

# **Energy efficiency in the iron and steel industry:**

Factors influencing improvement of energy efficiency in Jiangsu,  
China



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*University of Oslo, May 2013*

## **Acknowledgements**

This thesis would not have been possible without the help of a number of people. First and foremost, I would like to thank my informants, who let me enter into their enterprises and shared the information with me and even supply accommodation for me. I also give my appreciation to the guards in some enterprises, who help me to find the department heads and send me to another enterprise to conduct interview.

I am really grateful to my supervisor Hege Merete Knutsen for her insightful comments and friendliness. I learnt much more than this thesis from her.

I am also grateful to the University of Oslo and the Norwegian government for giving me such an excellent opportunity to further my studies and supplying financial support throughout my master degree program.

To all of my friends: thank you for your supports during my study progress. Special thanks to Wei Lu for sharing your ideas on my thesis and your encouragement. Thanks to my parents for your understanding.

Lastly thanks to Wei Wang, for being there throughout everything.

Xiaoxi Ou, Oslo, May 2013

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## **Abbreviations**

- MIIT Ministry of Industry and Information Technology
- NDRC National Development and Reform Commission

## Abstract

Improvement of energy efficiency is widely accepted as an efficient measure to relieve the crisis of energy resources and environment pollution; however, the energy utilization efficiency in China is still at a low level: the unit GDP energy consumption in China is 4 times to the world average level. Moreover, to fulfill the commitments of reducing 40% carbon emissions in 2020, China needs to improve the energy efficiency immediately. As a major resource of energy consumption as well as carbon emission, the iron and steel industry should take more responsibility to improve energy efficiency. However, current research in China mainly focuses on national or provincial energy efficiency, while the research on industrial energy efficiency is seldom. Furthermore, scholars tend to study factors that contribute to improving energy efficiency rather than factors constraining it. This has blocked the way of proposing operative methods for improving energy efficiency to some extent.

In this paper, I analyze conditions and factors that enhance and constrain energy efficiency in nine steel corporations in Jiangsu province. Primary data have been collected by semi-structured interviews. Introduction of more advanced technology, market competition, regulatory pressure by the central and local governments and enterprise management on energy efficiency are factors that may enhance energy efficiency and that I look into. Risks involved in investing in energy-efficient technology, uncertainty about the applicability of available technologies, lack of skills among the workers and lack of energy efficiency culture in the enterprises are the constraining factors that I look into. Due to the differences in the size and financial strength of the enterprises, the main enhancing and constraining factors vary with different types of enterprises (large-scale enterprises, medium-scale enterprises and small-scale enterprises). At the end of this paper, five measures are proposed in order to improve energy efficiency in the iron and steel industry

**Keywords:** the iron and steel industry, energy efficiency, enhancing factors, constraining factors

# 1 Introduction

## 1.1 The objective of this study

Since the reform and opening up, the economy in China is growing quite fast. According to the statistics of China (2011), its annual GDP growth rate between 1991 and 2010 is about 10.5%. As energy is an indispensable factor in economic growth, the energy consumption expanded both in volume and growth rate terms during this period, especially after the year 2002 (Ma, Oxley and Gibson 2009), which is supported by the high proportion of manufacturing industry and huge demand of energy-intensive products (Zhuang 2007). The output the contribution of the manufacturing sector to the total energy consumption was 70% of the total energy consumption in 2006. It increased from 64.6% in 2000, and the amount of CO<sub>2</sub> emissions related to the energy industry in China is 5.65 Gt<sup>1</sup>, which is 20% of the global CO<sub>2</sub> emission (Jiang, Sun and Liu 2010). China's iron and steel industry is the most energy-intensive and polluting industry in China with the 15% national energy consumption and 14% national pollutant. Besides, the iron and steel industry is the 'backbone' of CO<sub>2</sub> emissions.

The large amount of energy consumption and CO<sub>2</sub> emissions have not only aroused domestic concern about the problems of national energy security and serious environmental pollution, but also triggered an intense international discussion on China's energy issues. Under the severe stress from international society, the Chinese government made a commitment that China's CO<sub>2</sub> emission intensity would drop 40-50% by 2020 on the basis of emission in 2005 (Meng et al. 2011).

The energy demand will not decrease in a short time in China because China is one of the greatest exporting nations and still at the stage of rapid industrialization and

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<sup>1</sup> 1Gt=10<sup>9</sup> tons



urbanization. However, energy efficiency, as a tool of climate change mitigation, environmental protection and reduction of fuel import dependency(Fleiter, Worrell and Eichhammer 2011), give a large room for improvement of the present situation in China. Furthermore, energy efficiency is also a matter of cost saving and competitiveness at the level of firms. Although energy efficiency is a good way to solve the energy problems, studies have showed that energy-efficient measures are not always implemented and there are barriers to hinder energy efficiency improvement (Rohdin and Thollander 2006).

The low level of energy efficiency in China verifies the existence of barriers to improvement. The ratio of national energy consumption to GDP is 2.5 times the average level of the whole world, 3.3 times level in the United States, 6 times the number in Japan, and it is also higher than that of Brazil, Mexico and other developing countries<sup>2</sup>. In energy-intensive iron and steel industry, the average energy consumption of per ton steel in China is higher than that in advanced steel producing countries level by more than 10%, and the energy consumption of per unit gross value of industrial output is 3 times higher than the level of advanced steel producing countries (Han 2010). Therefore, it is necessary to find out which factors enhance and constrain energy efficiency improvement in China.

Even considering the wide range of enhancing and constraining factors to improved energy efficiency referred to in previous studies, few studies have contributed to the evaluation of factors influencing energy efficiency from the perspective of industries and with respect to enterprise size in China. Owing to China's special national conditions, a study on how influencing factors are actually experienced by Chinese enterprises can supplement existing research on improving energy efficiency.

To supplement research on the industrial energy-efficiency issue in China, the study will take the most energy-intensive industry in China—the iron and steel industry as the example and address the following questions:

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<sup>2</sup> Data source: <http://news.163.com/12/0524/14/829D2EG700014JB6.html>

- ✧ *Which factors enhance and constrain energy-efficiency improvement in China's iron and steel industry?*
- ✧ *How do large, medium and small enterprises respond differently to the influencing factors and why?*

## 1.2 Reasons for this study

**Relieving pressure on nature resource and environment:** The iron and steel industry mainly utilizes non-renewable primary energy. The high energy consumption and low efficiency of utilization in China increases the pressure of energy supply and CO<sub>2</sub> reduction. This research focuses on factors that influence energy efficiency and suggests some solutions to improve the energy efficiency in the iron and steel industry, which is meaningful for relieving the pressure of nature resource supply and environment pollution.

**Developing a more competitive iron and steel industry:** China's iron and steel industry is facing a problem of overcapacity and fierce competition drives iron and steel company to constantly reduce production cost to survive. Energy cost usually accounts for nearly 30% of the total cost in iron and steel enterprises, which is much more than that in advanced steel producing countries but also reflect China's huge potential in reducing cost in iron and steel industry. Improving energy efficiency is one of the effective methods to help the industry reduce cost, although to some enterprises, measures to improve energy efficiency may be costly and could reduce competitiveness at least in short run. Through clarifying the factors that influence energy efficiency, this research provides strategic suggestions to iron and steel enterprises to become more competitive.

**Fulfilling international agreements on carbon reduction:** Carbon reduction has developed into an international political issue although it is an environmental issue at the individual level. The International Iron and Steel Association stated that the carbon emission of iron and steel industry in China accounted for 51% of the total emission of the world's steel and iron industry, requiring China to improve the energy

efficiency and reduce the carbon emission. As a large nation, China has promised to reduce the 40-50% CO<sub>2</sub> emissions until 2020 based on 2005 (Han 2010) . This study will address ways to reduce carbon emission and thus it is meaningful for our country to fulfill the international agreement.

### 1.3 Background

#### 1.3.1 Achievements of China’s iron and steel industry

The iron and steel industry is an important basic industry in China and Chinese iron and steel industry has become one of the most important suppliers in the world. From 2001 to 2010, crude steel production in China increased from 0.15 billion ton to 0.65 billion, with an average annual growth rate of 17%. Moreover, the global share of Chinese crude steel production increased by an annual average of 11 per cent per year from 2001to 2010, growing from 17.8% to 44%. In other words, almost half of the global production of crude steel is produced by Chinese enterprises.

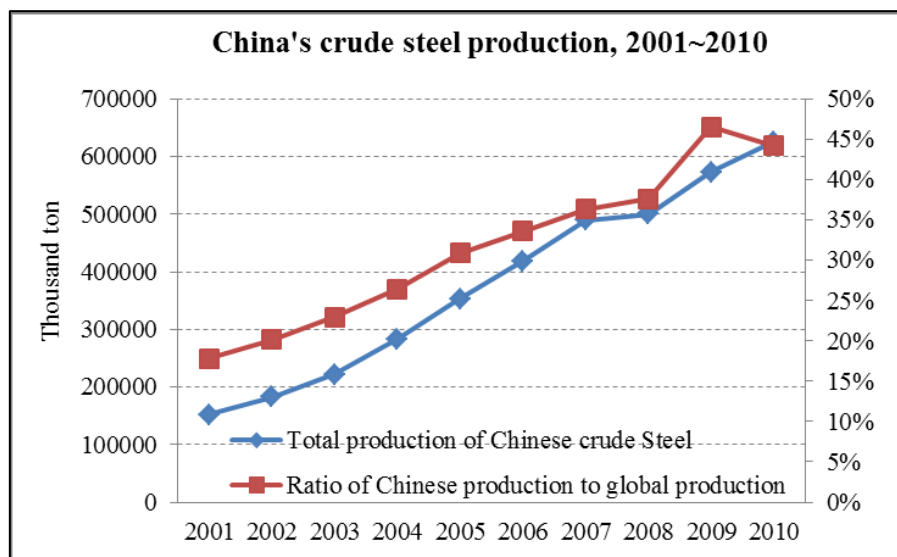


Figure 1.1The trend of China’s crude steel production

Source: Steel Statistical Yearbook 2011. <http://www.worldsteel.org>

With the increase of the iron and steel production, the energy consumption is huge due to the energy-intensive characteristic of producing iron and steel. In 2008, iron and steel industry consumed 0.52 billion tonnes of coal equivalent, which

accounts for 17.8% of the total energy consumption in China. However, the comprehensive energy consumption of per ton steel decreased from 1.94 tonnes of standard coal in 1995 to less than 1 tonne of standard coal at present and the number has decreased to 605kg in key large and medium-scale enterprises. In the past dozen years, the average rate of annual energy-saving reach 5.74%, which partly relieves the energy stress brought by large amount of production (Mao 2012) .

The energy used in the process of producing iron and steel is primary energy, especially coal (account for 70%) in China and with the consumption of the primary energy, secondhand energy such as high temperature, high pressure and coal gas can be recycled to improve energy efficiency. Generally speaking, the current amount of recovered secondary energy accounts for 35% of the total energy consumption, and the average recovery rate of blast furnace gas and coke oven gas have reached 94% and 98% respectively in 2007 while the heat recovery rate of high temperature arrived at 44% although average heat recovery rate is 25.8% in 2005. Besides, freshwater consumption per tonne of steel has fallen to 4 tonnes since 2010 and the cycling water using rate increased to 97.2% (Mao 2012). This shows the improvement of energy efficiency in China these years.

The pollution emissions also dropped following the reduction of energy consumption. The average discharge of wastewater is 2.2 tonne in 2009, 1/8 of the discharge in 1999 and the attainment rate of waste water reached 96.9%. Moreover, the emissions of SO<sub>2</sub>, industrial smoke and dust were reduced by 43%, 96% and 97% respectively (Shi and Chen 2011).

To further improve competition, the industry increases investment on advanced technology and equipment and the accumulated fixed-asset investments reached 2.6 trillion Yuan from 1978 to 2010 (Song and Liu 2013). The blast furnace below 300m<sup>3</sup>, converter and electric furnace below 200 thousand tonnes were phased during the period 2006-2008. In the same period, the average tonnage of blast furnace, converter and electric furnace increased to 870 thousand tonnes, 105 thousand tonnes and 37 thousand tonnes respectively (Shi and Chen 2011). Apart from that, the energy-efficient technology such as Blast Furnace Top Gas Recovery Turbine Unit,

Coke Dry Quench, Blast Furnace/ Converter gas recovery equipment have been widely introduced by key large enterprises in recent years. Generally, the small and medium metallurgical equipment is produced domestically while the large metallurgical equipment is introduced from developed countries but the localization rate of technology has been over 90% (Song and Liu 2013).

