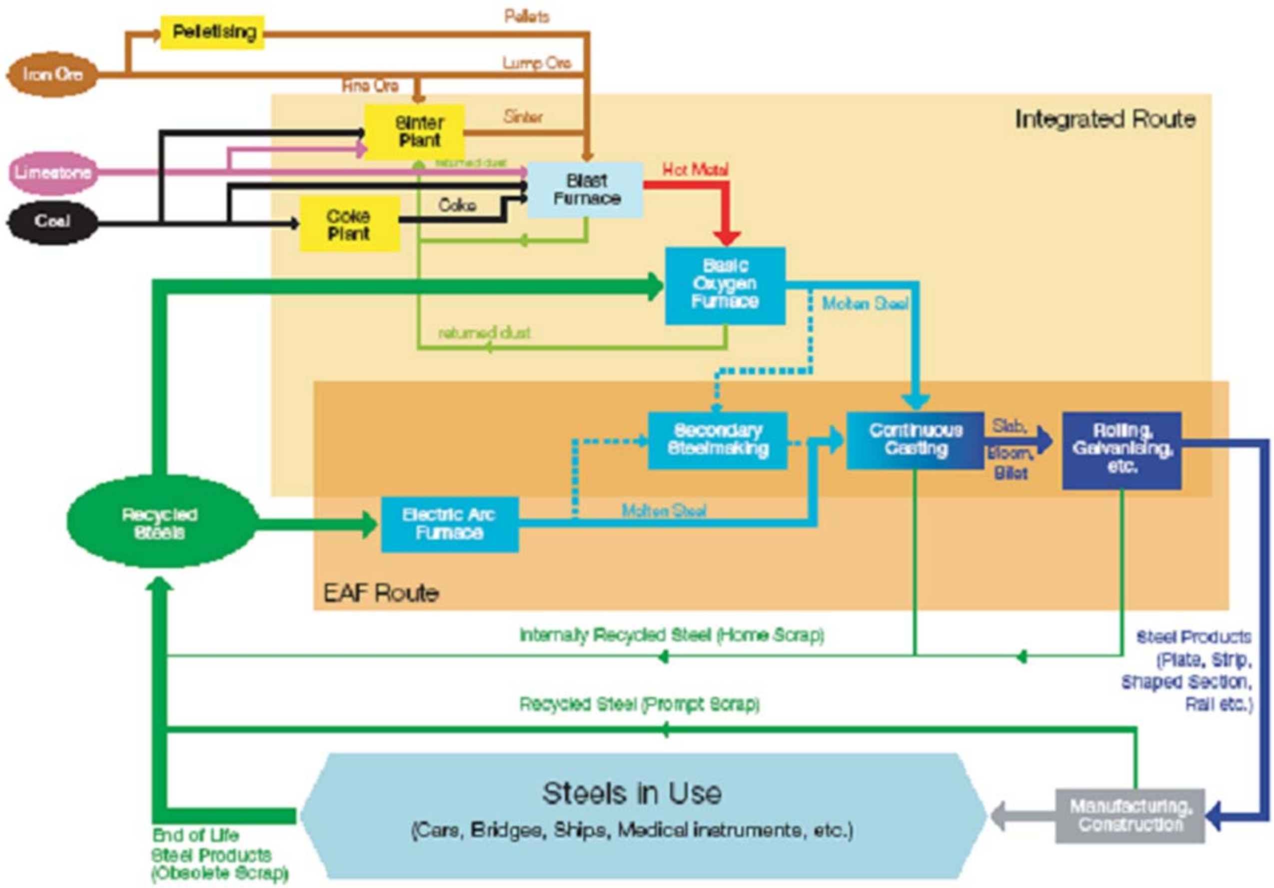

Figure 2.1 shows schematic drawing of the routes of production in iron and steel industry (US-EPA., 2015)

2.3 Sustainable Development for Iron and Steel Sector

Fruehan (2009) cited by (Strezov, Evans, et al., 2013) defines sustainable steelmaking goals as (i) conservation of natural resources: reduction of greenhouse gas emissions; reduction of volatile emissions; reduction of landfill waste and reduction of hazardous waste. However, Worldsteel Association (2012) provides a list of eight sustainability indicators based on environmental sustainability (greenhouse gas emissions, energy intensity, material efficiency and environmental management systems), social sustainability (lost time injury frequency rate and employee training) and economic sustainability (investment in new processes and products and economic value distributed). In the context of this study, sustainable development is defined with the consumption needs for iron and steel, and emission rates of greenhouse gases and priority pollutants to the atmosphere, relative to the industrial economic input. For this reason, the sustainability indicators selected for this study were the energy consumption in GJ/t of produced steel in case of EAF/IMF, greenhouse gas emissions expressed in t CO2 eq/t of produced steel or iron, and emission of priority air pollutants (NOx, SO_2, CO, PM_{10}, $PM_{2.5}$).

2.3.1 Iron and Steel Sector and GHG Emissions

Globally, energy-intensive industries like the iron and steel emit the largest share of industrial GHG emissions and it is of no doubt that in many countries the steel industry would have to face stringent environmental regulations, like the IPPC Directive in the EU or new rules for the emission trading mechanisms, after the entry into force of the Kyoto Protocol (Institute of Prospective Technological Studies Technical Report Series, 2003). Moreover, most of the energy consumed by the sector is generated from the consumption of fossil fuels.

Global steel industry with production of 1,129 Mt in 2005 emits 2,200 to 2,500 $MtCO_2$ or about 6 % to 7 % of global anthropogenic emissions (Worrell, Bernstein, et al., 2009), including emissions from coke manufacture and indirect emissions due to power consumption. Emissions per tonne of steel vary widely between countries: 1.25 tCO_2 in Brazil, 1.6 tCO_2 in Korea and Mexico, 2.0 tCO_2 in the USA, and 3.1 to 3.8 tCO_2 in China and India (Worrell, Bernstein, et al., 2009). The differences are based on the production routes used, product mix, production energy efficiency, fuel mix, carbon intensity of the fuel mix, and electricity carbon intensity (Intergovernmental Panel on Climate Change. Working Group 3, Metz, et al., 2007).

Global energy consumption of the iron and steel sector in 1990 was 12 % of the total annual energy consumption (Levine and Martin, 1995). The related CO_2 emissions were 1425 $MtCO_2$. World steel production increased from 200 Mt in 1950 to 847 in 2001, and is expected to grow further in the future, due to the increasing demand in developing countries (Worrell, Bernstein, et al., 2009). Hence reducing these emissions from iron and steel production sector must be an important part of climate change mitigation programs both at local and national levels. According to Institute of Prospective Technological Studies Technical Report Series (2003), the growth rate of greenhouse gas emissions in the iron and steel sector is the highest among all the energy end-user sectors.

For the Ghanaian iron and steel industry, CO_2 emissions and mitigation potentials through the adoption of energy efficiency measures are not well explored and analysis of energy sources, regionally or locally, is fairly limited. Energy consumption is the single largest source of carbon dioxide emissions in the iron and steel sector, which contribute to global environmental problems. Several valuable works have been identified, that deal with carbon emissions measurements reduction/mitigation prospects, and industrial energy efficiency, specifically regarding the Iron and steel industry in relation with climate change (Sarker, Corradetti, et al., 2012).

2.3.2 Iron and Steel Sector and Primary Air Pollutants Emissions

Air pollutants from iron and steel-making operations have historically been an environmental concern. The consumption of fuel and electricity is especially high in this process. The emission of air pollutants such as NOx, SO_2, CO_2, and CO is inappropriately high due to high fuel consumption and inefficient combustion. In addition, particulates such as soot and dust which may contain iron oxides have been the focus of control (Spiegel, 2011).

Air pollutants from iron and steel production processes vary with particular processes such as the engineering and construction of the production plant, the raw materials used, the source, amount and energy type required, the extent to which waste products are stored and recycled and the efficiency of the pollution control technology. The most important primary air pollutants that are emitted from the production of iron and steel include dust, NOx, SOx, PM_{10}, $PM_{2.5}$ etc. Notable among them is the coke which is a precursor for steel production worldwide and emits large quantity of dust, NOx, SOx and particulate matter (Spiegel, 2011).

SO_2 is largely formed in the combustion processes and depends primarily on the sulphur content of the fossil fuel used in the industry. Both coke and coke-oven gas used as fuels is the major sources of sulphur dioxide which has serious environmental health problem such as respiratory diseases. Like the sulphur oxides, oxides of nitrogen (NOx) are formed in fuel combustion processes and have serious environmental problems when they react with oxygen and volatile organic compounds in the presence of ultraviolet radiation to form ozone. Particulate matter is the most visible form of pollution emitted from the iron and steel industry and may enter the air during their loading and transport. They are normally generated in the sintering, smelting and melting processes, particularly when molten iron comes in contact with air to form iron oxides (Spiegel, 2011).

2.3.3 The Impact of Low Emission Iron and Steel Industry to the City/Urban Residence

The term 'low emission development' has now entered the development lexicon in a big way, and has acquired the mantra of common sense in the development camp today. However, there is currently no internationally agreed definition of low emission development. The view of 'using less carbon/emission for growth' expressed in DFID's White Paper (2009) (Maxwell, 2009) appears to be a common feature in what is implied by less carbon/emission (Mulugetta and Urban, 2010).

Urban areas normally generate almost one third of their nations' production while in some countries more than half national output is produced by one city. Cities and urban areas consume 75 % of the world's energy and produce up to 75 % of its GHG and its associated primary air pollutant emissions (OECD, 2010). Urban areas are their nation's innovation hubs, producing almost all patents (Marceau, 2008). Major cities are the epicentre to significantly reduce CO_2 and primary air pollutants emissions and Greater Accra region of Ghana is no exception.

According to Ericsson (2009), advanced technological innovation must take a central role in strategies targeting reduced emissions, particularly in using low emission measures as viable alternatives to 20th century physical infrastructure. Ericsson's 'five-step-plan for a low emission urban development' include: (1) making ICT a central part of national and city strategies and targets for reducing CO_2 emissions, (2) shifting focus from a 20th century physical infrastructure to a 21st century low carbon information infrastructure, (3) encouraging cross-sectorial partnerships with a focus on developing new and innovative services, (4) leading by example and create a level playing field and (5) opening innovation for low carbon/emission solutions.

All the above-mentioned strategic plans for low emission development may incur some impact on the iron and steelmaking industry. The scope and scale of the low emission development impact on iron and steelmaking industry mirror changes in steelmaking technology from improve energy efficiency, GHG and primary air pollutants measures to the most cost effective best available technologies (BAT) measures. Besides the LCD strategies, introduction of renewable energy technologies and energy efficiency solutions as well as cost effective BAT measures, cities will also have to be re-engineered in terms of their industrial set-ups, transport and land-use systems, their facility and urban design principles and the very use patterns they engender (Droege, 2002).

2.4 Energy Use in Iron and Steel Sector

2.4.1 Iron and Steel Production Routes and Their Energy Requirements

Iron and steel is one of the largest industrial emitters of CO_2, accounting for between 6 % and 7 % of anthropogenic CO_2 emissions globally (Kim and Worrell, 2002). There are different types of energy sources found in the basic steel industry in Ghana. Electricity is the most common and mostly used energy sources. Others are natural gas, coal, coke, firewood, furnace oil, diesel, kerosene, petrol, lubricant oil, LPG, and charcoal etc. Petroleum products are found as broad sources for Ghana energy source considering the current hydro-energy challenges the country is facing.

There are however, three main routes to produce steel. The integrated route (about 60 %) is based on the production of iron from iron ore in blast furnaces using mostly coke or coal as a reductant and energy source and subsequently converted to steel in the basic oxygen furnace (BOF). This route of iron production also typically involves the sintering of fines, which is the most polluting component of the iron making process (Strezov, Evans, et al., 2013).

The second route which is also known as the recycling route (about 35 %), uses scrap iron as ferrous resource and is less energy intensive than the integrated route. Steel production from scrap has a lower energy requirement since the scrap has already gone through the reduction process during its previous life cycle. It consumes much less energy (about 80 %) than the integrated or primary route, with CO_2 emissions reduction being a function of the source of electricity (Intergovernmental Panel on Climate Change. Working Group 3, Metz, et al., 2007). The scrap is smelted in an electric arc furnace. Current technology in this route uses electricity as its main source of energy. Hence the route could theoretically be close to CO_2 emission free depending on the energy source and technology used for electricity generation (Morfeldt, Nijs, et al., 2014), The remaining steel production (about 5 %), uses natural gas to direct iron ore reduction (DRI) technologies where the cokemaking requirement is avoided and iron ores are reduced directly to metallic iron with either coal gas or natural gas (via hydrogen and/or CO) as the reductant, to produce a briquetted metallic iron product known as hot briquetted iron (HBI) (Strezov, Evans, et al., 2013). DRI cannot be used in primary steel plants, and is mainly used as an alternative iron input in electric arc furnaces, which can result in a reduction of up to 50 % in CO_2 emissions compared with primary steel making (Intergovernmental Panel on Climate Change. Working Group 3, Metz, et al., 2007). Use of DRI is expected to increase in the future (Hidalgo *et al*., 2005).

Alternative methods for iron making are based on steel and can be produced in an electric arc furnace (EAF) using recycled steel scrap or HBI or mixtures of the two. Although fundamentally different in their approach, these processes all commonly pose environmental and sustainability challenges due to the increasing use of resources, land degradation and emissions of trace metals, greenhouse gases and atmospheric pollutants to the environment (Strezov, Evans, et al., 2013).

2.4.2 Factors Enhancing Energy Efficiency

Enhancing energy efficiency and using clean energy are effective ways to deal with the shortage of energy and the pressure of reducing carbon emission for most countries. However, the cost of using clean energy is high and therefore enhancing energy efficiency is a more operational method as long as the energy used in daily life and production is still primary energy (Ou, 2013). In order to enhance energy efficiency it is important to find what factors influence energy efficiency. There are nine main levels along the steel production value chain that steelmakers can use to reduce their energy consumption and environment impacts. These enhancing factors include the following aspects:

2.4.2.1 Improving the installed base and enhancing operations

Technologies that reduce energy consumption are essential in order to improve energy efficiency. Steel production differs significantly from plant to plant in terms of efficiencies and operational practices. Intergraded steel plants, for example, vary widely in energy consumption depending on the basic technologies they employ. Along the production value chain, the largest absolute differences in energy consumption generally occur in the iron making phase because blast furnaces consume varying amounts of reducing agents, reflecting differing qualities of sinter, coke and pellets as well as different operating models. There are also large variations in fuel consumption among hot stoves based on their respective modes of operation. Out-dated technologies such as open-hearth furnaces and ingot casting also consume considerable amounts of energy. In addition, inefficient reheating furnaces, limited hot charging or inefficient drive systems can increase energy consumption in the solid phase (Rubel, Wortler, et al., 2009).

A major lever for reducing energy use is the direct improvement of the individual aggregates that go into the steelmaking process. For example new state-of-the-art technologies to agglomerate the inputs for the blast furnace nit only consume considerably less energy than the older ones but also create higher-quality coke or sinter, contributing to lower energy consumption in the blast furnace. In addition, modern automation systems can be used to minimize the superfluous use of energy both by optimizing the operation modes of individual production units, such as blast furnace and electric arc furnace and by improving production logistics along the whole process chain (Rubel, Wortler, et al., 2009).

A significant lever for reducing net energy consumption is energy recovery. Especially in the liquid phase of the steel making process, large quantities of superfluous energy can be recovered in the form of heat, pressure and caloric value (of exhaust gases). These forms of energy can be reused in other process steps as sources of heat or electric power. In this context, the improved management and design of energy networks for power, gases or steam allow steelmakers to save additional energy. They can realize further improvement by emptying modern drive systems that combine highly efficient drives with state-of-the-art automation (Rubel, Wortler, et al., 2009).

2.4.2.2 Upgrading industrial power plants

Integrated industrial power plants generate electricity and heat for steel production both from fuels (natural gas) and from gas recovered from the iron and steelmaking processes. This age distribution suggests considerable potential for energy savings. Modern power plants are much more efficient than the older ones. Replacing old and out-dated power plants would allow steelmakers to realize substantial savings in their primary consumption (Rubel et al., 2009). For this reason there is a considerable global interest in new high-efficiency, low-emissions (HELE).

The terms subcritical, supercritical, ultra-supercritical (USC), and advanced ultra-supercritical (AUSC) describe the steam conditions by which electricity is generated in a thermal power plant. HELE technologies center on improvements to the steam cycle, allowing for higher steam temperatures and pressures and the consequent improvement in the steam cycle efficiency. A switch from subcritical to current USC steam conditions raises efficiency by around four to six percentage points. Historically, the majority of pulverized coal-fired plants were based on subcritical steam-cycle technology, but supercritical technology is now widespread, largely due to improvements in boiler tube materials (IEA CCC Report, 2014).