### 1.3.2 New challenge of energy efficiency improvement in China

Although China's iron and steel industry has made big progress in productive capacity, technique and energy efficiency, there is still a big gap between China and advanced countries.

The energy consumption in China's iron and steel industry is 10% higher and the energy-saving level of the large-medium-sized enterprises is 10% lower than the level of advanced iron and steel enterprises in developed countries. The energy-saving level of provincial medium-small-sized enterprises is even 40% lower. Moreover, restructuring of the industry into larger units is difficult as provincial governments open for and support entry of small firms to increase local employment and taxation.

Compared to the advanced iron and steel enterprises in developed countries, the current discharge of waste in China's iron and steel industry is still high. For example, the emissions of SO<sub>2</sub>, industrial smoke and dust are 1.24 kilogram per ton of steel, 0.6 kg per ton of steel and 0.27 kilogram per ton of steel respectively while the emissions in advanced countries are 0.25 kilogram SO<sub>2</sub> per ton of steel and 0.1 kilogram smoke and dust per ton of steel. In addition, the general utilization rate of advanced energy-efficient technology such as Blast Furnace Top Gas Recovery Turbine Unit, Coke Dry Quench, and Blast Furnace/ Converter gas recovery equipment in China is much lower than advanced iron and steel enterprises in developed countries (Yuan 2011).

Although the elimination of old equipment shows progress, it also reflects the currently backward techniques and equipment in China's iron and steel industry. The furnace over 1000m<sup>3</sup> is deemed as Blast Furnace in China (Yuan 2011), and there are

81 Blast Furnace in China in 2005, which produce 32% iron. However, the furnace over 3000m<sup>3</sup> is accepted as Blast Furnace in advanced countries. Take Japan for instance, there are only 30 Blast Furnace producing 83000 thousand tons of iron, in which, only one Blast Furnace is below 2000m<sup>3</sup>, 8 Blast Furnace with the capacity of 2000-3000m<sup>3</sup> and the rest 21 Blast Furnace are all over 3000m<sup>3</sup>. Moreover, the current advanced Blast Furnace mostly over 5000m<sup>3</sup> and the 1000m<sup>3</sup> even 2000m<sup>3</sup> Blast Furnace are phrasing out in advanced countries. Besides, the crude steel produced by Converters over 120 tonnes only accounted for 27.7% of the total amount. This percent is only half of that in advanced steel enterprises in developed countries (Yuan 2011).

The huge stock of advanced technology and equipment introduced from foreign countries help China's iron and steel industry to become more in line with advanced steel enterprises and supply a good platform for future independent R&D. However, the enterprises get used to introduce technology rather research on their own and the huge market demand and relatively low charge of resource and environmental pollution further increase their dependency on external R&D (Yuan 2011). According to the Chinese iron and steel industry association, the ratio of investment on R&D to revenues in individual enterprise is less than 1% and the ratio is even less than 0.5% in some medium-small-sized enterprises, while in some large-scale advanced enterprises, they invest more than 10% of the revenue on R&D (Yuan 2011). Moreover, the research conducted by enterprises mainly aim to resolve their specific problems and there is little communication between enterprises. This disperses research strength and thus brings research repetition. To reduce the dependency on foreign technology, central government and some research institutes have to take the responsibility of research and development, but they cannot guarantee the timeliness and continuity of the innovation, which usually leads to loss or interruption of innovation (Yuan 2011). If China's iron and steel industry cannot enhance the R&D ability, the development of the industry will be subject to difficulties in accessing foreign technologies for a long time and the goal of surpassing the performance of the advanced iron and steel producing countries will be hard to achieve.

There are great economies of scale in the iron and steel industry (Yuan 2011), but the industrial concentration is low in China's iron and steel industry, which hinders the improvement of the industry. There are 8012 iron and steel enterprises by the end of 2008, 871 more than that of 2004. Over the period of 2004-2008, the number of iron and steel enterprises increased in almost every province. Although the number of super-large-scale enterprises (with annual steel production over 0.1 billion tonnes) increased from 2 to 10, the increase resulted from swallowing up medium-scale enterprises rather than small-scale enterprises. The production capacity of small-scale enterprises did not decrease in this period and thus the problem of environmental pollution and low energy efficiency cannot be relieved (Shi and Chen 2011, Yuan 2011).

### 1.3.3 The status of Jiangsu iron and steel industry

The distribution of Chinese iron and steel enterprises shows that the production in the North of China is higher than that of the South and the production in East is higher than that of the West. East China and North China respectively provide 1/3 iron and steel of the entire country. Among the most productive provinces, Hebei province takes the first place with over 100 million tons of steel production, while Jiangsu province and Shandong province are second and third with steel production around 50 million tons (Mao 2012).

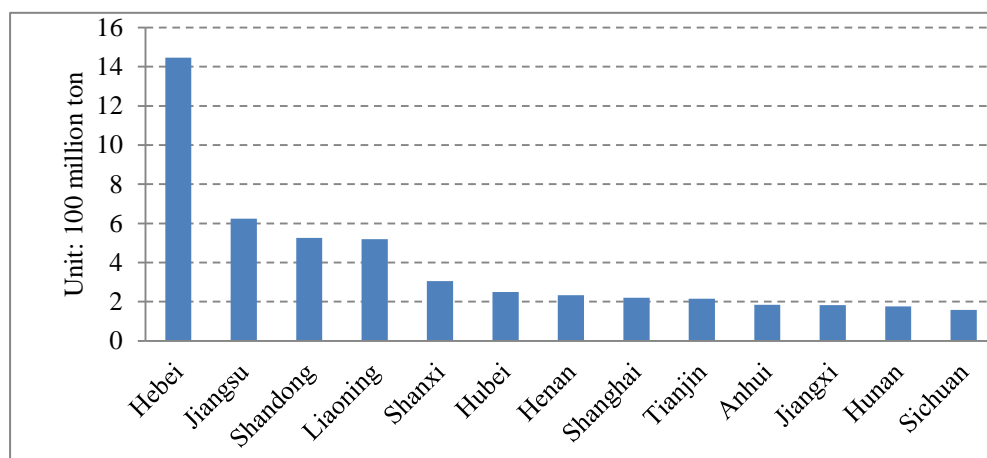


Figure 1.2 Production of crude steel in main provinces in 2010

Source: China Steel Yearbook (2011)

For the number of steel enterprise, Jiangsu province has the largest number of steel enterprises in China, 17.9% of the entire country. However, the number of steel enterprises in a province is not proportional with its steel production. Take Jiangsu province as an example, the number of steel enterprises in Jiangsu province is 12% higher than that of Hebei province but the steel production in Jiangsu province is even less than half of that in Hebei province. It is probably because Jiangsu province owns more small private steel enterprises and industrial concentration is lower than Hebei.

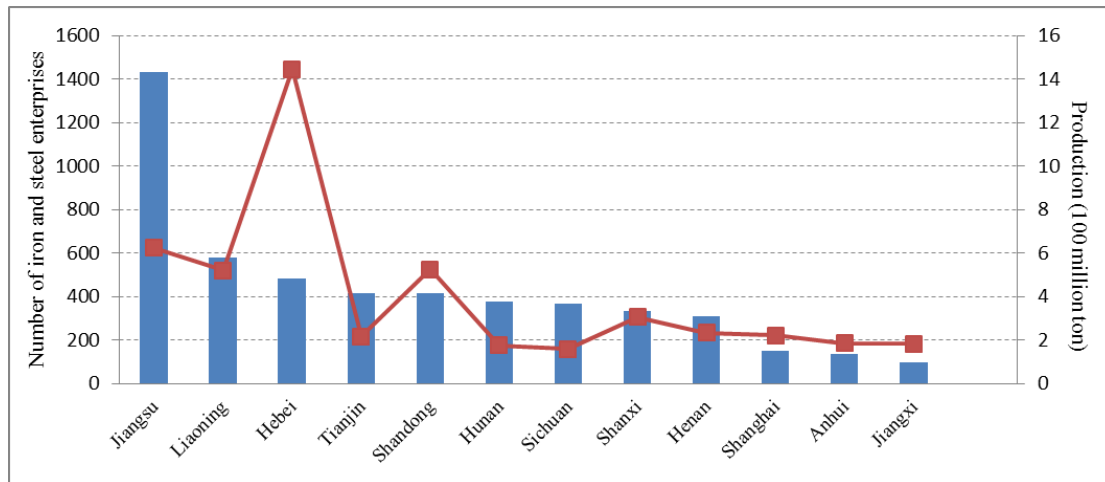


Figure 1.3 Iron and steel enterprises in the leading provinces

Source: China Steel Yearbook (2011), Shi and Chen (2011)

Jiangsu province is also a main steel consumer. The general steel consumption of the province ranks first in the whole country, in which the consumptions of bars-all, wire rod and rebar are much higher than other provinces and the consumption of steel plate ranks third(Mao 2012). Although consuming a relatively larger amount of energy, Jiangsu is one of the most energy efficient provinces in China. If every province has the energy efficiency level in Jiangsu, Shanghai or Shandong, the whole country could save 0.16 billion tonnes standard coal with the same productive structure in 2008, and the amount accounts for 36% of the whole iron and steel industry’s energy consumption that year (Shi and Chen 2011).

## 1.4 Organization of the thesis

The chapter after the introduction chapter deals with the concept of energy



efficiency and reviews the factors enhancing and constraining energy efficiency in previous studies, which lays a foundation for the choice of methodology and analytical framework in this thesis. I find in the previous studies that research on China's energy efficiency mainly focuses on the national and provincial level and will supplement this with a more enterprise-specific study I have chosen the iron and steel industry as my case and use a qualitative methodological approach to complement previous studies on China's energy efficiency.

After determining the research objective and methodology, I conducted interviews with an interview guide established on the basis of previous research in nine enterprises in Jiangsu province. Combining the materials I got from the interviews, I analyze influencing factors of energy efficiency in these enterprises. Moreover, these enterprises are divided into three types of small, medium and large enterprises and I dig into how differently three types of enterprises respond to the influencing factors of energy efficiency. In the end the suggestions on improving energy efficiency of iron and steel industry are proposed based on the analysis.

Figure 1.4 presents how I have organized my study and thesis. The first chapter states with my research background and researching meaning and I review the energy efficiency literature in Chapter 2. In Chapter 3 I describe the process of interview or process of getting data in detail and discuss the trustworthiness of my study. In Chapter 4 and Chapter 5 I present my analysis.

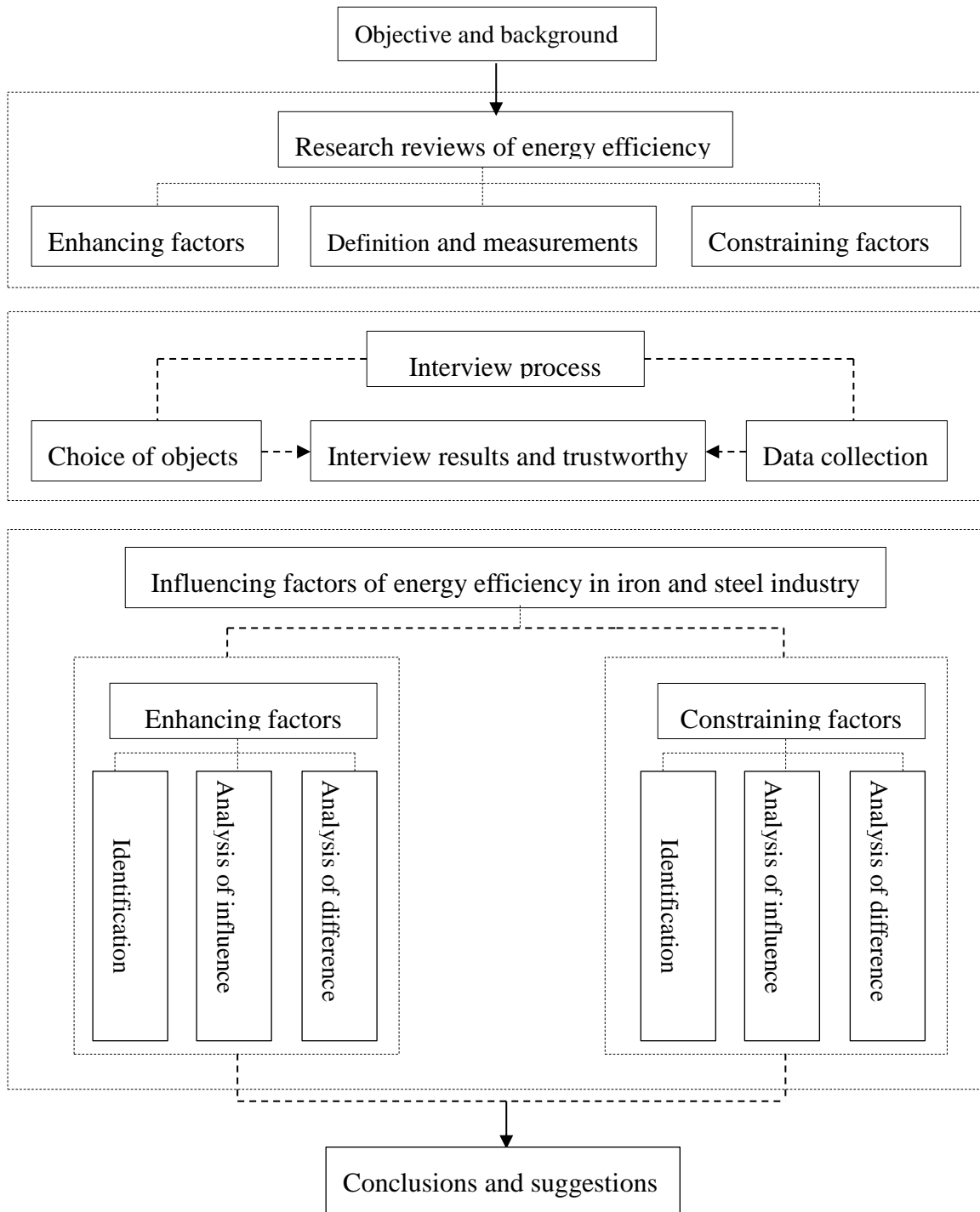


Figure 1.4 The framework of this study

## **2 Literature review**

As mentioned above, this paper will answer two questions: which factors enhance and constrain the improvement of energy efficiency in the iron and steel industry and how enterprises respond differently to these factors. Due to the different foundations these questions are based on, my analytical framework draws on three bodies of literature, one discussing the concept of energy efficiency, one discussing factors that enhance energy efficiency and one discussing factors constraining energy efficiency.

The definition of the energy efficiency should be clarified before analyzing factors influencing it. Energy consumption is growing fast with the rapid development of the global economy and how to improve energy efficiency with limited energy amount is becoming a hot research topic in many countries. Different disciplines conduct research on energy efficiency from different perspectives and their definition and measurement of the energy efficiency may lead to different explanations. Energy macro-efficiency, energy physical efficiency, energy thermodynamics efficiency, energy utilize efficiency, energy value efficiency, energy allocating efficiency and energy economic efficiency are the seven main indicators. This chapter put forward my definition of energy efficiency based on a review of these indicators.

The second and the third section of this chapter are reviews of literature discussing factors that enhance and constrain energy efficiency the influencing factors comprise economical, institutional, administrative and behavioral factors.

The following paragraphs review the main viewpoints from these three bodies of literature and summarize how it will be applied and evolved in my thesis.

### **2.1 Definition and measurement of energy efficiency**

In general, energy efficiency refers to producing the same amount of useful output or services using less energy (Patterson 1996). Compared to energy conservation implying a change in consumers' behavior, energy efficiency focuses

more on adoption of measures to reduce the energy consumption without change of relevant behavior and in other words, reducing energy consumption through applying effective measures rather than produce or consume fewer products in production or daily life. Meanwhile, energy efficiency is usually expressed by the ratio between the maximum quantity of energy services obtainable and the quantity of primary or final energy consumed (Oikonomou et al. 2009). However, the issue then becomes how to calculate the quantity of energy input and energy services obtainable.

The seven main indicators applied in research on energy efficiency are: energy macro-efficiency, energy physical efficiency, energy thermodynamics efficiency, energy utilize efficiency, energy value efficiency, energy allocating efficiency and energy economic efficiency. Sometimes using multiple indicators at one time is necessary because every indicator is based on specific assumptions and has pros and cons (Wei and Liao 2010).

**Energy macro-efficiency:** We commonly use energy consumption per GDP (or value added, total output) to measure the overall energy efficiency of a country, region or an industry. This indicator usually defined as the reciprocal of energy intensity that is expressed by the ratio between the GDP and energy consumption. It is simple to use energy intensity to reflect energy efficiency when there is no large change in input structure of energy, otherwise, the incomplete substitution of different energy sources may lead to deviation when input structure changes a lot(Liao 2008).

**Energy physical efficiency:** This indicator represents the energy used per unit of product, which is usually called physical-thermodynamic indicator where energy input measured in thermodynamic units (Giacone and Mancò 2012). For example, energy efficiency in the iron and steel industry can be measured by the amount of energy required to produce a ton of steel product. This indicator suits to comparing the efficiency between the enterprises with similar production structures and be used in longitudinal (time series) analysis. Due to the heterogeneity of industries, comparison between different industries using this indicator is difficult. Moreover, the energy used in different products may be supplied at the same time in an enterprise, therefore energy use in an individual product is sometimes hard to be separated,

which partly reduce the applicability of this indicator (Patterson 1996).

**Energy thermodynamics efficiency:** Thermodynamic indicator shows the degree of deviation of a process from the theoretical optimum (Giacone and Mancò 2012). The indicator is based on the first and second law of thermodynamics. First-law efficiency is called thermal efficiency as well, which is expressed by the ratio of value of the ‘useful’ output of the process and value of the input. For example, the light bulb with a thermal efficiency of about 6% means that useful input of electricity converted to light energy account for 6% of the total input and the other 94% is ‘waste’ heat (Patterson 1996).

**Energy value efficiency:** The same thermal equivalent can produce different effects because of the differentiated energy qualities. The energy inputs in some industries are low; however, the energy costs may be higher than other industries due to the high proportion of the high-quality energy (oil, natural gas) in the total energy inputs. The combination of the energy value efficiency and other efficiency indicators (energy macro-efficiency, energy physical efficiency) can help to find reasons for the gap of energy macro-efficiency or energy physical efficiency between different industries, regions and countries (Wei and Liao 2010).

**Energy allocating efficiency, energy utilizing efficiency and energy economic efficiency:** Energy alone cannot produce any output, so energy must be put together with other inputs in order to produce outputs (Hu and Wang 2006). The evaluation of the energy allocation efficiency should consider efficiency of other inputs as well. Meanwhile, energy allocating efficiency relates to the relative price of energy compared to other resources (labor or capital) and enterprises reduce the input cost through changing the structure of production factors. If the price of energy is too low, energy allocating efficiency is low because more energy will be used to substitute some other production factors (Wei and Liao 2010). Energy utilizing efficiency calculates by the reduction of resources’ input at the given combination of production factors. Thus, energy utilizing efficiency also can be seen as technical efficiency. Moreover, energy economic efficiency is the product of energy allocating efficiency times energy utilizing efficiency. It stresses the importance of energy efficiency

together with the cost saving. If some acts can enhance the energy macro-efficiency or physical efficiency while using much more capital, one can hardly say that the energy economic efficiency is high. Therefore, a multiple-input model should be applied to assess the energy allocating, utilizing economic efficiency in a region.

Because my research would be conducted in one industry, using energy physical efficiency indicator is feasible. However, in the due to the global calling on carbon emission reduction, the concept of the energy efficiency should not be limited to the physical area. Therefore I also address environment protection in the evaluation of energy-efficiency. In this respect, I rely on the indicator of energy value efficiency: Energy costs used in energy value efficiency include both the cost of energy input and the cost of disposing the pollution caused by consuming energy.

## **2.2 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 (Chai and Yeo 2011). In order to enhance energy efficiency it is important to find what factors influence energy efficiency. Based on the previous studies, I find the enhancing factors include the following aspects:

### **2.2.1 Technology improvement**

Technologies that reduce energy consumption are essential in order to improve energy efficiency (Tirole 1988), which is verified by studies both in developing and developed countries. Fisher-Vanden et al. (2004) use panel data to demonstrate that the expenditure on energy-efficiency R&D, the increase of energy price between 1997 and 1999, and ownership reform in enterprises are the main factors to promote energy efficiency in developing countries. The study conducted by Xu and Liu (2007) using

American data over 1980-2004 also shows that technology knowledge stock, oil price and percentage of tertiary industry are the main influencing factors on energy efficiency and that there is bidirectional causality between technology improvement and energy efficiency improvement.

Studies calculating the percentage of energy intensity variation caused by technology also verify the effects of technology. Garbaccio, Ho and Jorgenson (1999) use the input-output method to indicate that technology improvement explaining over 40% of the energy-efficiency variation in China during 1978-1995. Cai and Hu(2007), using CGE-MCHUGE model, also point out that 0.76% technology improvement can lead to the 1% energy intensity decrease in China in 2006-2010, that is to say, the range of the energy intensity decrease is larger than that of the technology improvement.

Besides the quantitative research on relations between technology improvement and energy efficiency, there are also studies focusing on the influencing mechanism of technology improvement. Xu (2009) explains the technology effects from three directions: R&D investment, human resource and FDI. Investment on R&D and human resource are basic conditions for invention in new energy-efficient equipment and drives energy efficiency improvements by fostering energy-saving awareness. The entry of foreign enterprises changes the local competitive structure, which stimulates domestic investments in R&D. Moreover, the technology overflow from transnational enterprises not only helps the improvement of domestic technology but also enhances human capital due to staff mobility from foreign enterprises to domestic ones. All these influences brought by FDI contribute to the domestic energy efficiency. Apart from those three directions, technology progress in itself can bring structural optimization of industries as well as products that reduce the requirement of materials and energy (Xu 2009).

### **2.2.2 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 (Shipley and Elliott 2001). 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.

Scarce energy resources and high energy dependency in Japan and UK make them give higher priority to energy efficiency improvement than the countries with rich resources. Japan proposed the Energy Conservation Act containing energy efficient programs in 1979 and got good results ensured by the strong legal tradition: 37% reduction in energy intensity was founded during 1979-2003 (Hendel-Blackford and Angelini 2007). UK also achieved success on energy efficiency improvement by introducing various energy regulatory policies, such as mandatory energy audits and conservation plans, as well as efficiency standards for air compressors and combined heat and power plants (Geller et al, 2006).

Some other countries including the Netherlands and Germany applied fiscal measures and voluntary agreements to stimulate energy efficiency improvement. To encourage more industrial units to take part in the energy efficient actions, voluntary agreements are usually complemented by fiscal stimulation, such as tax reduction, subsidies or investment grants (Geller et al. 2006). This measure is more popular among government policies because there are fewer negative impacts on industrial competitiveness (Hendel-Blackford and Angelini 2007).

In addition, educational and informative programs are also playing a role in energy efficiency improvement. Energy labeling programs, leading consumers to choose energy efficient products, are one of them. Besides, energy audits, energy manager training and energy management systems are also effective way to foster energy efficient awareness and improve energy efficiency (Chai and Yeo 2011).



### 2.2.3 Enterprises management

Technology plays a key role in energy efficiency improvement, however, enterprises receive differential results even they use the same technology. Sola and Xavier (2007) have conducted studies in ten industries including food, wood and chemistry, in Southern Brazil and find that the energy consumption in company D account for only half of the company B's although they belong to the same industry (food and wood) and produce similar goods.

People rather than advanced machines decide the productivity and organizational transformation (Deming 1990). Adopting energy efficient technology is important for sure, but how to adjust and manage the resources in organizations to guarantee the effective operation of technology is sometimes more important.

Establishing enterprise strategies and management system and employee's training are three important aspects in enterprise management, and 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 (Sola and Xavier 2007).

Management systems usually include detailed procedures in administrative and control area, which not only offer explicit direction and measures to achieve goals, but give a positive influence on energy efficient atmosphere. Sola and Kovaleski (in Sola and Xavier 2007) verify the positive relations between management system application and energy efficient awareness in Brazilian enterprises. The ISO14001 standard is a support tool accelerating technological innovation in companies (Sola and Xavier 2007). It also demonstrates a way in which management can affect innovation. According to 59 executives in Swedish foundry enterprises, long-term strategies and ambitions are deemed the most powerful drivers for energy efficiency (Rohdin, Thollander and Solding 2007). The evidence in Brazil that lack of strategy to search partnerships in universities and enterprises lead to the slow energy-efficient technology transfers from universities to companies also reflect the importance of strategy. Apart from that, stimulating the initiative of employees and offering training

for them as the effective way to transform individual cognition and behavior, are therefore also be a strategy driver for energy efficiency (Sola and Xavier 2007).

#### 2.2.4 Market competition

The viewpoint that competition provides a stimulating effect on efficient allocation of resources is widely accepted (Bai 2007); however, improvement of energy efficiency in the enterprises is induced by competition. It happens indirectly in the competitive environment through technology improvement and refined management (Jiang 2002).