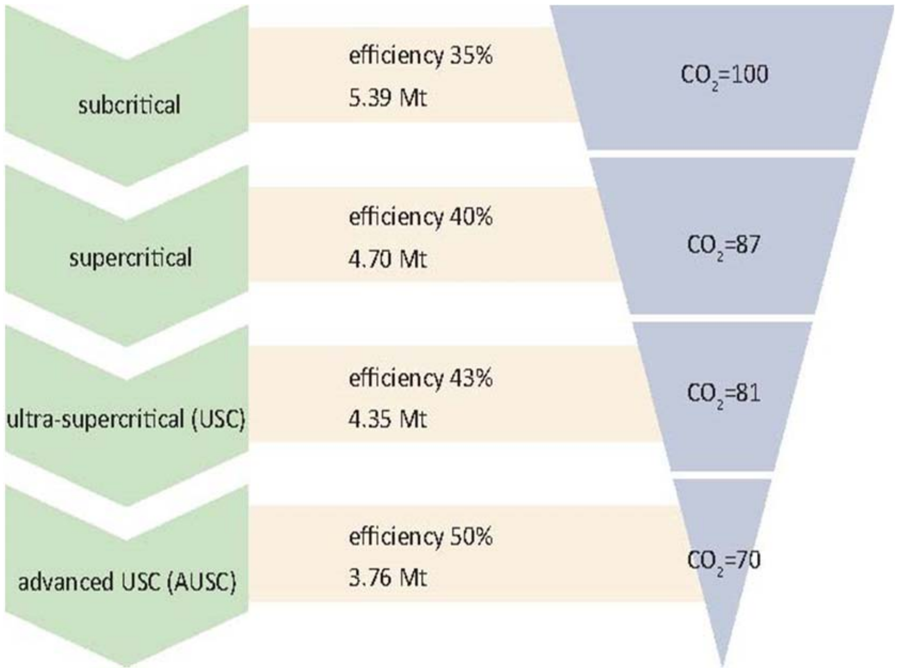

Figure 2.2: The impact of HELE technologies on CO_2 emissions (IEA CCC Report, 2014)

2.4.2.3 Expanding other industries' use of steelmaking by-products

Over the past decades, the steel production has increased and, consequently, the higher volumes of by-products and residues generated have driven to the reuse of these materials in an increasingly efficient way (Branca and Colla, 2012). The most significant by-products of steel production in terms of achieving energy savings in applications outside the steel industry are metallurgical slags (IEA CCC Report, 2014).

In recent years new technologies have been expanded, and some of them are still under developing, in order to improve the recovery rates of slags. On this subject material separation technologies and carbon sequestration could dramatically reduce CO_2 emissions from steelmaking processes. On the other hand, the increase of slags recovery and use in different fields of application, such as in building industry, road and water way construction and agriculture, allowed to reduce landfill slags and to preserve natural resources. In addition to the environmental achievements, these practices produced economic benefits, by providing sustainable solutions that can allow the steel industry to achieve its ambitious target of "zero-waste" in the incoming years (Branca and Colla, 2012).

2.4.2.4 Enhancing the quality of input materials and logistics

At the beginning of the value chain, steelmakers have the opportunities to enhance the quality of input materials such as fuels and ferrous ingredients and to improve logistics. For example by moving production sites closer to mines and by recovering higher scrap rates in steel production.

Using higher quality fuels and ferrous ingredients can theoretically save considerable amount of reducing agents (Rubel, Wortler, et al., 2009).

Optimized resource access is an issue primarily for plants that will be built in the future, so it will not have significant impact on global steelmakers' consumption of transportation energy in the near term. A more promising way to reduce energy consumption is the higher usage of scrap. Mini-mills which base their steel production largely on scrap consumes about half as much as energy as integrated steel works. In the steel industry the use of recycled steel, also called scrap, as a substitute for primary raw materials is an important factor reducing SEC and CO2 emissions (Rubel, Wortler, et al., 2009).

However, due to increased demand for steel and the long life cycles of steel products, there would be insufficient recycled steel available to meet society's demand for steel even if all used steel products were recycled at the end of their life time. In addition to the limited availability of the recycled steel, its price restricts the amount that can be added to the production process (Siitonen, Tuomaala, et al., 2010). According to Worldsteel (2008), the amount of recycled steel in 2006 was equal to about 37% of the crude steel produced that year.

2.4.2.5 Adopting new technologies and alternative production concepts

Although ideas abound, breakthrough energy-saving technologies are not likely to become available for widespread use in steelmaking in the next few years. For example, new reduction methods, such as hydrogen-induced processes, even if proved feasible, will not be commercially available for many years. Moreover, these processes will reduce CO_2 emissions only if nuclear or renewable power sources are used to generate the necessary hydrogen (Rubel, Wortler, et al., 2009).

Alternative concepts already in use, such as coal gasification and natural-gas-based fine-ore processes, are very attractive because they would allow companies to eliminate coking and sintering. But these approaches will have limited impact because their installed bases are so small. However, if they were to be widely adopted, they could save a lot of net energy used and lower net CO_2 emissions if the combustible off-gases are fully recovered and used to generate power and heat. Corex and Finex are currently the most promising concepts for substituting for the emissions and energy-intensive agglomeration and blast-furnace phases in the traditional steelmaking process; both have been well tested in large-scale applications (Rubel, Wortler, et al., 2009).

2.4.2.6 Improving control of environmental pollution

The steelmaking process contains many sources of environmental pollution, all of which call for optimized pollution-control systems. Sintering and coking, for example, generate heavy air pollution, which requires effective dedusting systems and the removal of nitrogen and sulfur compounds. Environmental-protection systems have played an important role in the steel industry for years (Rubel, Wortler, et al., 2009).

The most important area of pollution control over the next several years will be the reduction of CO_2 emissions. The off-gases generated by steelmaking processes, such as blast furnaces or Corex technologies, contain major amounts of carbon dioxide, carbon monoxide, nitrogen, and hydrogen comprising a gas mixture similar to the exhausts of oxyfuel-based power plants. So, in principle, steelmakers could apply the power plants' technology for CO_2 separation, which uses water condensation. However, the issue of subsequent CO_2 storage raises further problems (Rubel, Wortler, et al., 2009).

2.4.2.7 Governmental policies

There is a problem of externality in improving energy efficiency due to the partial character of public goods of energy efficiency. Because the market fails to deal with the issue of externality, governmental interference is needed to complement the market imperfection in energy-efficiency enhancement. Moreover, governmental interference as an external force is sometimes necessary to push the enterprise transformation to achieve the goal of carbon emission reduction (Ou, 2013).

There are five main forms in energy efficient policies or governmental programs: legislation, minimum efficiency standards, mandatory requirements, fiscal measures and voluntary agreements. Countries choose one or several above measures according to the culture and customs. Geller et al. (2006) suggested the application of fiscal measures and voluntary agreements to stimulate energy efficiency improvement. Voluntary agreements are usually complemented by fiscal stimulation, such as tax reduction, subsidies or investment grants and these important measures encourage more industrial units to take part in the energy efficient actions (Ou, 2013).

Again pragmatic energy efficient activities such as educational and energy labelling programs leading to the choice of energy efficient products by consumers as well as, energy audits, energy manager training and energy management systems are also effective way to foster energy efficient awareness and improve energy efficiency.

2.4.2.8 Enterprises management

Technology plays a key role in energy efficiency improvement, however, enterprises receive differential results even they use the same technology. Nowadays, the role of energy management has greatly expanded within the industrial cycles. Top management of the company participates in planning various enterprise strategies and energy management projects on a regular basis (Abdelaziz, Saidur, et al., 2011).

There is a strong correlation between energy efficiency and enterprise management, which means that the companies with better performance in management have high energy efficiency. The annual reports of the many companies should mention the details of energy conservation activities and various achievements by the company regarding energy conservation projects. Effective enterprise management strategies lead to the initiation of very important energy management projects including analysis of historical data; energy audit and accounting; engineering analysis and investments proposals based on feasibility studies and personnel training and information (Abdelaziz, Saidur, et al., 2011).

2.4.2.9 Market competition

Improving energy efficiency of the steel industry not only reduces its energy costs and pollutant emissions, but can also make the industry more competitive. Market competition provides a stimulating effect on efficient allocation of resources; however, improvement of energy efficiency in the enterprises is induced by competition. Currently, research and development investment is an effective way to enhance enterprise's competitiveness. However, enterprise's research and development enthusiasm would be depressed with the decrease of innovative incomes when the market competition has been fierce. Nevertheless research and development ability enhancements help enterprises to improve their competiveness, which is confirmed by some empirical studies (Ou, 2013).

2.4.3 Barriers to Energy Efficiency

Barriers to energy efficiency are not a particularly new topic, as a large body of literature can be found which dates as far back as the late 1970s, in the aftermath of the 1973 energy crisis. Several disciplines including engineering, economics, behavioural and organizational studies have made contributions to understanding barriers to energy efficiency (Sanstad and Howarth, 1994) and several others have investigated barriers to energy efficiency (Cagno and Trianni, 2013, Rohdin and Thollander, 2006, Thollander and Ottosson, 2008, Johansson, 2014, Apeaning and Thollander, 2013). Barriers to energy efficiency include all factors preventing or slowing down the adoption and diffusion of energy efficient measures (Sorrell, Malley, et al., 2004). The taxonomy of barriers are classified into three broad areas which includes economic, organisational and behavioural theories. Economic perspective classifies barriers into access to capital, hidden cost, risk, heterogeneity and imperfect information. Behavioural perspective classifies barriers into form of information, credibility and trust, inertia and values and organisational perspective classifies barriers into power and values (Sanstad and Howarth, 1994). Examples of the various barriers to adopting energy efficiency measures (DSTI, 2015) in iron and steel industry are detailed as follows:

- Organizational barriers and, in particular, a general lack of support from senior management play a key role in slowing the adoption of energy efficiency measures. Often energy efficiency is only seen as an operating expense for which budgets are limited and companies instead focus on their core activity, such as production expansion or improvement.
- A limited knowledge of energy efficiency, as companies often have no readily available access to information about new and existing energy-saving methodologies technologies.
- Perceived technical and operational risks associated with the implementation of energy efficient practices, due to unfamiliarity with energy-reducing technologies and practices relative to core business projects.

- Low or subsidized energy prices in some regions, meaning companies may not pay the full cost of their energy use and have less incentive to reduce consumption. Poor understanding of how to create support for an energy efficiency project, due to the perceived professional and functional boundaries within the organization. For example, staff responsible for handling a company's energy bills is different from staff procuring energy-using equipment, and those maintaining the equipment.
- Limited finances, due to the lack of familiarity with energy efficiency measures, may make companies hesitant about investing in projects that do not have a primary focus on increasing production capacity and revenue. Typically, companies would associate capital investment with company growth and not link this with energy efficiency projects.
- The perceived complexity of environmental management systems implementation, especially where it may also require the installation of hardware (e.g., instrumentation to measure energy and emission streams).

2.5 Abatement Options and Assessment Methods

2.5.1 GHG Abatement Curves

GHG abatement cost curve provide a consistent view of available abatement measures and their related cost, the methodologies that allows for emission reduction opportunities across the major sectors of the economy (Zhang et al., 2014). The Greenhouse Gas Abatement Process (G-CAP) has assisted several steel companies to develop Greenhouse Gas (GHG) management strategies. G-CAP identifies the CO_2 abatement alternatives within the business and the cost/time required to implement them. The key driver for steel producers to use G-CAP has been the emergence of a price on CO_2 emissions (Hatch Report, 2015). What previously could be emitted with no economic consequence to the business now presents significant financial risk. G-CAP provides the method for a business to take control of its abatement opportunities. By analyzing the amount of abatement that is achievable and the cost (in Net Present Value) to achieve it, a strategic plan is developed. The primary output is a Marginal Abatement Cost Curve (MACC) (Hatch Report, 2015).

2.5.2 Marginal Abatement Cost Curves (MACCs)

A Marginal Abatement Cost (MAC) curve is a straightforward way to show options that may be part of a low carbon development pathway, and what the costs and impacts of these alternatives could be. A MACC presents the extra (or 'marginal') costs and carbon reduction (or 'abatement') potential of these options relative to a baseline (Van Tilburg, Würtenberger, et al., 2010). Typical options in a MACC for iron and steel industry include switching to clean energy, improving energy efficiency, environmental management system (EMS) implementation, monitoring and reporting on air and water emissions to prevent limits being exceeded and taking corrective actions if they are exceeded, investing in the development and implementation of clean technologies to prevent pollution at the source, life cycle inventory (LCI) etc. (World Steel Association., 2008).

2.5.3 Stabilization Wedges

The "stabilization wedges" concept is a simple tool for conveying the emissions cuts that can be made to avoid dramatic climate change. Two key features for stabilization wedges are to allow emissions to double versus keeping emissions at current levels for the next 50 years and to predict the emissions-doubling path leading to significant global warming by the end of this century (Hotinski, 2015).

2.5.4 Abatement Cost Perspectives

Abatement cost studies are based on the notion that for a pollution control effort to be efficient, the marginal cost of abating pollution should be similar across plants, firms, industries, and sectors. If such costs are grossly unequal, then maximum environmental protection is not being obtained for the amount of money being spent (Davies and Mazurek, 1998).

A variety of methods such as top-down and bottom-up approach have been used to measure pollution abatement costs. However, there are difficulties of appropriately measuring (or even defining) abatement costs when inputs can contribute to both abatement and production. According to (Gray and Shadbegian, 2003), a bottom-up approach by adding pollution abatement costs to a standard Cobb-Douglas production function in iron and steel production is the preferred option, in that pollution abatement costs are associated with lower productivity levels at steel industry.

2.5.5 Cost Effectiveness of Possible Abatement Measures

GHGs and primary air pollutant emissions from iron and steel sector remains an important environmental issue. Efforts are been made to find the most cost-effective means of reducing GHGs and primary air pollutant emissions that contribute to environmental damage to achieve specific environmental goals (e.g. reduction of harm to human health, ecosystem protection). The International Energy Agency (IEA) states in the WEO-2009 report that by 2030 the energy saving and CO_2 reduction achieved by national policies and measures compared to baseline emissions will be bigger in the industrial sector than in any other final energy consumption sector.

The biggest emission reduction compared to baseline emissions can be achieved in iron and steel and cement sectors: more than half of the reduction of global industrial energy-related CO_2 emissions (Siitonen, Tuomaala, et al., 2010). This calls for additional GHGs emission abatement measures. However, measures need to be cost-effective and excessive costs may provide an argument to (temporarily) loosen goals for a certain area. Within this context the environmental benefits and sector costs of a set of abatement measures for GHG emission from iron and steel industry in Greater Accra Region of Ghana. The final goal is to select cost-effective abatement measures to reduce GHG and primary air pollutant.

The global deployment of current best available technologies (BAT) could deliver energy savings of about 20 % of today's consumption. Given the limited efficiency potential inherent in existing technologies, new technologies such as smelt reduction will be needed. Smelting reduction is a term assigned to a group of upcoming ironmaking processes which aim at overcoming certain fundamental problems of the existing blast furnace route. These problems include dependence on large scale operation, reliance on coking coal, environmental pollution, etc. (Basu, Syamaprasad, et al., 2007).

They can be considered as the latest development in pig iron production and omit coke production by combining the gasification of coal with the melt reduction of iron ore. Fuel switching can also help to reduce emissions. A switch from blast furnaces to gas-based direct reduced iron (DRI) could halve emissions, depending on the availability of cheap stranded gas (IEA, 2007).

Biomass (charcoal), plastic waste and CO_2-free electricity also offers interesting opportunities reducing CO_2 emissions by reducing both emissions from incineration and the demand for fossil fuels. Carbon capture and storage is also an important option that would allow the steelmaking sector to achieve deep reductions in emissions in the future. Large-scale CO_2 capture pilot projects at iron and steel plants must be urgently developed in order to better understand the cost and performance of different CO_2 capture methods (IEA, 2007).

2.5.6 Factors Constraining Best Available Technologies (BAT)

Barriers to BATs include all factors preventing or slowing down the adoption and diffusion of BAT measures. The following three sections review the constraining factors:

2.4.6.1 Counter-productive policies

Energy costs are an important profitability driver for industry, so clear and accurate price signals are crucial motivators of efficiency in the steel sector. For instance, energy subsidies and failure to price emissions of greenhouse gases or other pollutants emissions systematically mute incentives for efficiency investment. Uncertainty about future energy prices may also discourage certain suppliers and manufacturers from investing in the best available technologies; on the other hand, such price volatility may induce others to invest in efficiency as a strategy to reduce profit variability (MEF, 2009).

2.5.6.2 Limited capital availability

High interest rates for borrowing capital may reflect organizations' limited external access to capital and may prevent BAT (and other) projects from being undertaken even if they exhibit a high expected rate of return. Limited access to external capital for capital intensive investments in BAT may stem from financial market imperfections. Insufficient capital is important in determining the best available technologies (UNIDO., 2015). Iron and steel industries may require very high rates of return on all capital investments as a simple strategy to limit the performance risk. This requirement is particularly likely if the long-term market viability of the company is in question. Again management may also simply cap the total investment capital available to facilities managers or workers, effectively forcing them to focus on immediate fixes rather than substantial efficiency upgrades (MEF, 2009).