Intensified market competition can drive innovation in enterprises in order to avoid reduction of profits when the level of market competition is still low. At this time, R&D investment is an effective way to enhance enterprise's competitiveness. However, enterprise's R&D enthusiasm would be depressed with the decrease of innovative incomes when the market competition has been fierce (Aghion et al 2001).

FDI improves energy efficiency not only through technological spillover but through competition. The entry of foreign investment would change the original competitive structure, which force domestic enterprises to improve competitiveness to keep a good position when sharing markets with foreign enterprises. Under huge pressure, domestic enterprises usually imitate the technology and management style of foreign enterprises because of their advantages, at the same time, domestic enterprises increase input on R&D and enhance technical ability of employees to further absorb the technical spillover from foreign enterprises given that the small technological gap is beneficial to technology diffusion. Both of the imitation and R&D ability enhancements will help the domestic enterprises to improve their competitiveness, which is confirmed by some empirical studies (Shen and Sun 2009).

When analyzing spillover effects in China, Jiang (2002) argues that both domestic and transnational corporations were facing sharper competition with the entry of the FDI, which facilitated domestic R&D ability. The study conducted by Aghion et al. (2002) in the UK also shows that the intense competition brought by the

entry of FDI stimulates innovative awareness.

## **2.3 Factors constraining energy efficiency**

Energy efficiency has been widely accepted as a way to protect the environment, reduce dependency on energy imports and improve enterprises competitiveness (Bernan and Staff 2008, Worrell et al. 2009). However, a number of enterprises still have not adopted energy efficient measures although there are policies and competition stimulating them.

DeCanio (1998) for example, using the data of the US Green Lights Program, demonstrated that there is a lot of room to improve energy efficiency in lighting, but due to the organizational barriers, even cost-effective energy efficient investment cannot be put fully into use. The US Motor Challenge Programme launched by Department of Energy also met similar problems. The program calculated and confirmed the cost-efficiency of the energy efficient motors and supplied technical support to encourage technology adoption in enterprises, but the energy consumption of motors reflected that the situation of the program was not ideal (Xenergy 1998, Brown 2001). In the iron and steel industry, the application of the Coke Dry Quench not only reduces the productive cost through heat recycle of red cock but also produces steam that can be utilized to generate electricity and therefore reduced the emission of SO<sub>2</sub> and CO<sub>2</sub> through reducing steam production by burning coal (Bsteel 2011, Pan et al. 2010). However, the adoption rate of this technology is only 10% in China, and even in Japan with advanced steel technology, this rate just reached 60%.

Barriers to energy efficiency include all factors preventing or slowing down the adoption and diffusion of energy efficient measures (Sorrell 2004). The following three sections reviews the constraining factors mentioned in previous theoretical and practical studies.

### **2.3.1 Market failure**

The barriers of energy-efficiency improvement were explained using theory of

mainstream economics in early studies on energy efficiency. Market failure including the principal-agent problem, externality and imperfect information are main reasons hindering the adoption and diffusion of energy efficient measures (Jaffe and Stavins 1994).

With the development of scale and division in production, modern enterprises usually hire professional managers to operate one branch of group. The relationship between owners and professional managers is called principal-agent relation (Zhou and Mu 2010). Although having the obligation of creating values for shareholders, managers as rational people sometimes make choices for their own interest rather than the owners' and therefore the choices deviate from the optimal ones, which is called principal-agent problem. The asymmetric information between the owners and managers and short service term of managers may lead to a high rate of principal-agent problem (DeCanio 1998).

When the owners realize possibly sub-optimal choices taken by managers, they will call for a higher payback rate of new measures (DeCanio 1998). According to the survey in 288 American manufacturing enterprises, their requested payback rate of energy-efficient technology is 12% which is much higher than the historical real rate of return of 7% (Poterba and Summers 1991, DeCanio 1998). Therefore, the measures with profits higher than investment cost but lower than owner's anticipated criteria may not be adopted in this context.

Job hopping of managers every few years is another aspect of principal-agent problem. Because the service terms of managers are usually determined before they join the enterprises and the compensation is related to their behavior in office, they tend to choose projects with short payback period especially those can paying back during they are in office, which leads the projects with better performance but distant payoff fail to be chosen (DeCanio 1993). The studies conducted by Statman and Sepe (1984) also mention the sensitive relations between management strategies and employment characteristics of managers. They found that the amount of investment in projects with long payback period increases with increasing adoption rate of long-term employment contract of managers.

Imperfect information presented here mainly refers to weak communication between enterprises and suppliers of energy efficient measures. This may result in failure in adopting energy efficient measures, as the enterprises have insufficient knowledge about available of measures, such as the potential for savings. For example, after forming the impression that suppliers prefer to overvalue the potential of energy efficient technology, enterprises may raise the requirement of payback to offset the cost of risk caused by overvalue. Under this condition, the suppliers offering precise information with low payback are easier to be refused (DeCanio 1993). This was the main obstacle to energy efficiency improvement in Netherland enterprises. Thirty per cent of the enterprises knew little about the existence of advanced technology (De Groot, Verhoef and Nijkamp 2001).

Externality as another part of market failure has negative effect on both exploitation and utilization of energy efficient technology. Energy pricing ignores large amounts of social costs in the process of energy extracting and purifying, such as the emission of greenhouse gases, pollution of air, water and soil caused by energy consumption. When realizing the deficiency of pricing for pollution emission, enterprises tend to consume more energy and avoid taking the responsibility of handing the pollutions if there is no governmental supervision.

Technology risks relating to innovations and adoption of new technology can also hinder improvements of energy efficiency, although we know more about positive effects of innovation externality. Due the risk of adopting new measures, enterprises would rather bear the cost of high energy consumption and wait for the demonstration of technological safety by other enterprises before their own use. There are similar problems with innovation. Technology innovations require much capital. The capital and innovation usually comes from one or some enterprises, but the achievements are shared by the whole society. Thus, most enterprises want to be the ones getting a free ride, which also slows the process of enhancing energy efficiency.

### 2.3.2 Economic non-market failures

In addition to market failure, market barriers (economic non-market failures) are considered by researchers to be the main factor constraining improvement of energy efficiency (Rohdin and Thollander 2006, Rohdin et al. 2007). Capital insufficiency is one of them. The question is whether the enterprises can get enough capital from outside and the respective department in the enterprise can get enough capital when enterprise distributes it (Fleiter, Worrell and Eichhammer 2011). A survey in 50 manufacturing enterprises in Greece shows that 76% interviewees think that insufficient capital is the a main barrier of energy efficiency improvement (Anderson and Newell 2004). Similar results were found in the case of Swedish foundry industry (Rohdin, Thollander and Solding 2007).

The percentage of hidden cost is sometimes large especially when the enterprises want to invest in large equipment, so if enterprises are in shortage of money, the hidden cost can also influence the choice of enterprises. The average cost of collecting information for adopting energy efficient measures in 12 Dutch enterprises accounted for 2-6% of the total investment, and the percentage of verifying the reliability of technology reached 1-2% of the total investment (Fleiter, Worrell and Eichhammer 2011). After the adoption of certain technologies, adjusting some part of the previous productive structures or training the technical staff are necessary in order to ensure the operation of the new measures and the cost of these changes are also belongs to hidden cost (Mirza et al. 2009).

Risk and uncertainty of investment is another market barrier. Here risk e refers to interruption of production or deteriorating quality of production caused by new measures in production (Fleiter, Worrell and Eichhammer 2011). In a study of the Swedish paper industry, the risk of interruption of production was the most important barrier to implement measures to improve energy efficiency. Rohdin and Thollander (2006) found that more than half of the non-energy intensive manufacturing industry in Sweden chose e risk as the leading barrier to energy efficiency. In their study in Swedish foundry industry, the effect of risk was also obvious although insufficient

capital was considered the most important constraining factor (Rohdin, Thollander and Solding 2007). Rohdin and Thollander also indicated that the impact of risk and insufficient capital to enterprises depends on the state of business to some extent (Rohdin and Thollander 2006).

### 2.3.3 Social factors

The concept of energy efficiency includes both an economic and social meaning. In recent years, an increasing number of studies have looked into energy efficiency from the social perspective. According to Callon (1991) and Bijker (1994), choices of energy efficient measures are made under specific social conditions and social structure, industrial structure and enterprises as institutions. Thus, effective measures under certain circumstances may lose their effectiveness in other (Shove 1998). In the study of energy efficiency in the Swedish textile industry, Palm and Thollander (2010) stressed the effect of experiences, habits and institutions on diffusion and effectiveness of energy efficient measures other than the factors mentioned in traditional economics. Moreover, they also indicated that the cognition of energy efficiency, the communicative form of energy efficient information, principal part in charge of informative diffusion and technological application all influenced the level of energy efficiency after analyzing the influencing factors from corporative, industrial and strategic aspects. This study offers a new direction for explaining the difference of effectiveness of technology among enterprises (Palm and Thollander 2010).

Hierarchy is a main characteristic of organizational structure and the information passed in enterprises normally goes through hierarchical processing. The owners of enterprises tend to simplify the decision making and the criterion they refer sometimes is subjective; therefore the lack of scientific evaluation may influence the right choice of new measures (Robbins and Judge 2001, Gavetti 2005). Moreover, we can infer, from the conclusion of strong decisiveness of senior managers, that the status of the manager of the energy department in enterprise has a tight relationship

with the scale and speed of the adoption of energy efficient measures. If the status of department manager is low, the energy efficient project he or she proposed may be arranged after other projects, such as the improvement on production technique, supported by managers with a high status in enterprises (Sola and Xavier 2007).

Apart from the lack of strategies and institutions established by both governments and enterprises, the individual behavior such as personality and cognition of entrepreneur also can be barriers. For example, entrepreneurs' opposition to change and relying on others' innovation and environmental protection have a negative impact on energy efficiency improvement (Nagesha and Balachandra 2006). In the report of Asian energy efficiency, the lack of energy efficient perception of managers is the main barriers to energy improvement, which not only weaken the energy efficient atmosphere and further kill motivation of proposing and carrying out energy efficient measures, but also makes the problems such as low priority, lack of money more prominent (UNEP 2006). Deciding by the rule of thumb is another reason to explain the 'unfriendly' performance of entrepreneurs on the issue of energy efficiency. According to Simon (1979), the hypothesis of rational economic man is biased, while the idea that people choose to meet some conditions rather than optimisation in behavioral economics is more acceptable. So in many enterprises, it is possible to make a choice using previous experience to satisfy some criteria rather than choose the most effective measure through scientific evaluation, which may lead to the skip of some energy-efficient measures.

Some other contributions on energy efficiency can be founded in the classification of the constraining factors rather than describing the factors. Weber (1997) makes a distinction between the following constraining factors: institutional, market, organizational and behavioral. Based on a large number of studies, Sorrell (2004) developed the theoretical framework of Weber into a detailed classification on barriers. He categorized heterogeneity of technology, hidden cost and capital risk as economic non-market failure factors. Imperfect information, split incentives, adverse selection and principal-agent relationships belong to the category of market failure in his study. Besides, behavioral factors include bounded rationality, credibility, inertia



and values while organizational factors consist of power and culture. Trianni and Cagno (2011) have further operationalized Sorrel's classification of barriers. Lack of time or other priorities, lack of capital, lack of internal technical skill, difficulty in gathering external technical skills, poor information, lack of personnel awareness, lack of managerial awareness, low returns for energy efficiency investments and scarce information regarding energy efficiency opportunities are nine aspects in investigating barriers in Trianni and Cagno's study. Moreover, both Chai and Yeo (2011) and Trianni and Cagno (2011) argue that the different barriers are interdependent or acting on each other, and that the ideal way to remove barriers is to develop a systematic to approach after having clarified the relations among them. Otherwise, energy efficiency will stop at the level influenced by the remaining barriers even though some barriers have been cleaned up.

## **2.4 The conceptual framework of this study**

In this chapter I have presented two realms of literature that are useful for my later analysis: the definition of energy efficiency and what factors influence energy efficiency. I will now present how this will be used to create my analytical framework.

The first part is the literature of definition and measurement of energy efficiency. There are a number of studies on energy efficiency because it plays an important role in relieving environmental pollution and shortage of energy. However, there is no unified definition or measurement of energy efficiency. The current indicators to measure energy efficiency are energy macro-efficiency, energy physical efficiency, energy thermodynamics efficiency, energy utilize efficiency, energy value efficiency, energy allocating efficiency and energy economic efficiency. Based on these indicators, I have chosen to delimit my study of energy efficiency to energy physical efficiency, but I also add the environmental protection element into energy efficiency concept through including the cost of disposing energy waste into energy value efficiency.

The second realm of literature is important for choosing study objects and the

methodology of my study and in establishing the theoretical framework. Previous studies of energy efficiency in China and internationally show that it is necessary to discuss energy efficiency improvement from a micro perspective, especially on the barrier issue. Improvement of energy efficiency consists of many small improvements brought about by individuals and it differs how enterprises in different contexts experience and relate to the challenges of energy efficiency. For example, insufficient capital was the most important barrier for 50 Greek manufacturing enterprises (Anderson and Newell 2004), while risk is important in Swedish paper industry. However, in the studies of improvement of energy efficiency in China, scholars tend to discuss this issue from the national level, while studies at the industrial or enterprise level are few. Inspired by previous studies in developed countries, my study will choose the micro perspective from a methodological point of view, the studies applying a micro perspective usually choose a qualitative methodological approach and the material they analyze is the experiences, thinking, attitudes and actions of respondents. However, studies on energy efficiency in China are mostly quantitative. The one-sided quantitative method has a big limitation because as many factors cannot be quantified and many possible influencing factors have not been recognized in Chinese studies on energy efficiency. In my study on energy efficiency in the iron and steel industry in Jiangsu in China, I have chosen a qualitative approach.

### **3 Methodology: a qualitative case study approach**

Quantitative and qualitative methods can be used to complement each other. Conclusions from qualitative research could be analyzed further in a quantitative way, while qualitative research would push the quantitative analysis results to reach more in depth, and explain something that the quantitative analysis cannot. Therefore, the combination of the two can be considered as an effective method of repeated testing of the conclusions (Hay 2010). However, since they are conducted in different logic, with different characteristics and to obtain different analysis results, researchers usually choose one of them according to the research conditions or the type of attempting results.

As already explained above, I have chosen a qualitative methodological approach as it fits my objective of highlighting enterprise-specific experiences with energy efficiency measures in China.

Qualitative methods are usually in an interpretive position (Mason 2002) and suited to answering to questions about how and why (Yin 2008). The objective of my thesis is to examine and explain how different enterprises in the iron and steel industry in Jiangsu in China respond to factors that may enhance and constrain energy efficiency. How is their response conditioned by the size of the enterprises? These data vary largely across the different informants' answers and the qualitative methods can uncover this kind of information and help to achieve in-depth understandings.

A well-known tool to achieve in-depth understanding in qualitative method is in-depth interview, through which interviewer and interviewee can construct interactive relationships. Here, data and even the interview questions are co-owned and co-shaped (Cook et al. 2004). Since I conducted my fieldwork in companies and my informant were all leaders or core workforce who knew the industry well from various perspectives, the interactive relationships gave me more chances to follow up unforeseen topics and what I previously misunderstood during the interview situation. Moreover, the flexible research structure supported by the qualitative method make

the update implementable, thus it suits the research conducted by people, like me, who have limited knowledge about the case before start (Vognild 2011).

Another important difference between qualitative and quantitative method is the number of cases selected for research. Quantitative research usually requires large number of cases to achieve generalization based on the statistical techniques, while qualitative research usually carry out “thick description” referred by Geertz based on smaller number of cases (Davis and Baulch 2010). As a student, I only had six weeks available for the fieldwork and at the same time, the resources I have were insufficient to reach a large number of companies in the iron and steel industry, therefore, undertaking quantitative research is more pragmatic for me. Apart from that, most of the existing work on energy efficiency issue in China is of a quantitative nature, so in-depth interviews could contribute something new to understand energy efficiency in specific circumstances.

### **3.1 Selecting sites and choosing informants**

#### **3.1.1 Selection of study sites**

Steel enterprises in different areas supplied with different natural and social resources, and have different perception of energy efficiency, which affected their judgments upon the factors to energy efficiency, and in addition, caused the findings decentralized. Ideally, I would have liked to examine enterprises of different scales in different administration areas. However, limited time of two months did not permit extensive fieldwork. Hence I chose to delimit myself to only one of the administrative areas where the iron and steel industry is concentrated.

Most steel factories in China are located in the eastern region (Figure 3.1), especially in Jiangsu, Liaoning and Hebei province. I selected Jiangsu for my fieldwork due to its largest amount of enterprises.

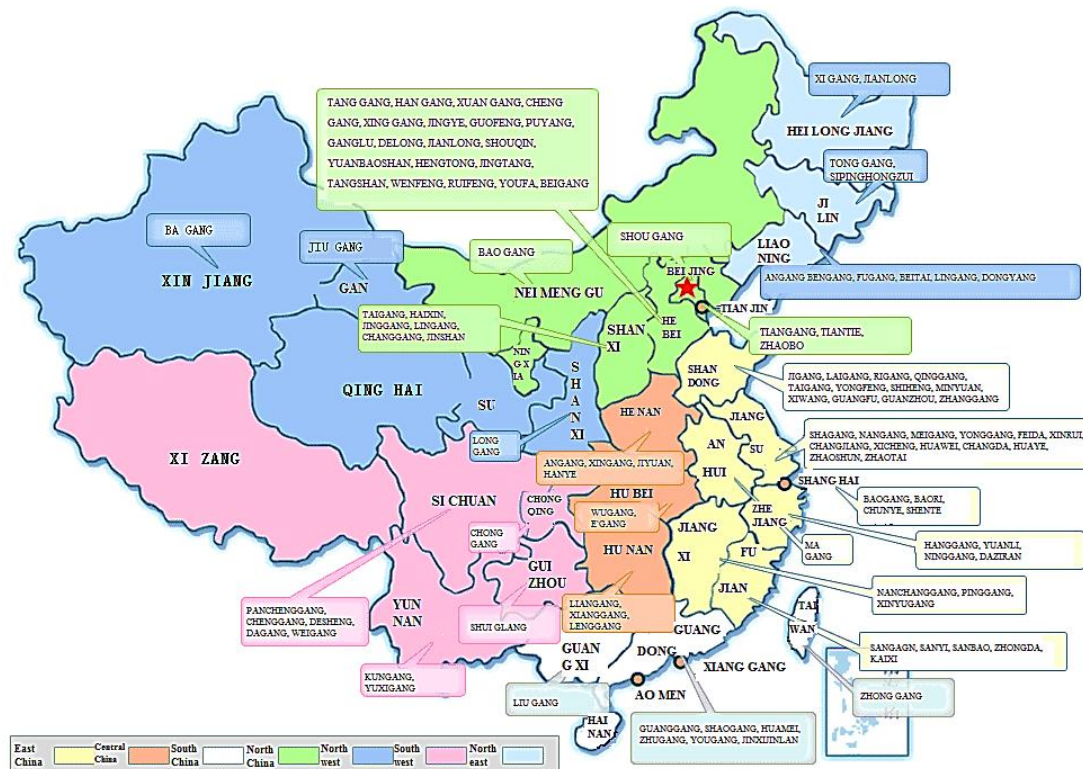


Figure 3.1 The distribution of Chinese steel enterprises

Source: <http://factory.mysteel.com/map/index.html>

Although Hebei province also has a large number of enterprises and the production capacity in this area ranks first in China, the enterprise structure in Hebei is different with Jiangsu's and not that suitable in this study. Large steel enterprises in Hebei are usually state-owned enterprise and some key medium-sized enterprises has the same enterprise property after merged into large enterprise group, while most small and medium sized ones were either Sino-foreign joint ventures or private enterprise. However, most of the steel enterprises in Jiangsu were private. One of them is the ShaGang Steel Group, which was the largest private iron and steel enterprise in China in Jiangsu. Even some state-owned steel enterprises have been transformed from state-owned to private ones. Because the sample size in this study is small and I will focus on the performances in different sized enterprises, keeping the similarity of organizational structure can ensure the identification of differences caused by enterprise scale. Therefore, the enterprise structure in Jiangsu province is more favorable.

Furthermore, Jiangsu was close to Shanghai, where I studied and I have better

knowledge of the social and economic situation of this province than the other iron and steel producing provinces. In addition, transport to the study area was convenient.

### 3.1.2 Choice of informants

Qualitative research requires that the interviewees are carefully selected for the in-depth interviews (Miles and Huberman, 1994). Hay (2010) distinguishes between seven kinds of sampling methods: deviant case sampling, typical case sampling, maximum variation sampling, snowball sampling, criterion sampling, opportunistic sampling and convenience sampling. Each method has its own characteristics and applied to different sample targets, but the combination of multiple methods was also widely used. The sampling method used in this study is a combination of typical case sampling and criterion sampling summarized by Hay.

Larger enterprises may face barriers that differ from those faced by smaller enterprises (Rohdin and Thollander 2006), which gives some guidance to the informant sampling in this study. Because the iron and steel industry is a high energy-consuming industry, the scale of the factory matters to the consumption of energy and energy efficiency directly or indirectly. The large enterprises usually has higher production capacity that means more energy demand, however, larger enterprises may use better equipment that can produce more efficiently and thus has a lower energy consumption per unit of product, while the small enterprises may has the opposite results. To find out about performance in differently sized enterprises, I first selected a typical small, medium and large enterprise, and then set a criterion mainly depending on two indicators to choose the rest enterprises. The two indicators are the number of employees and production capacity of steel. The number of employees is more than 15,000 in large enterprises while less than 6000 in small ones and the production capacity of steel is more than 1000 tons in large enterprises while less than 500 tons in small ones. The levels of medium enterprises are between those in large enterprises and small enterprises.

Additionally, the factories of the respective sizes have similar production chains

and do not outsource the high energy-consuming segments. The core material for my study was obtained directly from the enterprises.

The enterprises are selected from the member enterprises of the Iron and Steel Industry Association of Jiangsu Province, which are listed on the website of China Iron and Steel Industry Association. They include nine steel enterprises consisting of two large-scale enterprises, three medium ones and four small enterprises. The production chain covers a number of steps from sintering to rolling. The nine enterprises and the office of the industry association are located in southern part of Jiangsu province.

Table 3.1 Three types of the iron and steel enterprises

<b>Enterprises code</b>	<b>Type</b>	<b>Number of employees</b>	<b>Production capacity of steel</b>
A	Large	16,700	2050t
B		15,000	1200t
C	Medium	12,000	800t
D		11,000	800t
E		8,000-9,000	600t
F	Small	4,000	180t
G		3,725	100t
H		3,300	120t
I		5,000	150t

Source: supplied by informants

After determining which factory to visit during a field trip, the first step is to obtain an interview agreement from the supervisor, who is called "gatekeeper". The "Gatekeepers" may be the community leaders, or the manager of the enterprise or association or institution in question (Desai and Potter 2006). In my study the "Gatekeeper" is the general manager or the person in charge of the energy department in the steel enterprise. In practice, the person in charge of the energy department is the "Gatekeeper" to consult with, rather than the general manager in the factory. The energy department managers can decide on their own whether to accept to participate in interview or not. I think the direct contact with department heads is good for the validity of the interview results. If department heads are appointed by higher level

managers to participate other than spontaneously accepting interview themselves, they may not in the good mood to share the information freely and sometimes conceal real situations to maintain enterprise's image.

Information regarding possible contacts was downloaded from the website of each steel enterprise two weeks before the trips. Basic information about the study was provided on the telephone, such as the researcher's identity, the purpose, contents and procedure of the interview and etc. It was emphasized that trade secrets and sensitive information will not be involved, and that the research data will be kept confidential, thus avoiding being refused for the worry about leaking information. Five steel factories agreed on the telephone to be interviewed. The other five could not be reached by phone. Direct contact was taken with their heads at the energy departments. I had to pass through the security workers at the gate of the factories. If the management is not strict in the factory, the security workers let me in directly. Otherwise, they may say no on their own or ask their supervisor for approval to let me in. Fortunately, after communicating with the security person, I obtained accesses to the departments of energy and to meet the department heads. In this kind of trips, success depends on timing. If the calls are made one hour after the work time starts, the heads are often unavailable. But if they are called just at the time that the work day begins, it is easier to get interviews. The point is to arrive early and get access to the department heads before they arrange other work. If there are no emergency issues, they are most likely to accept the interview. It was relatively easy to arrange the trips directly with the department heads, either by phone or face to face. Even if they could not meet me, they appointed someone else with good knowledge of energy efficiency. If something professional or technical was hard to understand, they explained it patiently, which was very helpful in my work.

A letter of recommendation from the Fudan University was presented to the interviewees in order to state my identity and the purpose of research, in case of questions regarding authenticity.