2.5.6.3 Inadequate information flow

Lack of information on BAT opportunities may lead to cost effective opportunities being missed. An organization's lack of information about energy use, energy efficiency opportunities or the energy performance of technologies may translate into underpin best available technologies. In general, information problems possibly hindering best available technologies in iron and steel sector can be categorized into two broad groups. First, there could be inadequate information on the level and pattern of the better option of technologies to reduce emissions or for energy efficiency. Second, organizations may lack adequate information about specific BATs (UNIDO., 2015).

2.5.6.4 Lack of expertise

Substantial expertise are required to select BAT and integrate them into current operations whiles maintaining them over time, and upgrade them as advancements are made in order to improve operational development in iron and steel industry. Industrial managers can be overwhelmed by the numerous programs that promote BAT, and without in-house energy experts, may find it difficult to trust third-party information. Consultants may lack the industry-specific knowledge necessary to provide accurate BAT services and may use proprietary information gained by working inside a plant to assist competitors (MEF, 2009).

2.5.6.5 Inadequate workforce skills

A highly-skilled workforce drives economic growth and is required to enable diffusion of high-efficiency technologies. After the adoption of BAT measures, employees and managers need continual training to optimize technology performance. Experts have similarly found that a failure to effectively train the workforce responsible for maintaining BAT systems erodes their effectiveness over time (MEF, 2009).

2.5.6.6 Performance risks and high costs for new technology

Technologies that are new to an organization present a number of issues simply because they are new. The lack of a formal process for introducing new technology into steel industry is one of the biggest challenges faced by the sector looking to leverage new products (Tost, 2010). In today's manufacturing environment, where plants often operate almost continuously, integrating new technologies presents reliability and operational risks. Small technology changes, particularly in large integrated process plants, can lead to major changes in process and product performance. Uncertainty about potential new technology adoption and other benefits can be a further disincentive to take action (MEF, 2009)

2.6 Conceptual Framework

In this chapter, I have presented five realms of literature; however, two of them are very important and are useful for my later analysis: the definition and concept of low emission by adopting cost effectiveness of possible alternative climate abatement measures as well as the barriers that prevent the implementation of low emission measures of iron and steel industry in Greater Accra region of Ghana.

I will now present how this will be used to create my analytical framework. For the definition and concept of low emission, there are a number of studies because; it plays an important role in relieving environmental pollution and shortage of energy. However, there is no unified adoption of cost effective abatement measures that jointly reduce greenhouse gas emissions and air pollutants in Greater Accra which is the industrial hub of Ghana. Transforming existing iron and steel production systems in Ghana would require a twin action involving technological changes and improving energy efficiency.

A typical low emission iron and steelmaking approach generally recommends energy efficiency measures that could not only reduce energy consumption and air pollutant emission but also decrease the extra energy consumed by end-of-pipe options to control air pollutant emissions. Based on this, I have chosen to delimit my study to first explore the most cost effective different climate abatement measures on choice of technologies that will reduce CO_2 emissions and barriers that account for the adoption of low emission measures by the iron and steel production. Figure 2.3 shows the conceptual framework of the study.

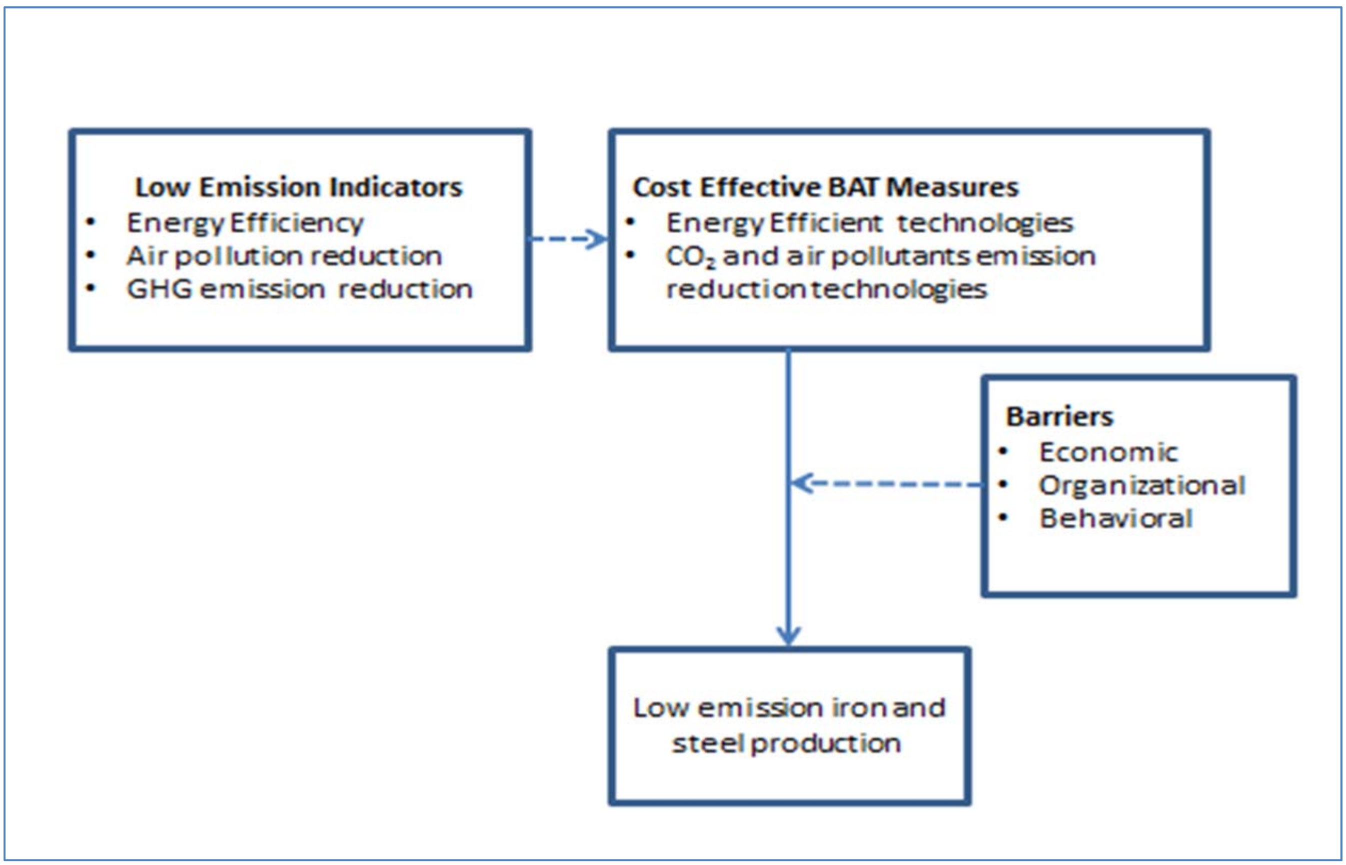

Figure 2.3: Typical approach for low emission iron and steel production.

Secondly, it is important for choosing study objectives and the methodology of my study and in establishing the theoretical framework. Previous studies on the efforts to find the most cost-effective means of reducing GHGs and primary air pollutant emissions that contribute to environmental damage to achieve specific environmental goals in developed nations show that it is necessary to discuss the issue in a much broader approach by incorporating both qualitative and quantitative approaches. Inspired by previous studies in developed countries, my study will choose primarily quantitative (measurement of abatement potential and cost of different measures) and secondary qualitative (barriers) methodological approach to study low emission iron and steelmaking industry in Greater Accra Region of Ghana.

Chapter 3: Research Design and Methods

3.1 Introduction

This chapter describes the methodological approach to be adopted in order to answer the research questions and satisfy the objective of this research. The theoretical concepts will be translated into empirical measurable features by selecting indicators and variables in an operationalization mode. The research strategy to be adopted will be explained as this provides empirical inquiry that investigates modern problem within its real-life context. This chapter again will present the research approach and the sources of information to stem as the backbone for the methodology employed. The sample size of the study area will be explained. Lastly, data collection methods, data analysis methods, validity and reliability will then be described in a consistent manner to cover all aspects of the theories/concepts to be studied in the research.

3.2 Operationalization: Variables, Indicators

Cost effective low emission iron and steel industry is a form of economic analysis that compares the relative cost and outcomes (effects) of low emission measures. It is generally expressed in terms of a ratio of a gain in low emission measure (energy efficiency and BAT) and the cost associated with the measures. Barriers on the other hand are postulated mechanism that inhibits investments in technologies that are both energy-efficient and (apparently) economically efficient (Apeaning and Thollander, 2013). In other words, a barrier comprises of all factors that hamper the adoption of low emission measures.

There were two sets of variables and indictors required at two different stages of the study.
First, for the assessment of cost effectiveness of alternative climate and air pollution abatement measures at the iron and steel industry using cost effectiveness analysis; and second, investigating the barriers inhibiting the implementation of low emission measures in Ghanaian iron and steel industries (Table 3.1 and 3.2).

Table 3.1: Variables and indicators for cost effectiveness analysis

Sub-questions	Variables	Indicator	Data Type
What are the iron and steel production routes used in the Greater Accra Region of Ghana and which one is the most cost effective?	Cost	1. Product value per ton of steel produced 2. Cost of energy consumption per ton of steel produced 3. Cost per ton of CO_2 4. Cost per emissions to air	
	Production route	5. Available production route in use	
	Energy Efficiency	6. Energy consumption in GJ/t of steel produced in case of EAF and IMF in	

		GJ/t of iron 7. Cost of energy used 8. Annual production of steel in tonnes 9. Available fuel (current fuel) source/type (Electricity, Diesel, LPG, etc.)	Quantitative Data
	GHG emissions	10. GHG emissions in tCO_2 eq/t of steel produced 11. Emission factors of fuel used	
	Air pollutant emissions	13. Emission factors of primary air pollutant in kg/t 14. Cost of current fuel use per unit of input or output	
What is the cost effectiveness of the current low emission measures used in iron and steel industry in Greater Accra Region of Ghana?	Cost effectiveness	15. Available low emission measures at sub-production processes currently in use 16. Annual production capacity (MT/y) 17. Emission reduction (Kg CO2/ton of product 18. Annual operating cost ($/ton of product) 19. Retrofit capital cost ($/ton of product 20. Lifetime of measure (yr)	Quantitative data
What is the cost effectiveness of the best available technologies (BAT) for low emission iron and steel production in Greater Accra Region of Ghana?	Best available technology	21. Available specific low emission measures available to replace steel production routes in Ghana	
	Cost effectiveness	22. Annual production capacity (MT/y) 23. Emission reduction (Kg CO2/ton of product 24. Annual operating cost ($/ton of product) 25. Retrofit capital cost ($/ton of product 26. Lifetime of measure (yr)	

Table 3.2: Variables and indicators for barriers inhibiting the implementation of low emission measure

Sub-question	Variables	Indicator	Data type
What barriers account for the adoption of the cost-effective climate and air pollution abatement technologies and measures by the iron and steel production industry in Greater Accra of Ghana?	Economic (access to capital, hidden cost)	1. Access to capital (the ability of companies to meet cost of credit/loans) 2. Availability of budget funding 3. Cost of energy 4. Cost of raw materials and products 5. Level of technical risk of production disruption	Qualitative Data
	Organizational (Power, culture)	6. Availability of skilled personnel 7. Level of information flow on technologies to reduce emissions or energy efficiency 8. Level of education/awareness on energy efficiency or emission reduction technologies 9. Level of senior management commitment	
	Behavioral (Information flow, values)	10. Level of information flow on alternative technology 11. Levels of inertia towards low emission technologies	

3.3 Research Strategy

Research strategy is basically the general approach to be adopted in order to answer and satisfy both the stated research questions and objectives of the study. The main objective of this thesis is to assess the cost effectiveness of different measures that will reduce CO_2 emission and primary air pollutants levels in iron and steel industry in the Greater Accra region of Ghana. This study will adopt the case study approach as this approach presents an empirical inquiry that investigates modern problem within its real-life context. Appreciating the problem and associated solution needs the integrating of a numerous pieces of evidence that are likely to be gathered by personal observation (Scholz and Tietje, 2002). More precisely, I will be using the exploratory, single embedded case study strategy.

3.3.1 Case Study as the Research Strategy

First, case studies are considered as most appropriate tools in the critical and early phases of a new management theory when key variables and their relationships are being explored (Yin, 1994, Eisenhardt, 1989). The choice of this strategy is suitable for this research as it will reveal the study objectives having conducted detailed investigation into the study. This strategy again, allows for problems to be studied in-depth within the case settings and therefore seeks to investigate the interaction of different factors that contribute to the focus of the low emission iron and steel industry. Observations, interviews and the analysis of documents were range of types of data that contribute to the enquiry into the low emission iron and steel production to provide bases for a rounded analysis of the problem (Anderson, 2004). To ensure that details of a study are well revealed from the perspective of respondents using multiple sources of data, case study design was relevant in this study (Tellis, 1997).

3.3.2 Types of Case Studies

There are different types of case studies designs and this includes: holistic as single unit of analysis (single holistic and multiple holistic) and embedded as multiple units of analysis (single embedded and multiple embedded).

The single embedded case study design was selected for this study because the problem/case under study is considered very unique and revelatory to understanding the problem. Hence this research serves a specific purpose within the overall scope of enquiry (Yin, 1994).

Research is conducted based on motivation and this can be classified intrinsic and instrumental. Intrinsic refers to when a researcher has an interest in the case while instrumental means when the case is used to understand something beyond what is obvious to the observer and collective-when groups of cases are studied (Scholz and Tietje, 2002). This research is being conducted based on instrumental motivation in order to gather scientific reasons and data to answer both the research question and fulfil the objective of the study (Scholz and Tietje, 2002).

The objective of conducting case study research could be exploratory, explanatory and descriptive (Yin, 1993). In this research, exploratory case study was used as it helps to gain insight into the structure of area under study.

A case study may be used as a method of research, teaching, or action/application. (Scholz and Tietje, 2002). Data collection and methods can also be classified as quantitative and qualitative

(Stake, 1995). However, in this research, both qualitative and quantitative methods were used as it fits into the study.

3.3.3 Overcoming Challenges of this Study

In this study, a clear and well defined research operational framework was formulated to serve as a measure to ensure internal validity on the issue of complexity of analysis as described by Gibbert, Ruigrok, et al., (2008). Again, on the challenge of multiple sources of data, "triangulation" was used to strengthen the study (Patton, 2002). Reliability of data was achieved through transparency and replication which was enhanced through measures such as careful documentation and clarification of the research procedures by specifying how the entire research has been conducted. Replication was accomplished by putting together a case study database, which includes the case study notes, the case study documents, and the narratives collected during the study. This was organized in such a way that, it will facilitate retrieval of information for later investigators (Yin, 1994). Data collected was cross checked with secondary sources of information, leading to a reliable and objective description of realities.

3.4 Research Approach and Techniques

Given that there is a limited amount of literature covering low emission manufacturing implementation in Ghana, using iron and steelmaking industry as a case, the thesis is aimed at contributing to this field of research by investigating the cost effectiveness of alternative climate and air pollution abatement measures at the iron and steel industry in the Greater Accra region of Ghana. In addition, the study incorporates the investigation of barriers for adoption and implementation of low emission measures by the iron and steel production industry, to throw light on the rationale for both the adoption and non-adoption of cost effective climate and air pollution abatement technologies and measures.

As already explained, I have chosen quantitative and qualitative methodological approaches as it fits the research objective of highlighting iron and steel industry-specific experiences with low emission measures and are tailored to answer and satisfy both the objectives and research questions. The focus of a quantitative methodological approach is to assess the cost effectiveness of alternative climate and air pollution abatement measures at the iron and steel industry.

Weighing the cost effectiveness against key indicators under different scenarios will enable the industry to create an evidence base to inform the selection of low emission measures and activities. The qualitative methodological approach is aimed at investigating the barriers in the implementation of low emission measures in Ghanaian iron and steel industries.

The thesis was conducted in the following four major steps: (1) Identifying low emission iron and steel production route that may be available for the Ghanaian iron and steel industry; (2) Examining the current low emission measures available in the Ghanaian iron and steel industry (3) Estimating the current cost effectiveness of CO_2 abatement measures and BAT measures based on emission abatement potential in the iron and steel industry and (4) Assessment of the barriers for adoption of low emission iron and steel industry implementation. Figure 3.1 below provides a step by step illustration of the research approach followed in the study.