### 3.2 The interview process

.An interview guide is usually applied in semi-structured interviews, but the sequence of questions needs not to be fixed (Hay 2010).

In order to conduct the interview naturally and smoothly, the basic information about the enterprise and the consumption of energy were asked for before questions about factors influencing energy efficiency. For the basic information, general questions were applied, such as “Is the scale of your factory XX billion?”, “Is it the equipment of improving energy efficiency as XX?” When the questions reveal that the researcher is prepared, then the interviewees are much more willing to share information. For example, after several general questions, the interviewees replied smilingly “you are surprisingly much familiar with us”, and also nodding to the questions. Such communication also raised my confidence.

After getting access to basic information about the enterprises, especially the use of energy-saving equipment, I began the main part of the interview with the question “how do you define the energy efficiency”. None of them gave me a clear definition of energy efficiency but mentioned energy consumption per unit of production. In fact, they preferred to give me examples that reflect their energy efficiency. For example, one interviewee said: “after we use frequency conversion motor, the energy consumption definitely decrease and I think it is the improvement of energy efficiency.” Because their examples usually included some information about influencing factors, my questions regarding the motivation and constrains of improving energy followed naturally. Although I had prepared a number of questions on influencing factors, these were closed questions and were not asked at the beginning of the interviews. I did not want the ideas of the interviewees to be tainted by my closed questions and I also want to find out whether the factors listed in my interview guide fitted their practical experiences. Instead, open questions like “what is the motivation to increase the energy efficiency” were posed so that they could tell what was on their mind. Hence on the one hand, their thoughts will not be confined to the issues in my interview guide, and on the other hand, the sequence of factors they

mention can guide the analysis regarding what is important to the interviewees. When the factors stated by the interviewees are the same as the ones in the interview guide, it shows that the preparation has been effective, and further information will be dug out according to their answers and my prepared questions. However, if the interviewee's opinion is not matching the key points in the guide, then new questions were asked to further analyze their points. In the interviews, some factors mentioned by the interviewees were not covered in the literature, and in such cases they contribute to make the analysis more complete. For instance, quite a significant factor (enterprises management) is ignored in the interview guide, but fortunately the first interviewee mentioned it. Thus it shows that semi-structured interviews may provide more information than the structured ones. Unlike unstructured interviews, the semi-structured interview guide can help the researcher to return to the topic when the talk deviates from the goal of the study (Hay 2010)

Before the trips to the factories for the interviews that had been agreed to on the telephone, the meeting time was double checked with the heads of the department, but they did not settle down the exact hour of meeting time and just said that I could come before or after lunch break in a specific day. No matter interviewing before or after the noon break, I always arrived in the office at the beginning of the working hours, which would ensure enough time for interview without interruption from other work arranged before the interview. It was also to ensure the quality of the interviews. Department heads were usually more enthusiastic and willing to answer questions in detail when working hours started.

When visiting the factories without appointment, the person in charge agreed to an interview, and it usually took place immediately. This saved time and travel costs but since the interview is made without early appointment, the meeting could be interrupted by other staff, or the interviewee could appoint somebody else familiar with the energy issue to take over.

The interviews usually lasted for 1.5 to 2 hours. After some interviews, I had learned the structure of the interviews by heart, which made the interview develop more naturally like a casual talk. Some questions were trimmed or merged, and then

the subsequent interviews lasted shorter, usually from 1 to 1.15 hours. The interview room is often set in the office of the interviewee or the conference room of the department. So the talk will not disturb the work of others in the enterprise.

During interviews, audio records and paper notes have different advantages. Audio recording makes the interviewer free to concentrate on the statement, and provides more time to organize the next question, while noting on paper can help the interviewer to think and avoid the scenario of losing the digital audio records. In practice, I usually recorded the talks by mobile audio recording application. Before the recording, the interviewee was asked for permission, as energy efficiency is a sensitive topic. In total, three enterprises refused. When recording, the applied device was put in the document bag and placed in hands' reach, but never touched. This was to avoid the attention of the interviewees in case they would instinctively feel uncomfortable about being recorded. In addition to audio recording, paper notes were still taken on key points. This was done in order to make the interviewees feel that their narratives are attended to. It also helps me to review the interview and adjust my interview guide easily. Moreover, it provides insurance for loss of data. It happens. Because of a mistake in operation of the mobile phone, one interview was not recorded. Fortunately the paper notes of key points were written down, thus the most important information of the interview was assured.

Although all the interviewees were met during the field work, there were two interviews conducted through communication online. These two interviewees agreed to interview when we met in their enterprises, but asked for communicating by email or QQ (chat software), because they were too busy to talk face to face and could only complete the questions in the interview guide in their spare time. Even though I told them that the interview could last for only one hour, they still insisted on using the computer. Computer-assisted communication has the advantages of, as stated in literature, saving cost, more convenience and less impact of the interviewer's performance on the interviewees (Hay 2010). It saves much time not to take dictation from the audio recording, and avoid mistakes that may happen in the process. However, it also causes difficulties. Firstly, the replies could take a long time, in my

case it took 3 months to get one of the replies, even if they were urged many times, after sending out the interview guide. Secondly, the contents were not complete in reply, which needs to re-organize the questions and send out again, and hence it took more time in sending and replying. Last but not the least, the answer got through Internet was briefer than the face to face interview, and less complementary information about the issue, although the answers were born out of careful consideration. Finally, after many efforts, the results of interviews got accepted.

Establishing a good relationship with the respondent is important to the quality of collected information. The appearance, attitude and behavior of the interviewer as well as the power relations between the interviewer and interviewee matter (Hay 2010). In order to obtain reliable and valid data, I always paid much attention to the words and deeds. I dressed casually to match the identity of a student and avoid making an official atmosphere in which department heads may hide some sensitive information. Many of department heads greeted me their best regards just like friends. I showed respect to them and always called them respectfully. The sentence “You are an expert in this area, and what you said is very important” made them feel that the information shared with me was valuable. During the interview, there was no interruption from the author in the stop of their words, which gave them time to think. When their answers were not completely understood, I asked questions such as: “Could I understand this issue as...?” Before the questions regarding barriers to energy efficiency improvement, their efforts were warmly praised. And then I sometimes expressed my understanding on the difficulties in improving energy efficiency from the perspectives of enterprises. For example, I might say “there are definitely difficulties in increasing energy efficiency and sometime you just cannot do anything about that.” It could somewhat mitigate their unwillingness to share the true facts. Sometimes, the interviewees worried that sensitive information may be exposed to the public in my research, and then guarantees were made that such information will only be used in my paper, and that the name of the factory or the interviewee will not appear in it. Although there are often asymmetrical power relations between interviewer and interviewee, this can be improved by gentle and respectful words and

deeds, in addition to being well prepared for the questions and have a basic understanding of the enterprise. Therefore, the interviewees could give relatively true feedback no matter the barriers caused by their own or governments.

### **3.3 Trustworthiness of the research**

Reliability refers to that the results will not be changed by different researchers, which means that no matter who operate the research they will ultimately get the same result, in accordance with the same procedure. If the researchers really influence the results, they should at least explain the progress of the impact and the possible results in the paper (Winnberg 2012). This study describes the field trips and the interviews in detail, states the data analysis step by step, explains the possible factors to affect the research result in trips, and also reflects the problems that happen in the study. As mentioned before, I tried not to influence the interviewee by my own opinions, and at the same time I tried to reduce the asymmetrical power relations between me and the interviewee to obtain the reliable information. Even though I cannot guarantee that the same results will be reached in another round of interviews, the considerations mentioned here can provide a reference for the same type of research in future.

The validity of the data 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 research (Takyi 2009). I try to guarantee the effectiveness of information in four steps. Firstly, design the interview guide carefully and adjust the guide according to interviewees' feedbacks. Secondly, begin the interview, as stated before, mainly with open questions, which frees the interviewees' mind and possible significant factors will not be ignored. Thirdly, by collecting information from different sources, such as general managers, managers of the energy department, as well as the steel and iron industry association. Last but not the least, it is necessary to keep confirming the information with the interviewees when processing information later. For this step, the contact of the interviewee is saved after each interview, thus one may reach them when confirmation is needed in

examining the content of the talks I have conducted my study with attention to all four steps.

### **3.4 Ethical dilemmas**

Ethical issues may be encountered throughout the whole qualitative research. When deciding the research topic, the object should be clear, and the expected conclusion should be also projected. If the study results have negative impact on the human beings participating in the research and the society, then the topic should be reset (Vognild 2011). Energy efficiency is a sensitive issue to the energy intensive enterprises, especially when enterprises think telling truth may bring negative impact for the development of enterprises, I paid much attention to ethical issues in the study and made the best effort to avoid negative impact on the interviewees.

To tackle ethical issues, the first step is to have an agreement with the subjects. The subjects should be totally clear on the object and procedure of research, which means that subjects understand clearly the issues they agree on (Brydon 2006). However, in fact, respondents cannot completely know the research procedure in the semi-structure interviews, because the contents of the interview are changing according to the interviewee's feedback (Miles and Huberman 1994). Nevertheless, the objective and framework of this study does not change and accordingly the practical procedure is the same as the one that is told to the respondent when asking for the interview. When contact is made with the interviewees (by call or face to face), the identity of the researcher the purpose of the research, the content of the interview should be introduced as well as information regarding how the results will be presented. . After they know the whole story, they can decide whether to accept the interview or not. The interviewer should not beg for interviews and should inform the potential interviewee that they are not obliged to answer any questions and can refuse any unwanted or inappropriate ones. I have followed this procedure.

Another important ethical issue is to keep information confidential. Both paper notes and audio recording should be archived carefully and select information that can

be made public into the research report carefully, which prevent the public to recognize the identity of the respondents easily (Hay 2010). Even if it veils the statement of the result to cover the identity of the respondent, the confidential principle cannot be broke anyway (Winnberg 2012). My study does not reveal the names of the enterprises and respondents in the field trips. I apply letters and serial numbers instead. For enterprises with easily recognized features, it omits some information related to their identity and abbreviates some contents to conceal their names. In addition, the paper notes are saved only in my reach, and the audio records have already been deleted after they are dictated into text. What is more, the electronic documents have been encrypted.

### **3.5 Summary**

This chapter states the reasons to select qualitative analysis as the research method, and it has described the process to obtain and analyze the information. I have commented on the selection of study area and informants, the interview process, information storage and processing, and ethical issues in the interviews. I have taken a number of measures to obtain valid and reliable data.

## **4 Enhancing energy efficiency in the Jiangsu iron and steel industry**

The analysis develops from four parts: technology improvement, policy-making, market competition and enterprise management just as the structure presented in the part of the above literature review, moreover, each part is further divided into three modules. The first module mainly describes the current situation of technology, policy, market and management in the iron and steel industry in Jiangsu province, the second module presents enterprises' views on these factors that affect the energy efficiency, while the third one explains how and why different categories of enterprises experience the various enhancing factors differently.

### **4.1 Technological improvement to enhance energy efficiency**

Tirole (1988) pointed out that the technological progress of enterprises and the technology improvement related energy efficiency gives an important force on improving energy efficiency. Technological improvement include not only the technological invention and innovation, but also the technology diffusion (Xu 2009), therefore both inventing and applying new technology and adoption of existing technology are able to improve energy efficiency.

In the iron and steel industry, the main procedures are coking, sintering, iron making and steel-making as well as rolling steel and coke oven, sinter machine, blast furnace, converter, and electric furnace are commonly the respective equipment used in the production. Because of tremendous need of energy including coal, pulverized coal, coke, electricity and gas in each link of the steelmaking process, the iron and steel industry is defined as one of the highest energy-consuming industries. Nowadays, people are paying more attention to improving the energy efficiency in the iron and steel industry because the problems of energy shortage and environmental pollution become more urgent. To relieve the pressure of resources and environment,



attempts to improve energy efficiency in the iron and steel industry are emerging in an endless stream and cover most production links in the iron and steel industry. The following lists some technologies required and recommended by Ministry of Industry and Information Technology (MIIT) of China to be adopted in steel enterprises to improve energy efficiency<sup>3</sup>:

### **(1) Coke Dry Quench (CDQ)**

Use cold inert gas or waste gas to exchange heat with red coke in dry quenching furnace. After absorbing heat from red coke, inert gas transmits heat to dry quenching furnaces and produce steam. Then cooling inert gas is blasted by the circulation fan back to dry quenching to cool the red coke. The intermediate (or high) pressure stream produced in this cycle can be gathered in steam pipe system and generated subsequently electricity. The Coke Dry Quench makes benefits by: 1) recycling part of the waste; 2) obtaining economic benefits by make good use of steam power in the production process to generate power (Pan and Wei 2005).