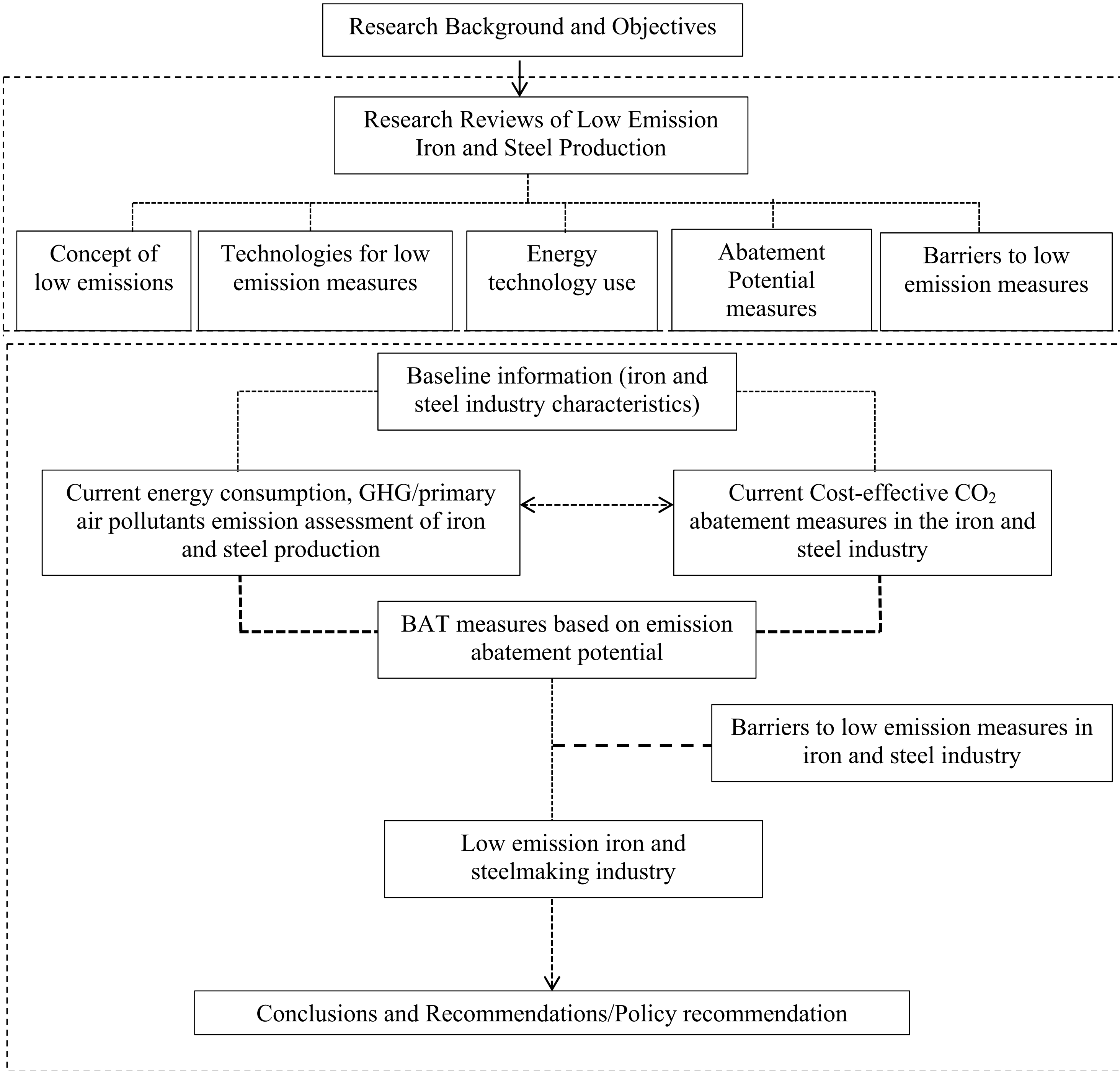

Figure 3.1 Step by step illustration of the research approach followed in the study.

3.5 Data Collection Methods, Sampling and/or Data Preparation

This section describes the methodologies and input data used in the analysis of this thesis.

The analysis and assessment of the cost effectiveness of different alternative climate abatement measures that would reduce GHG and primary air pollutants emission as well as energy consumption and extra energy consumed by end-of-pipe options in iron and steel industry is the key economic input into the preparation of the management plans towards low emission iron and steel production in Ghana. This first part of the study used quantitative method/approach which follows a largely formalised, logical and structured process implying the importance of measurement in the research (Bouma, Atkinson, et al., 1995). This part of the study used interviews to collect primary data and also made use of secondary data. Cost effective analysis was the analytical method that was used for the analysis. The cost effectiveness analysis took into consideration iron and steelmaking production routes comprising of electric arc furnace (EAF) and Induction melting furnace (IMF) production routes. The second part of the study used qualitative method/approach. Again, interviews were used to collect information on barriers inhibiting adoption of low emission measures in the iron and steel industry.

The input (raw materials including fuels which are producing CO_2 and primary air pollutants) are taking into account for the whole industry (through the production and emission factors). For each route a representative industry with known emission factors was selected with an assumption representing typical emission loads of the corresponding technology and/or emissions factors taking into account as average amounts, either as national factors, or as recommended by secondary data sources such as Intergovernmental Panel on Climate Change (IPCC) (Balanescu, Melinte, et al., , 2007). Secondary data was used from sources such as books, monitoring and evaluation reports, environmental management plans and scientific articles.

Low emission indicators selected for this study were the energy consumption in GJ/t per year of produced steel in case of EAF and IMF, GHG emissions expressed in t CO_2 eq/t of produced steel and emission of priority air pollutants expressed in kg/t (NOx, SO_2, CO, PM_{10}, $PM_{2.5}$, VOC) to the atmosphere. The data for energy consumption based on average rates for each route and direct energy consumption requirements by the iron and steelmaking plants to produce the final product of each plant as well as the GHG and primary air pollutants emissions for the EAF and IMF routes were collected from official records and available documents (Environmental Management Plans) and secondary sources specific to the selected industries (Worrell, Bernstein, et al., 2009, Galama, 2013, Strezov, Evans, et al., 2013).

Thus the main steps in the cost-effectiveness analysis include the estimation of the costs of potential pollution abatement measures, the estimation of their environmental impacts and the subsequent ranking of cost-effective measures (van Soesbergen, Brouwer, et al., 2008, Strezov, Evans, et al., 2013). Based on the calculated cost-effectiveness of possible measures a cost-effectiveness curve was drawn, from which the direct costs of different alternative climate abatement measures that would not only reduce GHG and primary air pollutants emission but also decrease the energy consumption and extra energy consumed by end-of-pipe options can be calculated for the entire iron and steel industry.

The second focus of the study is aimed at investigating the barriers for low emission measures implementation in Ghana, to throw light on the rationale for the adoption of the most cost effective alternative climate abatement measures in Ghanaian iron and steel industry.

Scholars around the world tend to discuss barrier issue from the national level, while studies at the industrial or enterprise level are few. The study of the barrier issues is explorative. For this kind of study, a qualitative research method was appropriate. In-depth interviews are a qualitative research method that is suitable to use when eliciting detailed information from relatively few persons (Johansson, 2015). Therefore, in-depth interviews were used to gain a deeper understanding of how industries (Managers/technical or Engineers/Operations who knew the industry well from various perspectives) at Ghanaian steel plants perceive their own companies' efforts to adopt and implement low carbon measures.

The interviews were semi-structured and thus allowed for follow-up questions and discussions. Interviews were made with managers/Technical and engineers/operations from iron and steelmaking industries. These plants were selected based on non-probability sampling, specifically, purposive sampling. The selection was based on the knowledge/expertise of the population and purpose of the study (Van Thiel, 2014).

The data or information analyzed is the experiences, thinking, attitudes and actions of respondents. The data or information from the various respondents may vary largely across the different respondents' answers and the qualitative methods can uncover this kind of information and help to achieve in-depth understanding. Analysis of the interviews was performed by identifying themes and categories that could answer the research questions. By finding common themes and categories, it was possible to compare and analyze the interviewed data.

3.5.1 Limitation and Challenges

One main limitation in the analysis and assessment of the cost effectiveness of different alternative climate abatement measures is the assessment of the environmental impacts of potential measures which is normally surrounded by a lot of uncertainty and the availability of cost data which is limited. In many cases the evaluation of costs and effects is based on expert judgment as widely applies in Europe (van Soesbergen, Brouwer, et al., 2008) and elsewhere.

However, this thesis carried out the cost-effectiveness analysis based on available data and information acquired through literature review, government records, secondary sources and in-depth interviews. The available data and information was then filtered and validated in terms of their usefulness and robustness. Although surrounded by many uncertainties the results of the cost-effectiveness analysis are considered important directions for the future prioritization of best available measures within the economic sectors towards low emission iron and steel manufacturing.

Much attention was paid to ethical issues in the study and best effort was made to avoid negative impact on the interviewees. To address this limitation, agreement was made between the subject (interviewee) and me (interviewer). The subjects was totally clear on the object and procedure of the research, which means that subjects understood clearly the issues they agree on (Brydon, 2006), and the information or data emanating from the interview would be confidential.

Externalities such as detail health impacts and other environmental impact besides CO_2 and primary air pollutants emissions were not included in the analysis.

3.6 Validity and Reliability

Validity and reliability are commonly used in both quantitative and qualitative researches. It was critically important to validate results for the estimation of CO_2 and primary air pollutants emissions as well as the barriers of low emission iron and steel industry implementation framework conducted in the study. The validity framework used involved: (1) feedback from experts and reliability checks were carefully incorporated into the interview scheme to obtain reliable information and data (2) comparison of results with similar results of other studies conducted elsewhere.

Also, to improve the objectivity of the research, multiple methods were used such as secondary sources of data and interviews. “Triangulation” was used as this strengthens a study by combining methods (Patton, 2005).

The validity of the secondary information obtained through the secondary sources of data and interview is embodied in two aspects. The first is how the study results cover reality and the second is whether the answers in interviews supply enough effective information for the object of the thesis.

Chapter 4: Research Findings

4.1 Description of the Study Area

Tema Metropolitan area (TMA), located in the Greater Accra Region of Ghana is a coastal district situated about 30 kilometers east of Accra, the capital city of Ghana. It shares boundaries on the North East with the Dagme West District (DWD), Southwest by Ledzekuku Krowor Municipal , Northwest by Adenta Municipal and the Ga East Municipal Assembly (GEMA) North by the Akuapim South District and the south by the Gulf of Guinea (Figure 4.1). The Ashaiman Municipal is in- lock district within the TMA. The Metropolis covers an area of 396 km and lies within the coastal savannah zone.

The Greenwich meridian (i.e. Longitude 0) passes through the Metropolis, which meets the equator or latitude 0 in the Ghanaian waters in the Gulf of Guinea. The southern tip of the Metropolis lies on the latitude 541 north. The Metropolis proximity to the sea with its low lying terrain which projects into the sea makes a natural endowment for harbor hence the construction of Tema harbor making the district “The Eastern Gateway of Ghana”. Tema came into focus in 1957 when the government decided to construct a port at the Metropolis natural harbor to serve as the main import entries into the country.

The topography of the Tema Metropolitan area is generally flat and forms part of the coastal plains, ranging from 0m south to 35 m north above sea level. The terrain of the district barely rises up to 65 m high. The almost flat nature of the Metropolis has made the district flood prone and therefore high cost of construction of drainage.

The Metropolis lies in the coastal savannah zone of Ghana. It enjoys a dry equatorial climate. Mean annual rainfall rages between 730 mm to 790 mm. The rainy season is usually from April to July (major rainy season) and from September to November (minor rainy season) the highest amount of rain is experienced in May, June and early July. Temperatures are high all year round with significant daily and seasonal variations.

The annual average temperature ranges between 25 °C and 30 °C in the major rainy season while in the minor season temperatures range between 34 °C and 40 °C. Humidity varies from 60 % - 80 % or more in the wet season to less than 30 % in the dry season. Generally, wind of low velocity blow over the area from the south during the day and evening and from the west in the night and early morning.

Tema is considered the "heart of the country's development. As a result of Tema being an industrial hub and the absence of reserve forest in the area, some areas were demarcated and reserved as greenbelt zones to control the micro climate of Tema (climate condition in relatively small area).

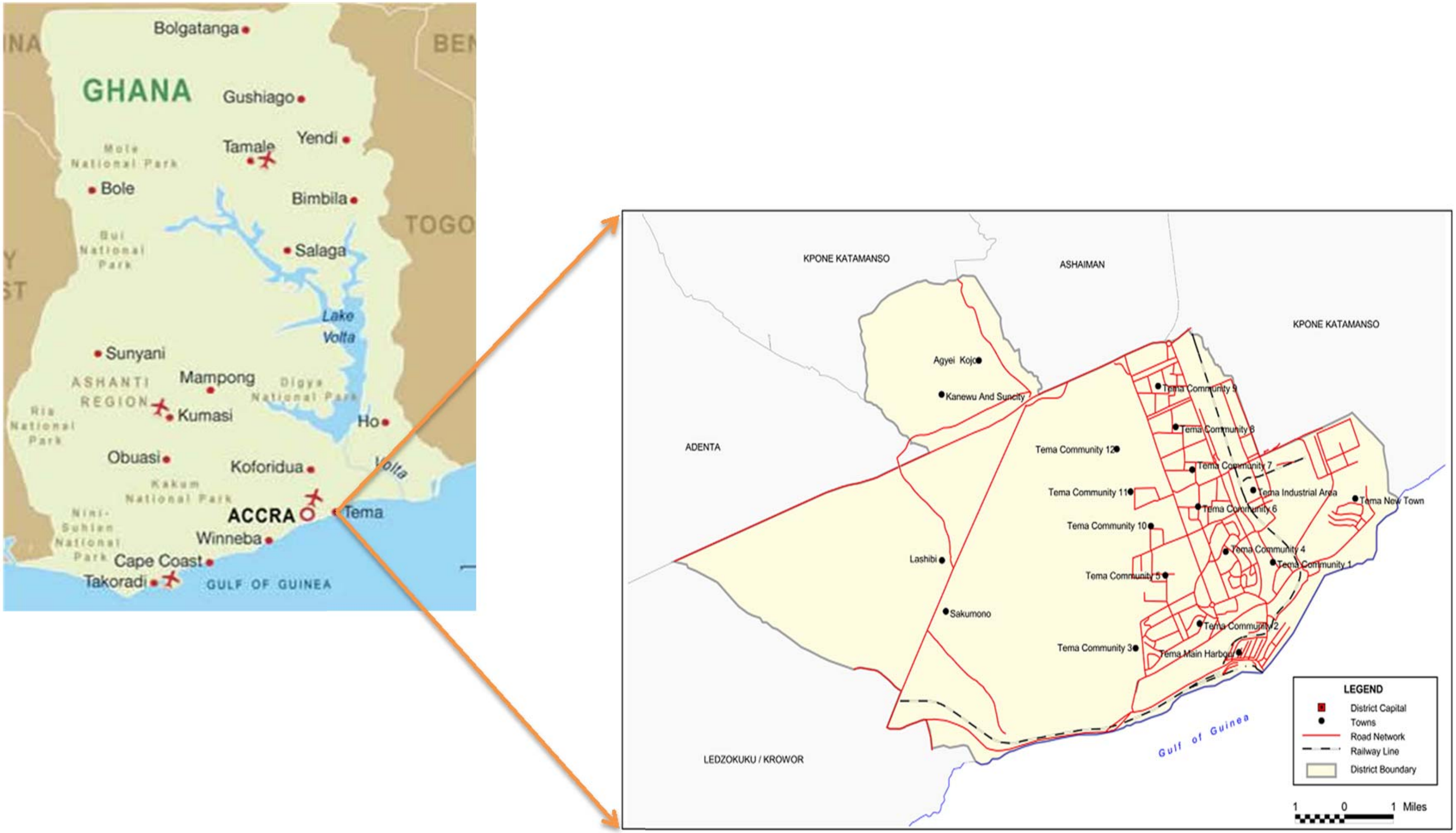

Figure 4.1 Map of Ghana Showing the study area (Tema) in the Greater Accra Region, Ghana

Figure 4.2 Google map showing Tema in the Greater Accra Region, Ghana

The 2010 Population and Housing Census indicate the total population of the Tema Metropolitan as 292,773 with 47.8 % been males and 52.2 % females (Ghana Statistical Service, 2014). The Metropolitan Area serves as the hub of Ghana's industrialization and home to Ghana's largest industrial area the "Tema industrial area". This industrial area is home to well over 600 industries which include aluminum and steel smelting industries, industries producing chemicals, clothing, consumer electronics, electrical equipment, furniture, machinery, refined petroleum products, etc**.** (Apeaning and Thollander, 2013).

The area is a strategic regional point because it hosts most of the high revenue earning manufacturing industries in the country. Besides, the industrial area is popularly known for its high energy end-use. This area also hosts most of the high electricity and petroleum product consuming manufacturing firms in Ghana (e.g. VALCO, an aluminum smelting company which until 2003 accounted for 16-17 % of total national electricity consumption (Apeaning and Thollander, 2013).

The number of industries and waste generated increases in the Metropolis without a corresponding increase in afforestation to absorb excess carbon dioxide generated by these factories, also areas that were reserved as green belts are encroached upon by people and developed as residential areas. These can lead to negative changes in weather condition and its associated effects such as loss of biodiversity, erratic rainfall pattern (MoFA, 2014). One important study conducted by (Ofosu-Ahenkorah, Brew-Hammond, et al., 2007) suggest that, the use of energy is poorly managed as such a large number of these firms exhibit high energy intensive production processes compared to similar processes in other countries.

4.2 Presentation of the Sample from Steelmaking Industries

There are eight registered different iron and steelmaking industries in Ghana, and all the eight companies were visited. All the eight registered companies agreed to participate in the study (which represents about 100 % response rate). The respondents who participated in the study provided vital information which was captured on the interview. The interviews were conducted with General Managers (Technical Directors) and engineering staff who dealt directly with operational issues within their respective firms. Figure 4.3 below shows the distribution of the positions of the respondents. A total of 3 technical directors and managers, and 5 engineering/operational staff were involved in the interview.

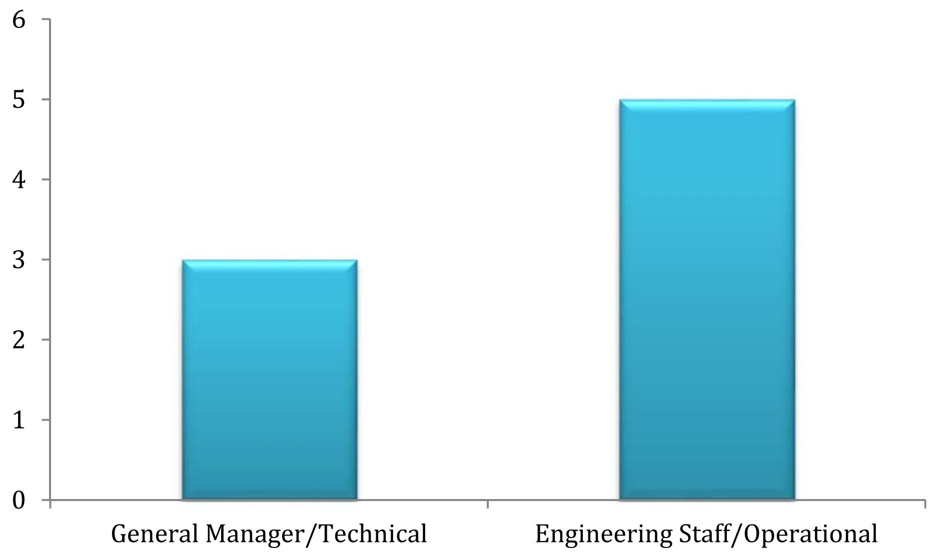

Figure 4.3 Distribution positions of the respondents

Exactly all the industries studied were iron and steelmaking industries; the industries produce essential steel products, grinding media and iron rods for the mining industries and the infrastructure industries, respectively. The products are for local consumption and for export to neighbouring West African countries. 38 % of the firms used electric arc furnace (EAF) whiles induction melting furnace (IMF) production route is used to produce 62 % of their products (Figure 4.4 below).

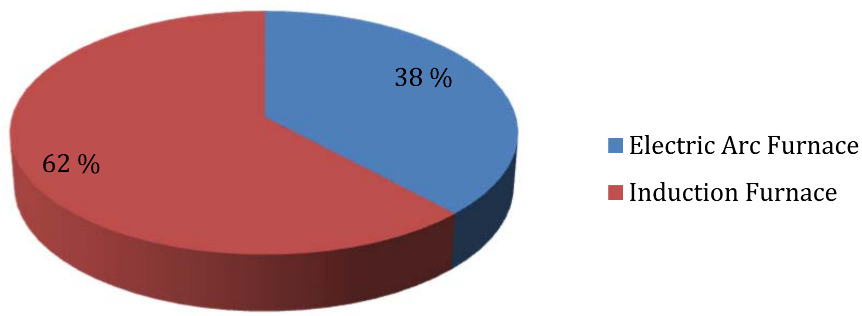

Figure 4.4 Distribution of production route of production

The interview with the firms' respondents was carried out in two sessions; in the first session, respondents were asked to describe the various cost effectiveness of alternative climate and air pollution abatement measures and strategies used in their firms and in session two respondents were asked to express their views on barriers that account for the adoption of cost effective climate and air pollution abatement measures implementation in the iron and steel production industry. All interviews were recorded and on the average each interview took about 45 minutes.

4.3 Assessment of the Two Major Iron and Steel Production Routes in Ghana

In Ghana, electric steelmaking routes, comprising of electric arc furnace (EAF) and induction melting furnace (IMF) production routes are used for the production of iron and steel. Electric production route are preferred over other routes due to the production of high temperatures compared to other furnaces and no energy is spent to heat fuel as compared to other routes (Central Pollution Control Board, 2010). Another key advantage of using this two major process is to achieve all grades of steel and melting scraps. The IMF is widely used as a result of high demand for mild steel ingots (apart from castings) to cater for domestic demand, which could not be adequately met by the large scale integrated steel plants (Central Pollution Control Board, 2010). Eight registered steel-making industries in the Tema metropolis of Ghana are using one of these routes of production with known emission factors was selected with an assumption that these represent typical emission loads of the corresponding technology. For confidentiality, the names of the various iron and steel industries remain anonymous.

For EAF, 3 steelmaking industries were identified with a total average production capacity of 17200 Mt/y. As a representative of the IMF production routes, five industries, with total average steelmaking capacity of 43950 Mt/y was also selected for the study. The EAF and the IMF production routes all use scrap as its sole feed for steelmaking.

The data for energy consumption from the respective iron and steelmaking industries was collected from the respondents from the various firms visited and the data was based on average rates for each production routes and based on direct energy consumption requirements by the steelmaking plants to produce the final product of each plant.

Greenhouse gas (GHG) emissions and priority air pollutants for the EAF and IMF production routes were also collected from the same source and were subsequently confirmed from publicly available documents specific to the selected industries (EPA-Akoben Report, 2014).

Accordingly, each of the selected parameters was converted to per dollar ($) value, i.e. the energy consumption was converted to GJ/$ and greenhouse gas emissions to kg CO_2/$ and pollutant emissions to g/$. The dollar value was the market price of steel products, expressed in metric tonne of hot rolled steel/iron rods ($478/t) for EAF and $415/t for IMF.

Table 4.1 compares the selected parameters for each of the two iron and steel production routes, based on a metric tonne of produced steel for EAF and IMF. From Table 4.1 it is apparent that, EAF production route has higher energy consumption requirements and emissions than the IMF route, meaning it requires more energy while emitting more greenhouse gases and priority air pollutants (SO_2, NOx, CO, PM_{10}, $PM_{2.5}$ and VOC) to the environment compared to the IMF. Data for energy consumption, CO_2 emissions and emissions to air are based on average rates for each route.

Table 4.1 Comparison of selected indicators, expressed in metric tonne of steel (EAF and IMF) between the two major iron and steel production routes used in Ghana.

Indicators	EAF	IMF
Energy consumption (GJ/t)	2.8	1.7
CO_2 eq emissions (t CO_2 eq/t)	0.34	0.21
Emissions to air (kg/t)		
NOx	0.4	0.07
SO_2	1	3.1×10^{-3}
CO	35	17
VOC	0.16	0.08
PM_{10}	0.23	0.19
$PM_{2.5}$	2.1×10^{-3}	1.3×10^{-3}

The EAF route requires the largest energy for steel production, mainly due to the use of intensive electricity for the EAF process, though the IMF also uses electricity but it consumes less power compared to EAFs. Again, the meltdown period of EAF starts after the furnace is charged with scrap and the charge is completely melted. This makes it an expensive process because of the high rate of energy and electrode potential (Krishnan, Vunnam, et al., 2013). IMF uses lesser quantity of refractory in its process and its expenditure on electrode is nil.

The energy consumption of the EAF iron and steelmaking route was found to be the largest, when plotted as MJ/$, compared to 4.09MJ/$ of IMF route. Similar pattern was exhibited when CO_2 eq emissions was plotted against the market value of the unit product (Table 4.2). Again the lowest value for the greenhouse gas parameter and primary air pollutants were very significant in the IMF production routes when plotted against the economic value.

Table 4.2 Comparison of selected indicators expressed in dollar value of the product between the two major iron and steel production routes.

Indicators	EAF	IMF
Product value ($/t)	478	415
Energy consumption (MJ/$)	5.85	4.09
CO_2 eq emissions (kg CO_2 eq/$)	0.71	0.51
Emissions to air (g/$)		
NOx	0.84	0.17
SO_2	2.09	7.5×10^{-3}
CO	73.22	40.96
VOC	0.33	0.19
PM_{10}	0.48	0.46
$PM_{2.5}$	4.4×10^{-3}	3.1×10^{-3}

The EAF and IMF were ranked against each other by normalizing each indicator to unity (1). The route that is more important is assigned a stronger weight than the other with the lowest consumption and emission factor within the aggregation procedure. The normalization was done to bring all of the variables into proportion with one another. The normalization was performed by dividing each of the emission and consumption parameters with the highest value of the corresponding indicator across all industries.

The normalized overall sustainability index for each industry was then created by dividing the lowest averaged index across all industries with the individual index for each industry, so that the normalized overall sustainability index of 1 was assigned to the industry with the highest sustainability performance with all other industries calculated proportional to the most sustainable industry as indicated by (Strezov, Evans, et al., 2013).

Table 4.3 Normalized sustainability index and production route ranking

	Iron and steel production routes	
	EAF	IMF
Normalized overall sustainability index	0.55	1

The normalized overall sustainability rankings as shown in Table 4.3 clearly put IMF production route first in ranking with the highest performance and a relative normalized sustainability index of 1. This is mainly due to low energy needs for IMF to produce a metric tonne of steel, low greenhouse gas emissions as well as low primary air pollutants emissions in its process. The EAF technology had the lowest normalized sustainability index at 55 % relative to IMF route.

The results shown in this study confirm that iron and steel production from EAF production route has the most significant emission reduction challenges that will need to be addressed in order to improve its overall emission reduction performance. This research is in variance with a similar study conducted by (Strezov, Evans, et al., 2013) who considered three iron and steel production routes, including blast furnace or blast oxygen furnace (BF/BOF route), electric arc furnace (EAF) and midrex as a representative technology for the direct reduced iron (DRI) steelmaking production route. In their study, EAF steelmaking was found to have the best emission reduction performance, closely followed by Midrex and BF/BOF was the lowest ranked iron and steelmaking route.

4.4 Current Low Emission Measures Used in the Iron and Steelmaking Industries in Ghana

Initially, to understand the general variation of the emission reduction measures used in the various iron and steelmaking industries, current methods of low emission inventory was carried out. The inventory revealed some measures that were currently in place to reduce energy consumption and mitigate the GHG and primary air pollutants emissions into the environment. All the eight studied industrial firms indicated that, their respective firms have introduced measures specifically to reduce energy consumption and primary air pollutants by lighting systems and sorting/filtering of scrap off foreign materials respectively.

The measures included:

- Replacement of incandescent bulbs with Compact Fluorescents Lamps (CFL)
- Optimization of daylight use and replacement of 38mm fluorescents with 26mm
- Using skylight to reduce the use of lights during the day etc.

Measure used for sorting of scrap was basically use of magnetic separator to separate scrap from foreign materials/contaminants prior to steel making process. This reduces the risk of including hazardous contaminants and to avoid explosion if there is explosive material.

The lighting measure rate of implementation was possible due to the current energy crisis and efforts by the Ghanaian government in the promotion of CFLs in the country through the Energy Commission as this measure steps up efforts to save more energy. None of the eight firms visited had light control systems (occupancy and vacancy sensors) to automatically or manually turn lights on when motion is detected and off when motion is not detected or the room is vacant.

However, three iron and steelmaking firms (Two EAF production route and one from the IMF route) confirmed, implementation of some low emission technologies including the introduction of adjustable speed drives, flue gas monitoring and control and energy efficient drives in the rolling mill used in the EAF production route as well as the introduction of medium frequency power transformers, engineered refractories and insulation of furnaces and design used in the IMF production route. With respect to the findings of the preliminary study, the interview was redesigned to query these low emission technologies used in the production chain of the EAF and IMF route.

The managers and the engineering staffs who were responsible for their respective industrial firms with the above-mentioned low emission technologies were asked to assess the performance (efficiency of the technologies) of the various low emission technologies with regard to reduction of emissions (adjustable speed drives; flue gas monitoring and control; energy efficient drives in the rolling mill; medium frequency power transformers; engineered refractories and insulation of furnaces and design). The measures were categorized, using a scale of 0 (under performance) to 1 (good/expected performance). Iron and steelmaking industries were coded according to the introduction of such low emission technologies in their respective firms (IMF1, IMF2, IMF3 and EAF1, EAF2, EAF3).

Figure 4.5 below highlights average low emission technologies that were assessed by the various respondents. Low emission technologies with average scoring greater than or equal to 0.5 was considered to be good performing measure (i.e. ability to mitigate the GHG and primary air pollutants emissions from the iron and steelmaking industries). The scores for the low emission measures are subjective scores.

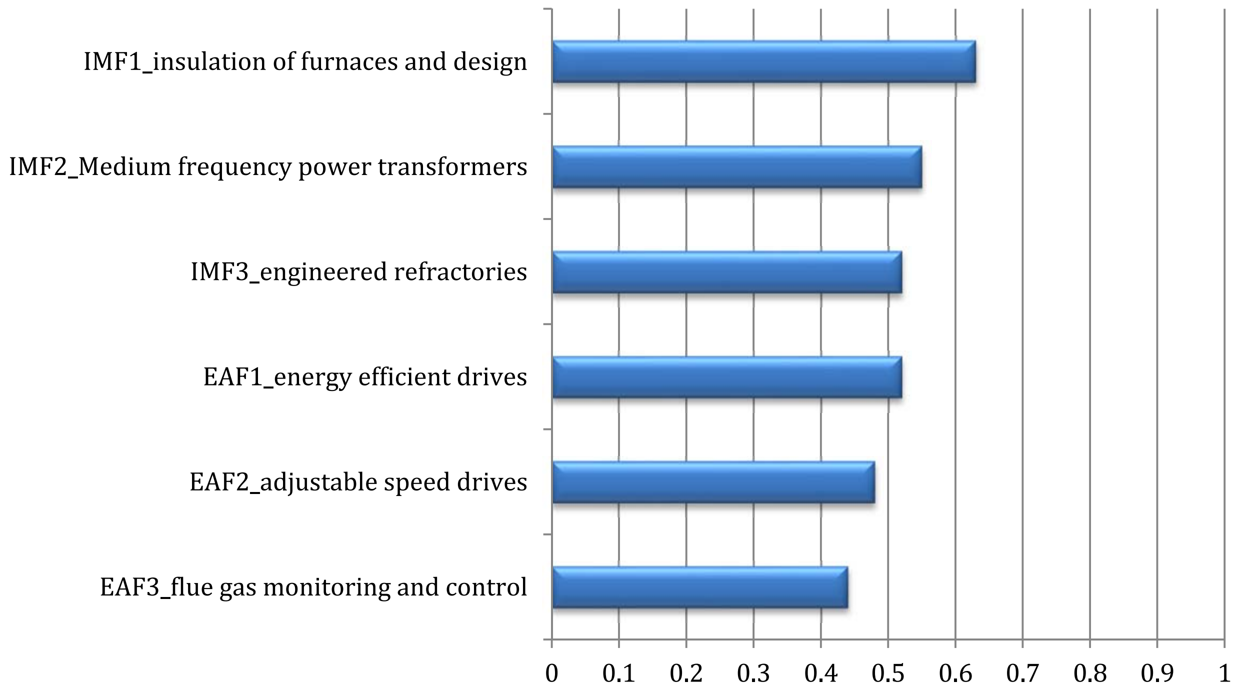

Figure 4.5 Average scoring of the energy efficiency and emissions of low emission technologies

The figure gives an insight into the performance (efficient emissions reduction) level of the low emission technologies implementation in the firms. It was convincingly clear from Figure 4.5 that, the low emission technologies incorporated into the IMF was having a good performance rate compared to the EAF (IMF and EAF production route had the highest and lowest score of performance, respectively). Hence, IMF production route firms with these low emission technologies is likely to have the most cost effective low emission measure whiles steelmaking production routes without such technologies are those having the most significant low emission challenges. This limitation need to be addressed in order to improve its overall performance, likely to have low emission challenges.

Relative to the maximum low emission performance score of 1.0, the performance level of individual low emission measures were very low in the three firms that were assessed; the reason for this huge gap and the feasibility of implementing these measures and other cost effective alternative climate abatement measure in all the eight studied iron and steelmaking industries will be made clear by the barrier analysis.