### **(2) Top Gas Pressure Recovery Turbine (TRT)**

Top pressure of a modern blast furnace is always up to 0.15-0.25MPa and thus potential energy exists in top gas. The Top Gas Pressure Recovery Turbine technology ducts the coal gas into the turbine expander by using the top gas press recovery, converts pressure into the machine energy, and drives the generation to generate electricity. Depending on the top gas pressure, it can produce 20-40 kWh electricity approximately every one ton of iron production. The greater the stove is, the higher the furnace top pressure is and the shorter the investment recovery period is. This technique is available to recycle about 30% of the power a blast-furnace blower need. This way of power generation does not consume any fuel and at the same time it does not produce environmental pollution but lowers power generation cost. Because of all these advantages, The Top Gas Pressure Recovery Turbine technology is now a major energy conservation project in blast furnace smelting (Li 2008).

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<sup>3</sup> Data source of (1)-(5): <http://wenku.baidu.com/view/a2635c3743323968011c9299.html> (In Chinese)

### **(3) Waste heat recovery of sintered gas**

Waste heat boilers are utilized to collect waste heat and then supply steam and heated water, which can be put to use directly or converted into electricity by use of a turbine, moreover, waste heat can be applied to take the place of oxidizing air in sintering machines or preheat oxidizing air, all of which make this technique a good approach to improve energy efficiency while reduce energy consumption in sintering circuit (Lu 2009).

### **(4) Desulfurization technique of sintering machine**

The flue gas produced by sintering machine includes sulfur oxide, dust, nitrogen oxides and dioxin and has a serious problem of air pollution. Currently, dry method and wet method of Desulfurization can effectively solve this problem (Liu et al. 2009).

### **(5) Regenerative type heating furnace combustion technology**

The biggest energy hog in steel rolling is steel rolling heating furnace, which uses up more than half of the total energy consumption. Regenerative type heating furnace combustion technology can help cool the high-temperature gas down to under 150°C below and the heat recovery rate is up 80% and therefore 30% energy can be saved (Xu and Lin 2001).

In addition to the technologies mentioned above, there are a large number of others techniques laying important roles in energy efficiency improvement in iron and steel production process. Table 4.1 provides an overview of the current adoptions of energy efficient techniques in the 9 interviewed enterprises.

Table4.1 Equipment and applied technologies in interviewed enterprises

Sample	Enterprise Size	Equipment	Applied Technologies
A	Large	Sintering machines 360m <sup>2</sup> , Blast furnace 2500, 5800m <sup>3</sup> , Converter 180t, Electric furnace 110t	CDQ, recovery of sintered gas, Desulfurizer, CCPP4, TRT, Regenerative type heating furnace combustion technology, Energy control center.
B	Large	Sintering machines 180, 550 m <sup>2</sup> , Blast furnace 1580 m <sup>3</sup> , Converter 120t,	Gas Recovery, TRT, Waste heat recovery of sintered gas, Desulfurizer, Regenerative type heating Furnace combustion technology, Energy control center.
C	Medium	Sintering machines 300 m <sup>2</sup> , Blast furnace 450&1080 m <sup>3</sup> , Converter 120t	Waste heat recovery of sintered gas, Desulfurizer, Regenerative type heating, Furnace combustion technology, Waste heat generating electricity.
D	Medium	Sintering machines 180 & 360 m <sup>2</sup> , Blast furnace 2000&2550 m <sup>3</sup> , Converter 120t, Electric furnace 100t	All the techniques required by MIIT except coal moisture control Recovery of heated stream, Gas generating electricity.
E	Medium	Sintering machines 90, 360 m <sup>2</sup> , Blast furnace 530 & 3200 m <sup>3</sup> , Converter 100&150t, Electric furnace 100 & 40t	Furnace dehumidified blast technology, waste heat generating electricity, VFD devices <sup>5</sup> .
F	Small	Sintering machines(data Confidentiality), Blast furnace 450 m <sup>3</sup> , Converter 65t, Electric furnace 70t	Regenerative type heating furnace combustion technology, VFD devices.
G	Small	Sintering machines 90 m <sup>2</sup> , Blast furnace 450 m <sup>3</sup> , Electric furnace 100t	Waste heat recovery of sintered gas, Regenerative type heating furnace combustion technology, TRT, VFD devices, Recovery of Waste heat.
H	Small	Sintering machines 28 & 52 m <sup>2</sup> , Blast furnace 450 m <sup>3</sup> , Converter 45t	TRT, CC-DR and CC-HCR <sup>6</sup> , Gas generating electricity, VFD device.
I	Small	Electric furnace 50t ,60t, 70t	Electric Furnace wall Technique.

A quick look at the table above indicates that large-scale enterprises not only apply the techniques the ministry requires but also the ones ministry recommends, such as Coke Dry Quench devices. In the meantime, most small-scale enterprises can only satisfy the requirement of MIIT on energy efficient techniques but do less on the

<sup>4</sup> Combined Cycle Power Plant

<sup>5</sup> Variable Frequency Drive

<sup>6</sup> CC-DR: Continuous Casting-Direct Rolling, CC-HCR: Continuous Casting-Hot Charge Rolling

ones MIIT recommends. Enterprise F, for instance, do not even use the Top Gas Recovery Turbine Unit facility which is required by MIIT. Compared with small-scale enterprises, medium-scale enterprises adopt more types of energy efficient devices; however, they apply less equipment that cost a lot compared with large-scale enterprises.

Although there is a relatively large difference in the equipment the different categories of enterprises adopt, managers generally do not deny the effectiveness of technology on energy efficiency improvement, and meanwhile they express willingness to continue to use new techniques. We can learn from their statements that the positive attitude towards energy efficient technology comes from: 1) technology does help them to reduce energy consumption per unit of product; 2) technology brings economic benefits, such as saving production cost. The same conclusions are also figured out in previous studies.

*“Technology assures energy efficiency improvement, we adopt all the techniques we should use now, and nowadays energy efficient technology is relatively mature. The techniques used by the entire industry are almost the same...” (Enterprise A, Large-scale)*

*“As I mentioned just now, blast furnace gas used in sintering process is recycled from iron making process. After gas, there is a TRT method which is mature and is begin to be put into practice. We have been used TRT since 2007. (Now) gas is not only enough for self-use, but also has some surplus... We started to use blast furnace gas to generate electricity. The first and second-stage construction went into operation April this year and will operate at their full load this June. It brings good benefit; the output of every day reaches 1,200, 000 megawatt-hours. We can purchase less electricity and save amount of money every month. ” (Enterprise A, Medium-scale)*

*“Now we apply technical schemes of hot charge and delivery. Steel billets produced by caster are still hot when delivered to steel wire process, which helps saving energy to heat the steel billets to 1000 °C. At the same time, it helps save logistics cost. Besides, it is economic that delivering waste gas to power plant to generate electricity... in exchange, power plant supply waste stream for free. ” (Enterprise H, Small-scale)*

Besides the promoting effect of energy efficient technology, production facilities exercise a great influence on energy efficiency in iron and steel production. Take TRT for example, a bigger blast furnace brings higher furnace top pressure which lead to

larger amount of electricity production and energy saving. In addition, some larger facilities themselves contain energy efficient techniques. Therefore, generally speaking, larger-sized equipment in iron and steel production is more conducive to save energy. From the above table we can see that larger-scale enterprises have large equipment capacity. Some equipment used in large-scale enterprises are even fourfold or fivefold larger than what small-scale ones use. This can partly explain why medium and small sized enterprises do not apply some energy efficient techniques even though they recognize the role of the techniques in saving energy and producing benefits.

*“Energy efficient technology should be integrated with practice. We made efforts to try and solve the steam bleeding problem before. It is difficult to connect it to grid because of its low pressure. We tried to generate electricity using steam but it turned out to be far from the expected goal...we pondered seriously and kept improving the technique for half a year and finally succeeded in raising the generating capacity...in fact, some techniques are immature and difficult to be put into practice. For instance, waste heat in flush slag water can be recycled according to the experts. We try to make use of it, but it's too difficult... We heard of successful cases, so we sent our skilled workers to visit and learn from others. ” (Enterprise C, Medium-scale)*

Although we can learn from the interviews that all of the nine enterprises agree that technology improvement is a significant factor of energy efficiency rise, their understanding of technology improvement in enterprises is confined to the technological progress through adoption of existing techniques. In other words, what they identify as their technological advance comes from technical innovation of other enterprises and their utilization of others' technology instead of their own technological innovation. This phenomenon is obvious especially in small-scale enterprises, which reflect the low R&D ability on energy efficient technology in Chinese iron and steel industry.

*“We only carry out some minor modifications. Sometimes, they come from staff's wisdom. But we are indeed weak in R&D. When facing big technical improvement, we have to resort to metallurgical design institutes.” (Enterprise F, Small-scale)*

*“(R&D) is often in the field of producing while energy efficient (techniques) mainly rely on purchase. We make more efforts on application instead of R&D*

*considering our strength.” (Enterprise D, Medium-scale)*

*“Some of the energy efficient techniques are developed by ourselves while some are bought. The latter one accounts for a larger proportion.” (Enterprise A, Large-scale)*

To sum up, the argument that technology improves energy efficiency has been confirmed in the interviews conducted in these iron and steel enterprises. However, it also shows that difficulties exist in technological innovation even enterprises approve the positive effect of it.

## **4.2 Governmental policies to enhance energy efficiency**

The enhancing effect on energy efficiency improvement induced by energy policy is known from many countries. Take Japan for example, the implementation of the energy conservation bill in 1979 reduced the energy intensity by 37% from 1979-to 2003 (Hendel-Blackford and Angelini 2007). The report conducted by United Nations points out that lack of effective policies on improving energy efficiency, weak enforcement of environmental policies and legislations and energy policies only aimed at short-term rapid economic gain are all lead to the lower energy efficiency in developing countries. In addition, the report categorize the existing and new policy instruments into legislative instruments, economic instruments and voluntary instruments and summarize 11 types of policy, such as law & regulations, standards, codes of practice, fiscal subsidies, property & tradable rights, bonds and deposit refunds, liability systems, voluntary agreements, information & programs and R&D. (UNEP 2006)

Similar to the energy efficiency policy types summarized by UN, the energy policies of China include standards, economic incentive and penalty, mandatory targets. The following are some policies concern to iron and steel industry.

In 2005, the first ‘Iron and steel industry development policy’ of China was published. The iron and steel industry energy consumption indicators, the level of equipment and technical and economic indexes are specified in the policy objectives and in the industry technology policy. For example, comprehensive energy

consumption per ton of steel will be reduced to 0.73 tons of standard coal by 2010; comparable energy consumption per ton of steel will be reduced to 0.69 tons of standard coal; Fresh water consumption per ton of steel will be reduced below 8 tons. In 2020 those indexes should be reduced below 0.7 tons, 0.64 tons and 6 tons. To ensure that the iron and steel industry upgrade and achieve sustainable development, sintering machine should be constructed with its area no less than 180 square meters; the height of coke oven carbonization chamber should be no less than 6 meters; the effective volume of blast furnace should be no less than 1000 cubic meters; the nominal capacity of converter should be no less than 120 tons; the nominal capacity of electric furnace should be no less than 70 tons. The blast furnace of new project must be equipped with Blast Furnace Top Gas Recovery Turbine Unit device and pulverized coal injection device; coke oven must be simultaneously equipped with the Coke Dry Quench device and matched the dust collector as well as coke oven gas desulfurization devices; coke oven, blast furnace and converter must be equipped with gas recovery device; electric furnace must be equipped with dust recovery device. It also points out that: ‘All production enterprises must reach both national and local pollutant emission standards; the total major pollutants emission indicators of the projects under construction should be strictly implemented by the approved environmental impact assessment report (table) regulations; the production, whose pollutant emission exceeds the approved total amount or pollutants emission indicator, will not be allowed’.<sup>7</sup> In order to ensure the effect of the policy, the government started the energy saving project. The project includes a thousand enterprises whose energy consumption accounted for 50% of total energy consumption of national industry in 2006 (Zhang 2010).