Table 4.4 Average scores of low emission performance measures in the iron and steel industry

Production Route	Low emission measures	Average score
IMF	Insulation of furnaces and design	0.63
	Medium frequency power transformers	0.55
	Engineered refractories	0.52
EAF	Energy efficient drives in the rolling mill	0.52
	Adjustable speed drives	0.48
	Flue gas monitoring and control	0.44

Insulation of furnace and design of the IMF technology was considered to have the highest average score performance. Insulation of furnace greatly reduce the heat losses through the walls of the furnace by providing a layer of material with low heat conductivity between the internal hot surface of a furnace and the external surface, thus keeping the temperature of the external low. The operational manager when interviewed of the performance of this technology affirmed that, the installation of the insulating material has significantly cut down heat loss (by 45 %) thereby increases the efficiency of the furnace. He further emphasized that, the insulation design of the furnace made it possible for the facility to attain a much larger and spacious design that encourages the operations with loading and unloading of materials.

The second highest average performance score was achieved in the introduction of medium frequency power transformer which has helped to reduce energy loss and increase productivity in the IMF production route in iron and steel company. The operational manager of the steel smelting firm claimed that, the introduction of medium frequency power transformer has reduced the firm‘s annual electricity bill by 25 % since its introduction.

Next to medium frequency power transformer is the introduction of engineered silica brick refractories in IMF production route, which has a high resistance to thermal shock (spalling), flux and stag resistance and high refractoriness. The outstanding property of this is that, it does not begin to soften under high loads until its fusion is approached. The operational manager claimed that, the introduction of this facility has reduced fuel consumption (increased fuel efficiency by 20 %) because it has reduced the holding time and the timing between batches has been optimized providing a vital effect on energy intensity.

Introduction of energy efficient drives in the EAF rolling mill production route attained the fourth highest average performance score. Two managers of the EAF steelmaking firm confirmed the introduction of this effective way of saving cost. They stressed that, the facility has helped to reduce production cost by moving away from mechanically controlled methods to variable-speed drives with inverters which offer a more economical alternative options by ensuring that no more energy is wasted and saving of up to 30 % and in extreme cases even up to 40 %.

Average performance scores of 48 % and 44 % were achieved in the introduction of adjustable speed drives, and variable speed drives (VSDs) to control and monitor flue gases in EAF iron and steelmaking route. Adjustable speed drives offer opportunities to operate dust collection fans in a more energy efficient manner. The use of VSDs can reduce energy usage of the flue gas fans, which in turn reduces the losses in the flue gas. The managers of the respective firms revealed that, the newly installed adjustable speed drives use less energy than the already replaced fixed-speed operated one. They averred that, the adjustable speed motor allows the airflow to be regulated and it is more efficient to directly regulate fan motor compared to the fixed-speed operated one where the airflow is invariably higher.

4.5 Current Cost Effective CO_2 Abatement Measures in Iron and Steel Industry in Ghana

The iron and steel industry is the largest industrial source of CO_2 emissions due to the energy intensity of steel production, its reliance on fossil fuels and reductants (Carpenter, 2012), and the large volume of steel produced – totalling 61150 Mt/y with total average production capacity of 17200 Mt/y and 43950 Mt/y as a representative of the electric arc furnaces (EAFs) and induction melting furnaces (IMFs) technologies respectively.

The carbon intensity of iron and steel production varies considerably between the production routes, ranging from 0.34 tCO_2/t and 0.21 tCO_2/t crude steel for scrap EAF and IMF routes respectively. There are a number of measures that are available to abate direct and process CO_2 emissions from the two different iron and steelmaking routes used in Ghana (IMF and EAF).

For the operation of EAF, there are a number of measures including the application of reliable and efficient process controls to shorten the melting and treatment time, using the foamy slag practice, efficiently capturing the furnace off-gas, cooling the furnace off-gas, dedusting using a bag filter, etc. (BREF, 2006) and other related application that is embedded in some EAF and IMF technological route of production of iron and steel. Some of these has been discussed earlier on the current technologies that have been implemented in Ghana (i.e. adjustable speed drives; flue gas monitoring and control; energy efficient drives in the rolling mill for the EAF technology as well as the use of medium frequency power transformers; engineered refractories and insulation of furnaces and design for the IMF route).

Measures, that are already implemented on existing plants (EAF and IMF) to further reduce GHG and primary air pollutants emissions to the environment was considered and were subsequently used to estimate the cost effective CO_2 abatement measures. Data and information about the emissions reduction (kg CO_2/tonne of product), annual operating costs ($/tonne of product) retrofit capital costs ($/tonne of product), measure lifetime (years) and all of those measures were based on available international data (secondary data) sources (Worrell, Bernstein, et al., 2009, American Iron and Steel Institute (AISI), 2010, Galama, 2013) (Table 4.5).

However, there was no data on engineered refractory implementation in the IMF route and the adjustable speed drives installation on the EAF route that were implemented to reduce CO_2 and its related primary air pollutants emission to the atmosphere. Thus measures such as the introduction of flue gas monitoring and control and energy efficient drives in the rolling mill used in the EAF production route as well as the introduction of medium frequency power transformers and insulation of furnaces and design used in the IMF route were accessed for its cost effectiveness.

Table 4.5 Low emission measures applied to EAF and IMF steel production (Worrell, Bernstein, et al., 2009, American Iron and Steel Institute (AISI), 2010, Galama, 2013)

Technologies	Emissions reduction (kg CO_2/t of product)	Annual operating costs ($/t of product)	Retrofit capital costs ($/t of product)	Measure lifetime (yr.)
Steelmaking - EAF				
Energy efficient drives in the rolling mill	1.6	0.0	0.3	20
Flue gas monitoring and control	8.8	0.0	3.1	15
Steelmaking - IMF				
Insulation of furnaces and design	8.1	0.0	15.7	10
Transformer efficiency	10	0.0	4.3	15

So, the various steps to calculate the cost-effectiveness of different pollution abatement measures that are already in use in the various steelmaking industries in this study was through the application of cost-effectiveness criteria including: estimation of the annual CO_2 reduction capacity of each measure; estimation of the total operational costs or investment for each pollution abatement measure and calculating and ranking of possible pollution abatement measures based on their cost-effectiveness ($ per year reduced kg CO_2).

Table 4.6 Ranking of combinations of CO_2 abatement measures on steelmaking technologies based on their cost-effectiveness

Technologies	Emissions reduction (in 10^4 kg CO_2/year)	Costs ($/year)	Cost-effectiveness ($/$10^5$ kg CO_2)
Steelmaking - EAF			
Energy efficient drives in the rolling mill	2.752	1.9	6.9
Flue gas monitoring and control	15.136	11.9	7.9

Steelmaking - IMF			
Insulation of furnaces and design	35.5995	23.8	6.7
Transformer efficiency	43.95	14.3	3.3

A measure's cost-effectiveness is calculated by simply dividing the annual cost (column 2) by the annual effect (column 1). The measure with the lowest cost per year of kg CO_2 emission reduction is the most cost-effective measure. In this particular study, transformer efficiency is the most cost-effective solution, followed by the insulation of furnace and design and energy efficient drives in the rolling mill. Introduction or installation of flue gas monitoring and control on the EAF processes is the most costly measure per year of kg CO_2 emission reduction. Overall, the CO_2 emission reduction measures instituted on the IMF were the most cost-effective compared to EAF steel production route.

Marginal abatement cost curves that linked the individual plant's emission levels to the cost of additional emission abatement measures was constructed. Figure 4.6 presents an estimate of the maximum potential of all the four technical GHG abatement measures (low emission measures) below $ 25 per tCO_2e if each measure was pursued. It shows that the abatement cost for all the four current measures (energy efficient drives, flue gas monitoring/control, transformer efficiency and insulation of furnace) were all positive (Table 4.7).

Table 4.7 Current low emission measures with their corresponding marginal abatement cost ($/$tCO_2$) and tones of avoided CO_2 emissions per year ($MtCO_2$/yr)

Measure Name	MAC ($/t CO_2)	Mt CO_2/yr
Energy efficient drives	1.90	27,520.00
Flue gas monitoring/control	11.90	151,360.00
Transformer efficiency	14.30	172,000.00
Insulation of furnace	23.8	355,995.00

This means that all the implemented current low emission measures will incur cost instead of bringing monetary savings. However, they had the potential to abate CO_2 emissions. The Figure 4.6 revealed interesting results, unlike transformer efficiency being the most cost effective measure, followed by insulation of furnace, energy efficient drives and flue gas monitoring/control in that order through the application of cost-effectiveness criteria to assess the most cost effective measure(Table 4.6), the MACC identified the insulation of furnace having the highest abatement potential with a significant amount of CO_2 savings per year at highest cost, followed by transformer efficiency, flue gas monitoring/control and energy efficient drives in that order.

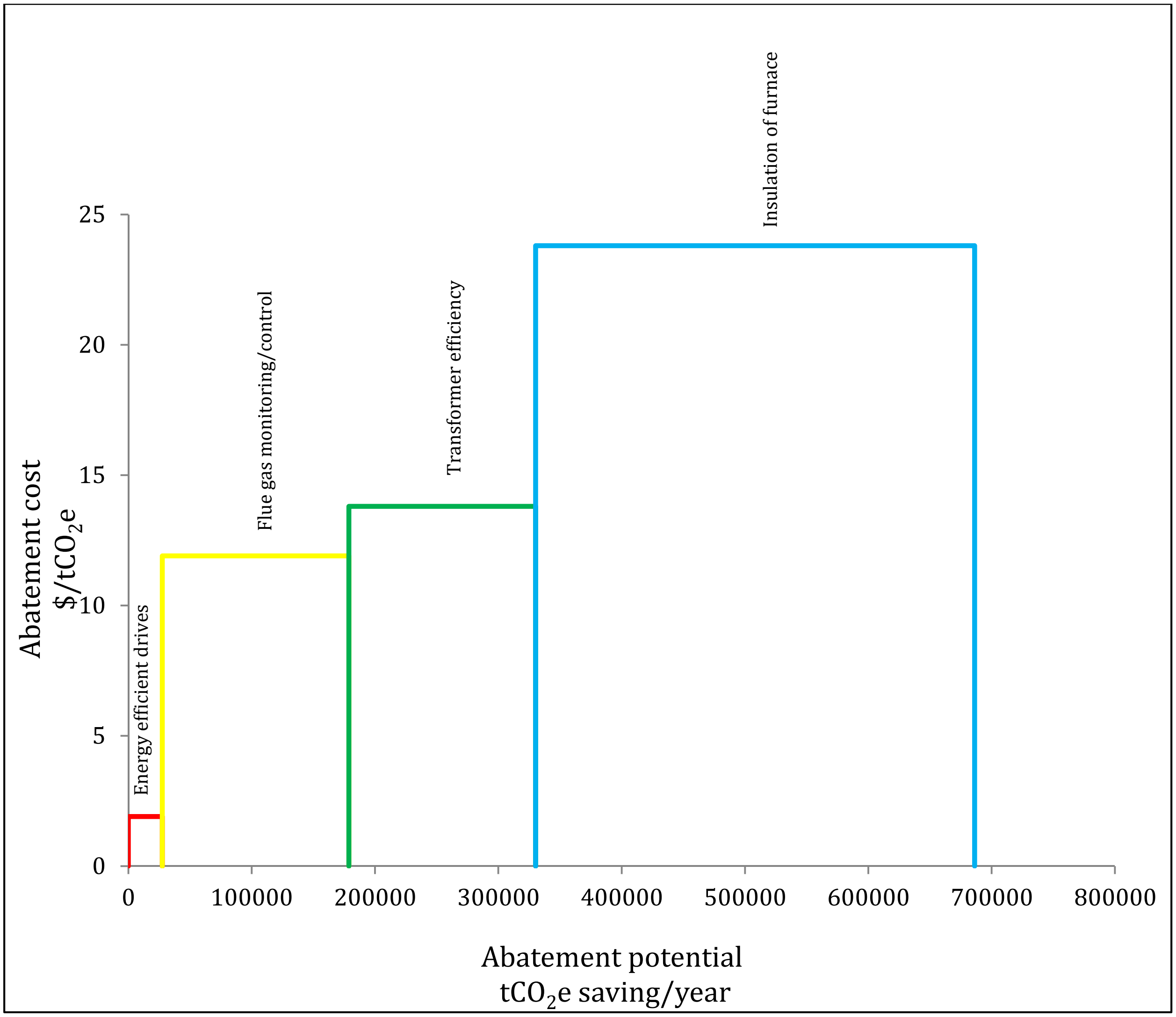

Figure 4.6 Marginal abatement cost curve for the current low emission measures in iron and steelmaking industry in Ghana.

4.6 Best Available Technology Marginal Abatement Cost Curve (MACCs)

MACC is defined as a graph that indicates the marginal cost (the cost of the last unit/extra cost) of emission abatement for varying amounts of emission reduction (Kesicki and Ekins, 2012). They are used to analyze investments and the impact of policy measures in order to find the least-cost options to achieve a certain target, such as climate change mitigation (Levihn, Nuur, et al., 2014).

In the context of this study, MACCs were illustrated with tones of avoided CO_2 emissions (Abatement potential tCO_2e saving/year) on the x-axis and costs per reduced tonne of CO_2 ($/$tCO_2e$) on the y-axis (Figure 4.7). In this research, nineteen (19) specific low emission measures that could replace certain parts of the existing EAF and IMF technological production routes were used to construct the MACC. This curve linked the individual plant's emission levels to the cost of additional emission abatement (i.e. marginal abatement, relating to specific actions and technologies. Data and information used to estimate and construct the MACCs included the emissions reduction (kg CO_2/tonne of product), annual operating costs ($/tonne of product) retrofit capital costs ($/tonne of product), measure lifetime (years) and all of those measures were based on available international data (secondary data) sources (Worrell, Bernstein, et al., 2009, American Iron and Steel Institute (AISI), 2010, Galama, 2013) (Table 4.8)

Table 4.8 Low carbon measures with their corresponding marginal abatement cost ($/$tCO_2$) and tones of avoided CO_2 emissions per year ($MtCO_2$/yr) (after Worrell, Bernstein, et al., 2009, American Iron and Steel Institute (AISI), 2010, Galama, 2013).

Measure symbol	Measure Name	MAC ($/t CO_2)	Mt CO_2/yr
A	Bottom stirring/stirring gas injection	7.99	201,240.00
B	DC arc furnace	-61.90	909,880.00
C	DC twin-shell with scrap preheating	-32.20	190,920.00
D	Eccentric bottom tapping	13.80	151,360.00
E	Efficient caster ladle	1.19	18,920.00
F	Energy efficient drives	1.90	27,520.00
G	Energy monitoring	3.93	63,640.00
H	Flue gas monitoring/control	11.90	151,360.00
I	Foamy slag practice	-4.60	182,320.00
J	Improved Process Control	1.50	302,720.00
K	Near net shape casting thin slab	-650.70	4,563,160.00
L	Oxy-fuel burners	-37.20	404,200.00
M	Preventive maintenance	15.65	25,800.00
N	Recuperative burners	39.10	605,440.00
O	Scrap preheating-post combustion shaft furnace (Fuchs)	-147.50	607,160.00
P	Scrap preheating-tunnel furnace (Consteel)	-50.00	605,440.00
Q	Transformer efficiency	14.30	172,000.00
R	Variable speed drives	17.39	285,520.00
S	Waste heat recovery	4.96	32,680.00

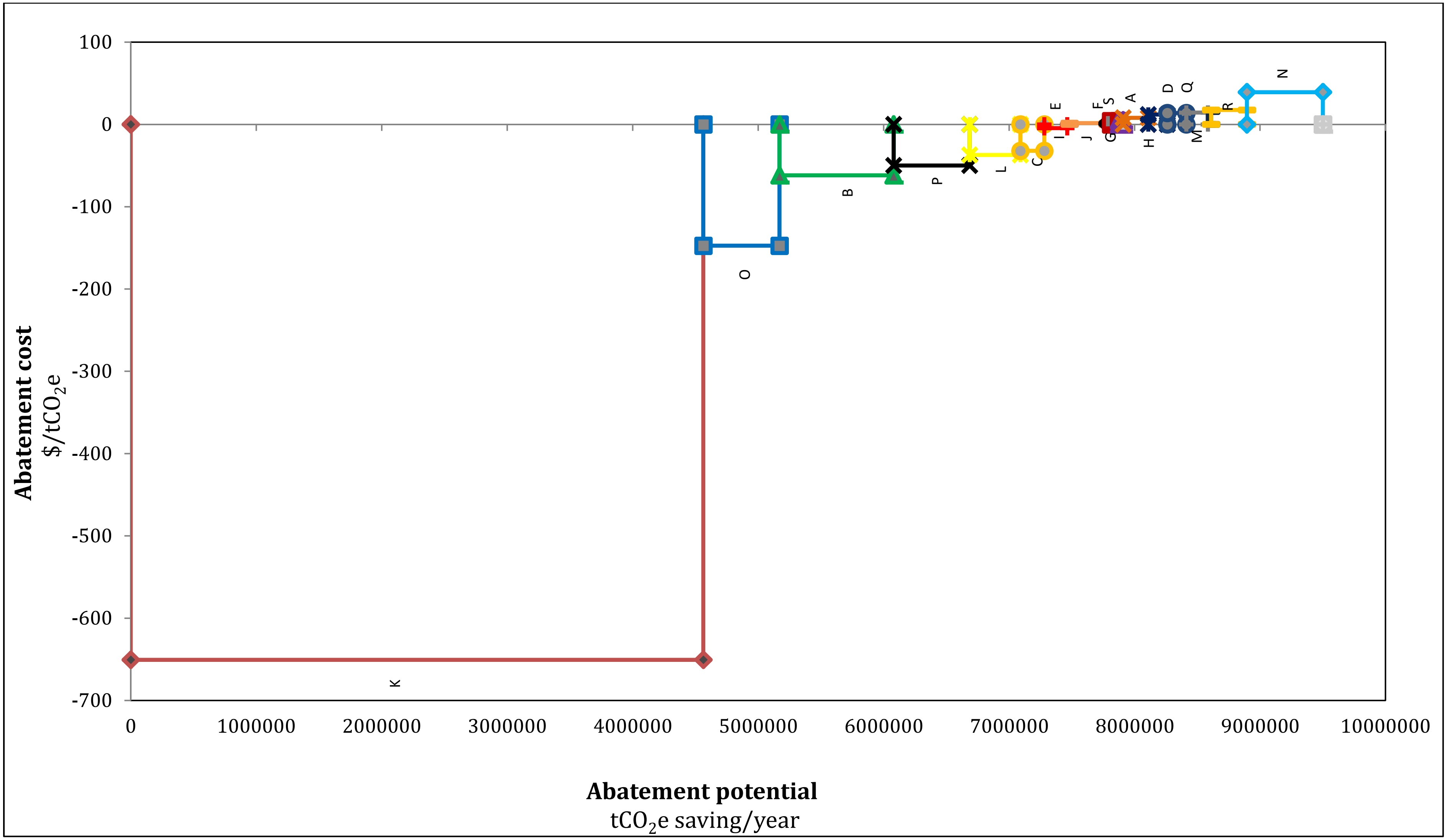

Figure 4.7 Marginal abatement cost curve for low emission measures in iron and steelmaking industry in Ghana.

Figure 4.7 above presents an estimate of the maximum potential of all technical GHG abatement measures (low emission measures) below $ 100 per tCO_2e if each measure was pursued. It shows that the abatement cost of B, C, I, K, L, O and P representing DC arc furnace, DC twin-shell with scrap preheating, foamy slag practice, near net shape casting thin slab, oxy-fuel burners, recuperative burners and scrap preheating-tunnel furnace (consteel) are negative (Table 4.8).

This means that all the above-mentioned low emission measures will bring monetary savings instead of incurring a cost and had the potential to abate CO_2 emissions. It is evident that K has the highest abatement potential with a significant amount of CO_2 savings per year at least cost, followed by O, B, P, L, C, I, E, J, F, G in that order. The most expensive measure is the N, costing around $ 39.1/ton followed by R ($ 17.39/ton), M ($ 15.65/ton), Q ($ 14.3/ton), D ($ 13.8/ton), H ($ 11.9/ton) and A ($ 7.99/ton) in that order.

Hence the most cost effective alternative climate and air pollution abatement measures are: near net shape casting thin slab (K), followed by scrap preheating-post combustion shaft furnace (O), DC arc furnace (B), scrap preheating-tunnel furnace (P), oxy-fuel burners (L), DC twin-shell with scrap preheating (C), and Foamy slag practice (I) etc. in that order. They have the highest abatement potential with a significant amount of CO_2 savings per year at least cost. Implementing these measures in the iron and steel industry will show major reduction potentials for both the energy use and significant emissions reduction.

Economically, it is more expensive to abate a tonne of CO_2 e with the introduction of recuperative burners costing around $ 39.1/ton followed by variable speed drives ($ 17.39/ton), transformer efficiency ($ 14.3/ton), eccentric bottom tapping ($ 13.8/ton), flue gas monitoring/control ($ 11.9/ton) and bottom stirring/stirring gas injection ($ 7.99/ton) in that order. This simply means that installing more of these measures will not be cost effective if a prior measure already reduced a significant amount of CO_2 and primary air pollutants.

However, when the current abatement technologies were compared with the best available technologies, it was revealed that the current technologies were not the most cost effective measures compared to the best available technologies. Hence, there are great opportunities for the industries to invest in the best available cost effective measures including near net shape casting thin slab, scrap preheating-post combustion shaft furnace, DC arc furnace, scrap preheating-tunnel furnace etc. which could earn the respective industries money instead of incurring cost. Thus the implementation of these measures will be critical to reach the environmental objectives of low emission iron and steel production. This will serve as a key economic input into the preparation of the low emission iron and steelmaking management plans. The reason for this huge gap between the current technologies and BAT as well as the feasibility of implementing these BATs in all the eight studied iron and steelmaking industries will be made clear by the barrier analysis.

4.7 Barriers to Low Emission Measures in Iron and Steelmaking Industries

In the second session of the interview respondents were asked to express their views on barriers that account for the adoption of low emission measures and the implementation in the iron and steel production industry. Slight modifications were made to the interview guide to suit the case study based on primary study conducted at the industrial firms to get first-hand information on the processes involved in production of steel.

The parts of the interview guide on the implementation of cost effectiveness of alternative climate and air pollution abatement measures and barriers for the adoption of low emission measures applied the use of a scale to quantify the response of the respondents. To avoid imbalance, these results were initially classified under two groups; The use of EAF and IMF for production in the respective firms, then the average score for each response under the groups were calculated and ranked.

With respect to the response from the interview, all the respondents' affirmed the existence of alternative cost effective GHG and primary air pollutants abatement measures gap in their respective firms and this therefore necessitated efforts to explore the existence of barriers for the implementation of low emission iron and steelmaking. The study of low emissions barriers to iron and steel industry is a multi-disciplinary field with contributions from theoretical backgrounds like, neo-classical economics, organizational economics, behavioural theory and organizational theory (Apeaning and Thollander, 2013). Based on these theories, our findings of low emission iron and steel production barriers were broadly classified under three main categories namely Economic, Organizational and Behavioural as defined by (Sanstad and Howarth, 1994) in Table 4.9

Table 4.9 Categorization of barriers and related theoretical barriers to low emission measures in iron and steel industry in Ghana

Related barrier classifications		
Economic	Organisational	Behavioural
• Access to capital	• Power	• Values
• Hidden cost	• Culture	• Inertia
• Risk		• Form of information
• Heterogeneity		• Credibility and trust
• Imperfect information		

However, numerous empirical studies (Rohdin and Thollander, 2006, Rohdin, Thollander, et al., 2007, Thollander and Ottosson, 2008, Apeaning and Thollander, 2013) conducted have confirmed the existence of barriers to improving low emission in various industrial firms. Studies of empirical barriers aimed at explaining the existence of the low emission gap, by investigating how these barriers exist and operate, the contexts in which they arise and the manner in which different intervention can be used to bridge the gap (Apeaning, 2012).

'Empirical barrier findings are meaningful only when linked to a well-articulated theoretical framework. Similarly, theoretical assertions are meaningful if only they stand up to empirical scrutiny' (Sanstad and Howarth, 1994). This means that all empirical low emission barriers have a theoretical connotation; as such empirical barriers can best be interpreted by using a theoretical framework (Sanstad and Howarth, 1994). Table 4.8 below highlights barriers considered to be important (i.e. barriers with average scoring greater than or equal to 0.5) by respondents and their related theoretical backgrounds.

Table 4.10 Classification of important barriers for the adoption and implementation of low emission measures by the iron and steel production industry

Ranking	Empirical barrier	Related theoretical barrier
1	Lack of budget funding	Access to capital
2	Access to capital	Access to capital
4	High cost of energy	Hidden cost
4	Cost of raw materials and production	Hidden cost
6	Inefficient technology	Heterogeneity
6	Lack of technical skills	Imperfect information

To unveil the existence of low emission manufacturing gap within the studied iron and steelmaking industries, respondents were asked to rate the importance of 15 barriers for low emission measures in iron and steelmaking industries; using a scale of 0 (not important) to 1 (very important). Figure 4.8 below represents the overall ranking of the barriers.

The highest ranked barrier for the adoption/implementation of low emission measures was “Lack of budget funding” closely followed by “access to capital/investment”. Both barriers are theoretically related to “access to capital”. About 88 % and 75 % of the managers and the engineering staff of their respective companies indicated lack of funding and access to capital market to generate enough funds or loan to facilitate the adoption of alternative cost effective measures that will not only help reducing GHG and unintentionally produced primary air pollutants but also to enhance their production as well. It was indicated that the interest on loans is so huge that it deters industries from going for loans. Some also attributed it to lack of environmental consciousness to the investors or the managers of the capital market on issues relating to low emission manufacturing. Again, some managers attributed this limitation to the limited number of environmental advocacy groups and non-governmental agencies that would raise concern about environmental quality and the lack of proper environmental policy and regulations.

“High cost of energy” and the “cost of raw materials and production” were ranked as the fourth highest barrier and these two barrier drivers can theoretically be linked to “hidden cost”. 63 % respondents claimed that the volatile energy prices resulting from the energy supply deficiencies is important factor that is hampering the top management decision to indulge in the implementation of low emission measure in their respective companies. The unrelenting rise in the cost of raw materials is cutting corporate profits, hitting stocks and in some cases pushing up consumer prices. The cost of raw materials and production cost increase is also due to exportation of scrap out of the country. The demand for steel is very high but the raw material is not able to meet demand. This has become important factors that deter the managers of the company to adopt low emission measure which is not part of the core activities of the company. On the high cost of energy, most respondents stated that, they will rather allocate capital to other production related investments for them to compete in the capital market.

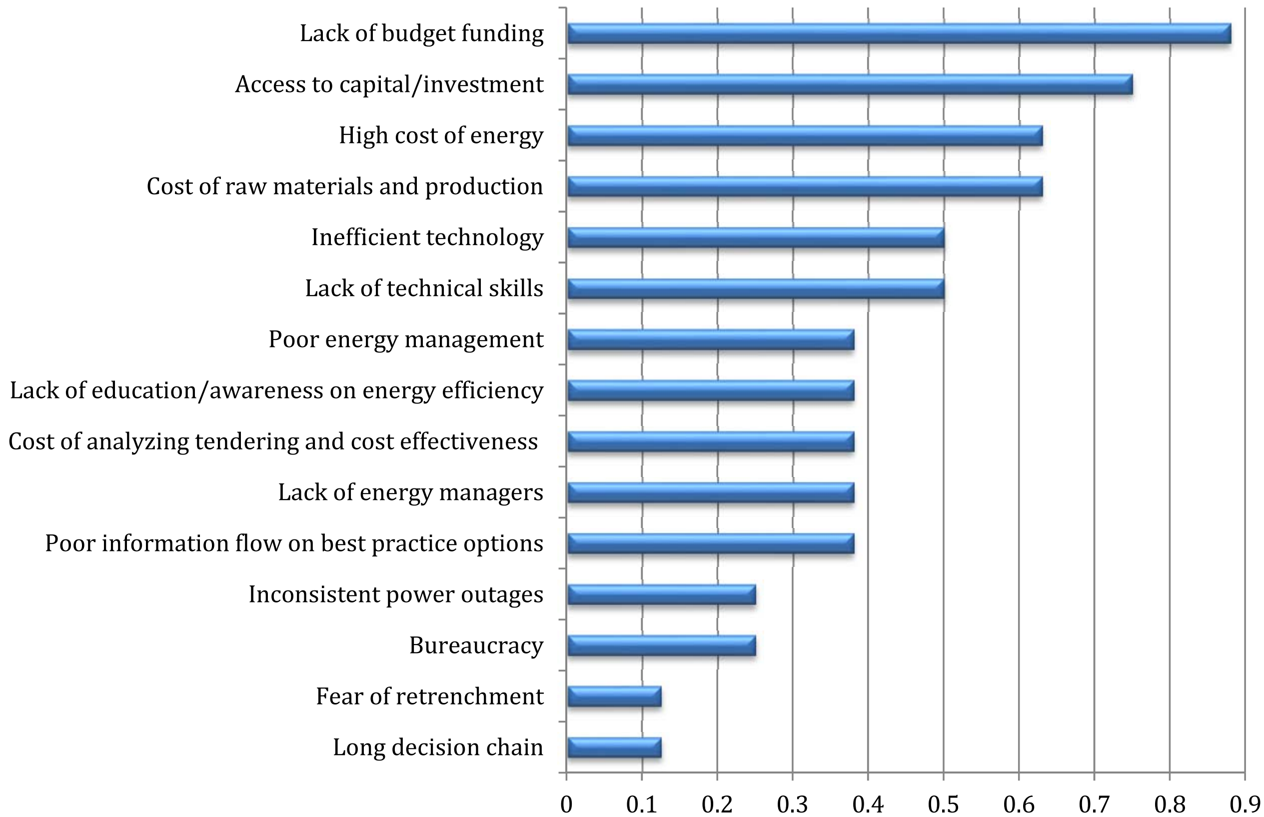

Figure 4.8: Ranking results of barriers for implementing the low emission measures by the iron and steel production industry.

The sixth most ranked barrier for implementing low emission measure is “inefficient technology” and “lack of technical skills. The former is related to “heterogeneity of technology”. 50 % respondents remarked that the installation of adjustable speed drives, VSDs for flue gas monitoring and control etc. that offers opportunities to operate dust collection fans in a more energy efficient manner was below the supplier’s assured performance. Additionally, technical production risks, lack of competent power engineers and other externalities associated with change of technology (due to energy efficiency improvement) were stated to be a very important barrier by respondents. Lack of technical skills” which also ranked sixth along with “inefficient technology” may be related to “imperfect information” which is impeding the implementation of low emission measure in the under-studied iron and steelmaking companies. 50 % respondents confirmed that, they lack skilled personnel to evaluate the performance of their facilities and also efficiently manage and operate the technology. Some firms had instituted new technologies (adjustable speed drives; flue gas monitoring and control; energy efficient drives in the rolling mill of EAF technologies) to enhance performance but the limitation of skilled and qualified personnel inhibited the ability of companies to take up low emission measures. The inability of the firms to also appropriate the benefits of implementing these measures (due to the lack of skilled personnel) developed a “split incentives” between parties who stand to gain more from the implementation of energy efficiency measures and those who gain less (Apeaning, 2012). This inability also discouraged the uptake of low emission measures to reduce GHG and its related primary air pollutants.

Barriers like "poor energy management", "lack of education or awareness of energy efficiency" cost of identifying opportunities, analyzing cost effectiveness and tendering", "lack of energy managers", "poor information flow", "inconsistent power outages", "bureaucracy", "fear of retrenchment" and "long decision chains" are ranked in deceasing order.

"Poor energy management" and "cost of identifying opportunities, analyzing cost effectiveness and tendering" can theoretically be linked to "hidden cost" whiles "lack of education or awareness of energy efficiency" is linked to "culture". 38 % engineering staff claimed energy management is a passing fancy. When shortages occur or prices spike unexpectedly, energy become the crises de jour and receives the full attention of their respective firms, then when market conditions change, energy management is once again relegated to a minor concern and this therefore impede the top management decision to adopt low emission measure.

In addition to poor energy management, the respondents claimed that the cost involved in contracting experts or consultants to identify and analyze low emission measures and other related facility performance were very high and as such, management normally do not want to incur additional cost of identifying opportunities, analyzing cost effectiveness and tendering. With respect to the absence of education or awareness of energy efficiency, three respondents emphasized on the lack of culture of low emission measures and are also not aware of the positive environmental implication of such measures which will aid them to adopt the best available measures that may incur additional cost to their already cash-strapped firms.

Lack of energy managers" and "poor information flow" are barriers that may be related to "power" and "imperfect information" respectively. 38 % of the respondents affirmed lack of energy managers and the responsibilities of the energy managers have been allocated to the engineering staffs that lack sufficient power to initiate low emission measures because the top management overlooks such measures and tend to concentrate more on the core business activities of their respective companies. Accurate availability of information within any firm is an important decision making parameter and it aids in the implementation of low emission measures. Effective information flow goes beyond the availability and content of the information but also it should be specific and personalized, vivid, clear, simple and above all it should be close in time to make relevant decision. These limitations were important deterrents to the adoption and implementation of low emission measures with the studied iron and steelmaking industries.

Frequent disruption of electric power is also important barrier that can theoretically be linked to "hidden cost". Inconsistent power outages has resulted many iron and steel companies to invest huge capital to provide alternative power sources to run their businesses and has consequently forced many steel firms to carry high cost structures which reduces efficiency and results in loss of competitiveness for their products, hence relegating low emission measures behind. For companies who cannot incur this cost, production is stopped until there is electricity to resume production and this does not make such companies competitive.

Meaningless bureaucratic goals are most often important deterrents to the adoption and implementation of low emission measures. This barrier may be linked to “inertia”. 25 % respondents affirmed that, their companies utilize bureaucratic structures to direct their resource allocation and product development and this inhibit the ability of the companies to implement low emission manufacturing.

Retrenchment is also an important factor which is deterrent to the implementation of low emission measures. Few respondents (12.5 %) claimed that, technological changes will render their organizational products uncompetitive for the existing volatile market leading to a large number of employees leaving the organization. Some respondents argue that, the implementation of this low emission measures will enable greater production by fewer employees which will have a tremendous impact on the middle management ranks. The inability of the firms to also appropriate the benefits for implementing advanced technologies that will make use of few employees developed a “split incentives” between parties who stand to gain more from the implementation of such measures and those who gain less (Apeaning, 2012). This inability also discouraged the low emission measures. Another equally important factor is “long decision chain” This barrier may be linked to “power” and it lacks influence on the company’s top management agenda and therefore deter management from adopting low emission measure not only to reduce the GHG emission but also primary air pollutants emissions as well.

Nevertheless, the above-mentioned barriers to low emission measures identified in the iron and steel industries were classified into the following three categories: economic, behavioral, and organizational as defined by (Sanstad and Howarth, 1994) in Table 4.9

Table 4.11 Classification of barriers to low emission measures in iron and steel industry in Ghana into categories of barriers

Economic	Organisational	Behavioural
• Lack of budget funding	• Poor information flow	• Bureaucracy
• Access to capital	• Poor energy management	• Fear of retrenchment
• Cost of energy	• Lack of education/awareness on energy efficiency	
• Cost of raw materials and production	• Long decision chain	
• Inefficient technology	• Lack of energy managers	
• Lack of technical skills		
• Inconsistent power outages		
• Cost of analysing and tendering		

Chapter 5: Conclusions and recommendations

5.1 Conclusions

This study provides in-depth assessment of low emission measures in iron and steel production in the industrial hub (Tema industrial area) of Ghana. The research findings were sufficient enough to answer all the three research questions posed. All the research questions were answered in Chapter 4 of this thesis. Section 4.3 answers the first research question about the iron and steel production routes used in Ghana and the one which is the most cost effective low emission measure. The second research question was to find out the most cost effective current low emission measures used in iron and steel industry in Ghana and was answered in Section 4.4 and 4.5 Chapter 4. The third research question was answered in Chapter 4, Section 4.6 and it was to assess the most cost effectiveness of the best available technologies (BAT) for low emission iron and steel production in Ghana. The last but not the least research question was to investigate barriers for the adoption and implementation of low emission measures in the iron and steelmaking industry in Greater Accra region of Ghana it was answered in Section 4.7 Chapter 4.

Conclusions are given for each of the research questions posed.

1. What are the iron and steel production routes used in the Greater Accra Region of Ghana and which one is the most cost effective?

Comparative assessment of the two major iron and steelmaking routes, those of electric arc furnace (EAF) and induction melting furnace (IMF) production route against a selection of energy consumption and emission (CO_2 eq and priority air pollutants) parameters were conducted to select the best available climate and air pollution abatement measures and their costs in Ghana.

The energy consumption of the EAF iron and steelmaking route was found to be the largest, when plotted as MJ/$. The least energy intensive process, when plotted against the economic value of the unit product, was found to be the IMF steelmaking route. However, when CO_2 eq emissions were plotted against the market value of the unit product, EAF production technology had the largest value. The lowest value for the greenhouse gas parameter was the IMF process. EAF technology had several orders of magnitude higher NO_x, SO_2, VOC, PM_{10} and $PM_{2.5}$ emissions when plotted against the economic value.

Comparison of the overall low emission performance showed that the IMF steelmaking ranked first and was having the best performance far above the EAF steelmaking route, mainly due to low energy needs for IMF to produce a metric tonne of steel, low greenhouse gas emissions as well as low primary air pollutants emissions in its process. The EAF steel production route had the worst performance on every emission level, including greenhouse gas emissions, and all priority air pollutants emissions to the environment. In conclusion, the IMF technology was considered to be the best available climate and air pollution abatement measure compared to the EAF in the iron and steel making industry in Ghana. This corroborates studies conducted by CPCB, (2010) on electric arc and induction furnaces. The study indicated that several reasons such as less energy consumption, less environmental pollution, lesser quantity of refractory use makes IMF technology more popular as compared to EAF. Furthermore, expenditure on electrode is nil and the initial investment is less on plant and equipment in relation to EAF. Thus there are economic advantages in making steel through induction furnaces route compared to EAF (Central Pollution Control Board, 2010).

2. What is the cost effectiveness of the current low emission measures used in iron and steel industry in the Greater Accra Region of Ghana?

The current low emission measures that are already implemented on existing plants (EAF and IMF) to further reduce GHG and primary air pollutants emissions to the environment was considered and was subsequently used to estimate their cost effectiveness. It can be concluded that, transformer efficiency is the most cost effective measure followed by insulation of furnace and energy efficient drives in the rolling mill. Introduction or installation of flue gas monitoring and control on the EAF processes is the most costly measure per year of kg CO_2 emission reduction. Overall, the CO_2 emission reduction measures instituted on the IMF were the most cost-effective compared to EAF steelmaking measures. Transformer efficiency helps to reduce energy loss and increase productivity (US EPA, 2012) and from the research this was the most cost-effective measure. In practice, flue gas control system have proven to be of limited utility since continuous emissions monitoring provide a substantial amount of information for EAF facilities that includes most of the information that VSD system provide. Hence operators have found that VSD systems are not able to predict problems that occur in EAF due to the variability in the scrap and also from energy fluctuations (American Iron and Steel Institute (AISI), 2010). These factors affect EAF emissions hence the most costly measure.

3. What is the cost effectiveness of the best available technologies (BAT) for low emission iron and steel production in the Greater Accra Region of Ghana?

The selection of the most cost-effective BAT measures to reach the environmental objectives of good and sound low emission status of all iron and steel industries. Marginal abatement cost curves (MACCs) was used to analyze cost effectiveness of nineteen alternative climate and air pollution abatement measures that were available for the steelmaking industries in Ghana. It was again used to analysed four current technologies that were already implemented in some iron and steel industries visited. It can be concluded that, near net shape casting thin slab, followed by scrap preheating-post combustion shaft furnace, DC arc furnace, scrap preheating-tunnel furnace, oxy-fuel burners, DC twin-shell with scrap preheating and foamy slag practice etc. were revealed to be the most cost effective alternative climate and air pollution abatement measures. These measures have the highest abatement potential with a significant amount of CO_2 savings per year at least cost. It was further revealed from the MACC that, the introduction of recuperative burners costing around $ 39.1/ton followed by variable speed drives ($ 17.39/ton), preventive maintenance ($ 15.65/ton), transformer efficiency ($ 14.3/ton), eccentric bottom tapping ($ 13.8/ton), flue gas monitoring/control ($ 11.9/ton) and bottom stirring/stirring gas injection ($ 7.99/ton) would make economic loss due to its expensive cost to abate a tonne of CO_2.

Economically, it is more expensive to abate a tonne of CO_2 e with the introduction of recuperative burners costing around \$ 39.1/ton followed by variable speed drives (\$ 17.39/ton), preventive maintenance (\$ 15.65/ton), transformer efficiency (\$ 14.3/ton), eccentric bottom tapping (\$ 13.8/ton), flue gas monitoring/control (\$ 11.9/ton) and bottom stirring/stirring gas injection (\$ 7.99/ton) in that order. This simply means that installing more of these measures will not be cost effective if a prior measure already reduced a significant amount of CO_2 and primary air pollutants.

4. What barriers account for the adoption and implementation of low emission measures by the iron and steel production industry in Greater Accra?

Results from the interviews identified barriers hindering steelmaking industries in Ghana from adopting or investing in low emission measures, it can be concluded that, all the barriers considered to be of high importance are lack of "budget funding", "access to capital/investment", "high cost of energy", "cost of raw materials and production", "inefficient technology" and "lack of technical skills". All the barriers are theoretically related to economics. The two most important barriers ("lack of budget funding" and "access to capital/investment") are related to access to funding for the implementation of low emission manufacturing. Most of the interviewees attributed this barrier to the lack of management decision to place priority on low emission manufacturing but rather were interested in decisions that could improve productivity and produce immediate dividend in shorter time. This therefore makes "lack of budget funding" as a major deterrent for low emission iron and steel production. "Access to capital and investment" was also considered to be the second most important barrier hindering the implementation of low emission measures. This is as a result of the lack of credit worthiness of the steelmaking firms and even if they managed to get the loans, the risks associated with those measures; thus inhibiting most firms from adopting low emission measures.

From the results of the barrier survey, 63 % respondents claimed that, "high cost of energy" and the "cost of raw materials and production" are considered as an important barrier (ranked in 4th place); the ranking of this barriers partly stems from the fact that the iron and steel producers are facing energy price volatility and resource (raw materials) costly while the consumers face the prospect of high prices. They further affirmed that, due to high cost of energy, many low emission initiatives are eliminated from projects before the real costs are understood. Further, most respondent confirmed that, "inefficient technology" and "lack of technical skills" by the engineering staff to manage the plants is a critical factor inhibiting their efforts to adopt and implement low emission manufacturing.

50 % of the respondents affirmed that, top management of the respective firms will rather focus their attention on increasing production and profits rather than reducing emission or investing in low emission manufacturing. Barriers like "poor energy management", "lack of education or awareness of energy efficiency" cost of identifying opportunities, analyzing cost effectiveness and tendering", "lack of energy managers", "poor information flow", "inconsistent power outages", "bureaucracy", "fear of retrenchment" and "long decision chains" are ranked in deceasing order. This research corroborates the findings of an extensive survey of barriers to industrial energy efficiency conducted in Asia under a project title "Greenhouse Gas Emission Reduction from Industry in Asia and the Pacific". Lack of financing and effective policies were identified as key barrier out of the four thematic barrier categories namely: "management", "knowledge/Information", "financing" and "Policy" (UNEP, 2006). This research again corroborates the findings of Apeaning and Thollander,

(2013), by investigating barriers to and driving forces for industrial energy efficiency improvements in African industries, using Ghana's largest industrial area as a case study. In their study, "lack of budget funding" and "access to capital" was revealed to be the most important barriers impeding the implementation of cost effective energy efficiency technologies.

However, findings of this study was in variance to series of studies conducted in Sweden (Rohdin and Thollander, 2006, Rohdin, Thollander, et al., 2007, Thollander and Ottosson, 2008, Johansson, 2014) and in Jiangsu, China (Ou, 2013) in different industries. Technical risks such as risk of production disruptions topped the barriers ranking in a study on Swedish pulp and paper industry by Thollander and Ottosson (2008). Rohdin and Thollander (2006) also identified cost of production disruption/hassle/inconvenience as the most important barrier in a similar study of barrier to energy efficiency in non-energy intensive manufacturing industry in Sweden. Moreover, Johansson, (2014) identified lack of time as a major barrier to improved energy efficiency than lack of access to capital in her study to investigate energy management practices at eleven iron and steel companies in Sweden. Further, Xiaoxi Ou, (2013) also indicated interruption of production and long payback period as the most important factor constraining energy-efficiency in the iron and steel industry in Jiangsu, China.

5.2 Recommendations and Policy Recommendations

The suggestions for further work would provide additional information which could be needed to guide decision and policy-makers in steelmaking industries to take action to adopt the implementation of low emission measures in order to improve the steel industry's competiveness and to reduce GHG and primary air pollutant emissions into the environment.

The cost-effectiveness analysis carried out for the current CO_2 abatement measures in iron and steel industry in Ghana simply assessed the emission reduction capacity of a number of measures or combinations of measures without detailing the target level. Hence, it would be of interest to perform detailed studies that will take into account target levels.

The selected low emission indicators for assessing the best available climate and air pollution abatement technologies in this study did not consider other aspect of low emission indicators of each of the selected industries. It may be interesting to conduct a research on the solid waste, freshwater consumption and land use requirement of low emission iron and steel production.

The study of barriers for the adoption of the most cost effective climate and air pollution abatement measures by the iron and steel production industry, where managers and engineering staff were interviewed, could be complemented with additional interviews with relevant stakeholders that are experienced and knowledgeable about low emission manufacturing, employees at other positions at the steel companies, from CEOs to operators. It would be interesting to analyze if the interviewees' experiences and opinions differ depending on the implementation of low emission measures. Additional interviews would give a more comprehensive view of the subject studied and facilitates broad base knowledge suitable for policy implementation.

On policy recommendation, this study presents a good insight for future industrial policies and government intervention towards low emission manufacturing improvements in Ghana.

The study recommends technical and financial support by government, especially the introduction of subsidies on environmental protection technologies to industries that have adopted low emission technologies in order to bridge some economic barriers experiencing by industries. This will not only help more iron and steelmaking industries to enjoy these subsidies, but also stimulate an early adoption of low emission measures to other energy-intensive firms to reduce the GHG and primary air pollutants emission into the environment. Further, there should be pragmatic governmental framework geared towards low emission implementation and management in Ghanaian industries; by formulating policy instruments and initiating low emission schemes and programs. Moreover, the government of Ghana needs to develop a broad-based framework in order to promote industrial low emission measures and public campaigns to increase the awareness of industrial low emission measures. Also Industrial enforcement bodies should recognize and embrace a strong and healthy industrial base. They should ensure that industries comply with regulations in order to reduce the impact of steel and other production processes to neighbouring communities.

In addition to that, when industries are able to adopt BAT measures, organizational and behavioural barriers will have to be bridged. Hence managers and employees will need to have continual training to optimize technology performance. This is because a failure to effectively train workforce to maintain BAT systems erodes their effectiveness with time.

The research covered a limited scope hence it will be interesting work for future study is to analyse what policy measures would be required to realize low emission measures in the iron and steel industry as well as other manufacturing industries. Such a study could include interviews with policy makers, technocrats and experts from industries.

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Annex 1

ERASMUS UNIVERSITY, ROTTERDAM, THE NETHERLANDS
INSTITUTE FOR HOUSING AND DEVELOPMENT STUDIES (HIS)
MSC. URBAN MANAGEMENT AND DEVELOPMENT (UMD)-JUN/JULY 2015

RESEARCH TOPIC: "LOW EMISSION IRON AND STEEL PRODUCTION (A CASE STUDY OF GREATER ACCRA REGION OF GHANA".

Juliana Bempah is a student from Erasmus University, Rotterdam pursuing MSc. Urban Management and Development with Institute for Housing Studies (IHS). This interview guide will assist the researcher to gather data for academic purposes and data collected will be treated with confidentiality. The researcher appeals to the respondent to give his/her maximum cooperation and time. Thank you.

Personal Information:

Name:
……………………………………………………………………………………………….

Gender: Male ……..   Female ……….

What is your position in this Organization? ………………………………………………

<u>Part 1: Quantitative assessment of cost effectiveness of alternative climate and air pollution abatement technologies and measures</u>

1) Current technologies

- How much was the initial investment in the current production technology
- What is the energy use of your current technology?
- What are the emission factors (GHG and air pollutants) of your current technology?

2) Current production processes

- Can you tell me the cost of the current production process?
- What is the energy use involved?
- What are the emissions factors (GHG and air pollutants) emanating from the production process?

3) Current fuels

- What is the cost of the current fuel use per unit of input (m3 of fuel) or output?
- What are the emissions factors (GHG and air pollutants) of the fuels used?

4) BAT (alternative) technologies (more energy efficient)

- Can you tell me the cost per unit output involved in this BAT?
- What is the energy use per unit of output of this technology?

- What are the emissions factors (GHG and air pollutants) of this BAT?

5) BAT (alternative) processes (more energy/resource efficient)

- What has been your cost of production since adopting this BAT?
- Can you elaborate on the energy use of the BAT?
- What are the emissions factors (GHG and air pollutants) of this BAT?

6) Alternative fuels (less polluting)

- What is the cost of using alternative fuel?
- What are the emissions factors (GHG and air pollutants) of this alternative fuel?

Part 2: Assessment of barriers that prevent the implementation of low emission measures and technologies in the iron and steel industry

7) What are the barriers that prevent the implementation of cost-effective low emission measures and technologies?
8) Does your company have budget funding to support low carbon technologies? From your experience with this company, can you provide me with some funding sources available to the company in the event that the company wants to procure BAT that is energy efficient and has the potential to reduce GHG emissions and local air pollutants?

9) Does your company have access to capital and do you know the extent of capital investment involved in a BAT? (the ability of companies to meet cost of credit/loans)

10) In your opinion, do you think the cost of energy can make your company readily and easily accept a low carbon technology or measure into the production process?
11) To what extent is the workforce educated/aware of low carbon technologies and measures that are energy efficient and can reduce emissions?
12) In the event your company wants to adopt a low carbon technology, do you have that number of skilled technical personnel in your plant?
13) Can you explain to me the level of information flow on best practice options and availability of alternative cost effective technologies?
14) What can you tell me about the commitment of senior management towards low carbon technology?
15) How has the inconsistent power outages prevented you from adopting low carbon technologies in these resent times?
16) Can you elaborate on technological challenges the company experiences when new technologies are adopted? (Technical risk of production disruption, Technical skill, Perceived technical and operational risk)
17) Is there any other information you will want to include apart from the above mentioned issues?