In addition to a series of standards to force enterprises to improve their energy efficiency, the government also published fiscal policies to encourage enterprises improving energy efficiency initiatively. Fiscal policy includes not only subsidy but also includes “economic sanctions”. For example, the government ceased the export

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<sup>7</sup> “Iron and Steel Industry Development Policies” published in 2005

Source: [http://www.gov.cn/gongbao/content/2006/content\\_320630.htm](http://www.gov.cn/gongbao/content/2006/content_320630.htm)

tax rebate for steel enterprises from September 2006 and turned the tax capital into subsidies for energy-efficient technology application and update for equipment of low energy efficiency. Moreover, the National Development and Reform Commission began to implement differential power prices according to the industry energy intensity and increased the research input for energy technology from 6.8 billion dollars in 1998 to 39 billion dollars in 2004 (Tan 2010, Zhou, Levine and Price 2010). In addition to the national fiscal policy, the Jiangsu provincial government and municipal governments provided subsidies for the iron and steel industry to improve energy efficiency. For example, the government will provide subsidies to enterprises according to a certain proportion of the capital invested on energy efficient technology by the enterprises. Besides, for the improvement of energy efficiency gained through a certain technology, enterprises will receive the reward of 240 Yuan per tons of standard coal.

The view point that the support from the government is the major power to change the energy demand situation have been proposed by scholars (Zhang et al. 2009); however, according to interviewees, restrictive policies have much better effect than supportive policies on improvement of energy efficiency in the enterprises than moreover, the effects of policies are various in different sized enterprises.

*“The project is mainly supported by the investment from the budget of the central government. National subsidies are higher than local ones. We have a lot of applications for energy-efficient technological transformation projects and the scales of these projects are large..... The subsidies from the government are according to the amount of our investment on these energy-efficient projects. For example, in last year, we invested in a desulfurization project from which we gained a reward of 10 million Yuan from Development and Reform Commission according to our investment on this project. However, it’s much lesser than our investment on that project, 60 -70million Yuan in total.” (Enterprise A, large-scale)*

*“There are lots of policies concerned. Some subsidies, such as tax rebate. There is an energy-efficient product list from the government. If we apply those products on the list we will have a certain tax concession at the end of year, not much yet..... There are many kinds of National scientific research foundation; some are subsidies for energy-efficient project. The government encourages enterprises adopt energy performance contracting as a form of subsidies. However, the subsidy is little, compared to our investment. 100 million Yuan we invested, few million Yuan of*



*subsidies we gained. The investment on energy-efficient project of iron and steel industry is generally huge, as you see.” (Enterprise D, medium- scale)*

*“More subsidies you want, more materials for applications you need to prepare, more examination you need to do. In fact, our leaders said, we have to do something on energy-efficient projects even without the subsidies from the government. Of course, we wish more subsidies than we gained now, it is far from enough.” (Enterprise E, medium scale)*

*“The threshold of national and provincial subsidies is high. It is hard for our small-size enterprises to enjoy the subsidies. Central government only gives subsidies to those who can save more than 10 thousand tons of standard coal, which is impossible for us. The subsidies we get mainly from municipal government. We only get provincial subsidies twice by now. Provincial subsidies are usually more abundant while municipal subsidies are more frequent, 50-100 thousand one time for example. Even these small subsidies are supplied in a specific period. Take Top Gas Recovery Turbine Unit project for example, you can get subsidies when the state supports it, but now you have no subsidies because government begin to encourage other new measures, so the information about the subsidy is very important, you can get money only if you know the policies.....we sometime cannot enjoy the subsidies even we prepare to adopt the energy efficient measure when government still support it because the construction period of certain techniques are long and the process of approval is complicated, the supportive policies may be over before we adopt it.” (Enterprise F, small-scale)*

*"The subsidies are too little. There are several reasons to explain why we seldom get subsidies. We sometimes don't know the information on subsidies so we missed the reward. For example, a lot of enterprises got subsidies on the last supportive project, but we do not know that information at that time and when we heard of it, the supportive subsidies had been ended. The one (reason) is that governments do not supply subsidies on the minor modification by enterprises themselves. In addition, you must prepare lots of materials for approval, if you do not hand in these materials, you cannot get subsidies and we once miss the subsidy because of this reason.”(Enterprise G, small-scale)*

Although almost all of the enterprises have reservations about the promoting effects of supportive policies, the reasons for the reservations are not exactly the same for small-sized enterprises and medium-large-sized enterprises according to their feedback. The reason for large and medium-sized is the small amount of subsidies compared to the total investment and they argue that policies cannot influence their decision on energy efficient investments. The small-sized enterprises usually miss subsidies because of their lag in the process of adopting energy-efficiency measures. Besides, small enterprises suffer from lack of information and complex processes of

approval. Hence, it is understandable that the policy on subsidies is not appreciated by small-sized enterprises.

Although managers expressed that they would continue to improve energy efficiency to save costs for enterprises no matter the governmental constraints the effects of restrictive policies are obvious both in large and small-sized enterprises according to the information they feed back. The restrictive policies not only play a supervisory role in improving the patchy performance of enterprises in enhancing energy efficiency but also necessary to facilitate the adoption of energy efficient and environment-friendly measures that may be helpless for making profits for enterprise but beneficial to the social welfare.

*"Energy saving can reduce the cost for us, so we would like to do that, so it is not the governmental constraint that force us do this thing. As long as the cost is lower than the payback, we would choose the energy efficient measures..... (Policy) are very strict, our big-sized enterprises also feel stressful. We had saved 710000 tons of standard coal in the 11th Five-Years and need to save 1440000 tons more in the 12<sup>th</sup> Five-Years. We have adopted all the energy efficient measures and there is little room left for improvement, I do not know what we can do to satisfy the requirement."* (Enterprise A, large-scale)

*"We are influenced by the restrictive policies to some extent because arriving standards is premise of continue production, so no matter what kinds of methods you use..... if there was no constraints, we may not choose some techniques or measures because we need to consider the economic benefits."*(Enterprise D, medium-scale)

*"A new list of eliminated equipment will be published on October. The electromechanical equipment of Y series is not on the elimination list before, but in the 12th Five-years, we need the eliminate all of them. Although it means that the techniques on the list are energy-consuming, if there is no relevant policy, we definitely would not replace the Y series because it is not that energy-consuming for us.....facing the restrictive policies, we have no other choice other than obey them. Another example is desulfurization; it does not produce any benefits for enterprises even reduce our benefits, but we still need to buy professional equipment to accomplish the task government gives us.....If an energy efficient measure is profitable, we would adopted it even without government's supervision."* (Enterprise C, medium-scale)

*"The effect of restrictive polices is large. For example, no one takes charge of the possession rate of instrument in the past, but from 2008, after we joined the 'one thousand enterprises' program, government required that rate must reach 90%. To make us know more about dour energy consumption, they also send people to examine*

*the instrument to make it precise. If there is no governmental requirement, we would not do like this, it takes lots of money after all.....we sign contract with government with a standard of reduction of energy consumption. If we cannot reach it, we would be punished in terms of heavy tax that hard to bear.” (Enterprise H, small-scale)*

*“The effect of restrictive polices is more obvious than that of supportive ones. If government set criterion, we have to try our best to arrive it first.” (Enterprise I, small-scale)*

The promoting effect of restrictive policies is presented in the feedback of enterprises. However, managers choose various measures to cope with the constraints that are differentiated among different types of enterprises. Medium and small-size enterprises, for instance, adopt available and new technology for them, such as burning blast furnace gas to generate electricity or waste heat recovery to tackle constrains. Their main challenge is to continually eliminate energy-consuming techniques in order to attain the Government’s standard of energy efficiency. The large-scale enterprises optimize management, such as applying energy management system. They sometime also play a trick on their index value to cope with checks. The reason is that they have adopted most energy efficient techniques and it is hard to improve further from an existing high level of energy efficiency.

*“It is difficult for us to finish the mission of saving 0.29 million tons of standard coal in the 12th Five- Year. In fact, we have implemented most of the energy-saving projects in last Five-year, and there are no more energy-saving projects now. So it is hard for us to complete the task. We sometime play a trick on data because we have to ‘achieve’ goals or we will be punished.....” (Enterprise E, medium-scale)*

### **4.3 Market competition to enhance energy efficiency**

According to Sinton, the falling energy intensity in China is caused by the change of energy behaviors brought by Chinese economy reform (Sinton, Levine and Qingyi 1998). In socialist market economy, enterprises are self-financing and the fiercer the competition is, the higher the efficiency of resource allocation. This is in line with Bai (2007) that the enhancement of market competition can remarkably promote the utilization efficiency of science fund. Market competition brings technological progress, and the technological progress promotes the energy efficiency.

That is to say, market competition promotes energy efficiency by stimulating technological progress. This is corroborated by the following study of the energy efficiency in iron and steel industry in China.

The iron and steel market in China has been oversupplied for a long period. The depressed economy this year makes the competition fiercer in this field. On the demand side, investments in fixed assets that are highly relevant to steel consumption declined dramatically, especially in real-estate. Moreover, the rising rate of domestic main steel consumption fields such as automobile, shipbuilding and family appliance declines, which makes the pressure of steel sales higher. On the supply side, the production capacity of crude steel in China has risen to 970 million tons while the domestic demand is only 700 million tons. In addition, the equipment and products in most iron and steel enterprises are homogeneous, which lead to the gradual loss of competitiveness in some leading companies and therefore the profit would be even lower in the whole industry.

*“Our rivals are not limited to the Jiangsu province; they are also in some surrounding cities. Each enterprise has its own stable sales tube, for example, there are some fixed sales points of our company in surrounding cities, in Zhejiang, Shanghai and Jiangsu and each one is responsible for the sales of a fixed range. But the whole industry is in recession, we are all exploring new market, which may intrude into others’ range and makes others feel threatened. Anyhow, rivals are everywhere.” (Enterprise C, medium -scale )*

In such a fierce competition and low-differentiation market, enterprises must reduce cost to survive and improving energy efficiency is an effective method to survive for the steel enterprises as the cost of energy consumption generally accounts for 30% of the total cost in iron and steel industry.

*“The improvement of energy efficiency has strengthened our competitiveness greatly. As our boss said, the reason why we got profit while many others were in a deficit this year was that the cost saving by improving energy efficiency reached tens of millions Yuan. We are trying our best to reduce cost. For instance, we create contests to promote energy efficiency and set goal of energy saving.” (Enterprise C, medium-scale )*

*“The improving of energy efficiency could improve competitiveness from 2008 to 2010 because it can save cost for us at that time. Recently, environment protection is*

*included in the energy efficiency evaluation, so the effect of energy efficiency on competitiveness is hard to say because you know that environment protection cannot increase our profits.” (Enterprise H, small-scale)*

Though there is no objection to the effect of market competition on energy efficiency among enterprises, the three types of enterprises reflected differently on how they cope with competition. When they were asked the question ‘will you improve energy efficiency while your rivals’ efficiency has been improved’, large-scale enterprises choose to improve their own efficiency when their rivals do because they are always watching the new actions of their rivals. However, some small-scale enterprises give a ‘No’ answer since they worry about their business and product viability.

*“If other companies have improved the efficiency, we would also improve it. We would do that as long as there is room for improvement. The association of iron and steel industry offers us the figures of energy consumption of per ton steel, we will analyze why they (figures) are lower in other companies and send people to learn their better techniques. If some appliance does not work well, we also go out to learn. While they are our competitors, there must be something good for us to learn.” (Enterprise A, large-scale)*

*“If one technique is mature, it is usually be quickly popularized. Of course every company will keep its own secret, but the characteristic of this industry makes us communicate a lot. We just use technology but not produce it.” (Enterprise D, medium-scale)*

*“The key point is that our decisions depend on our company’s policies. The total iron and steel field is oversupplied at present, at this time, it (using new energy-efficient technology) may cause problems if the leader is considers to shift to another field. We do not certainly follow others’ paces, but make decisions according to our own conditions... .. if we shift to another field after three or five years, then a change to apply energy efficient technology makes no sense. (Enterprise F, small-scale)*

*“We also visit and observe other enterprises and some enterprises come to our companies for studying too. We study less on energy efficient measures especially through direct way. Most of them (studies) are indirect. For example, they bring some information about energy efficient technology only when we go out to learn productive technologies. Saving resource is affiliated to production.” (Enterprise G, small-scale)*

Generally speaking, the improvement of energy efficiency has been an effective way to improve competitiveness as energy cost takes a large proportion of total cost in

the iron and steel industry. However, there is still objection among enterprises on the effects of improving competitiveness caused by energy efficiency when environmental protection is included in the concept of energy efficiency. In the words of enterprises, spending on environmental protection brings more social benefits but little corporate benefits. Moreover, the three types of enterprises responded differently to enhance energy efficiency in other enterprises. Most large and medium enterprises study and adopt energy efficient measures actively when they find a gap of energy efficiency between themselves and others. But some small enterprises do not do well in this case because they put more attention to the technological improvement of production and have little energy to cope with efficiency issues. In addition, their insufficient efforts on energy efficiency are also related to the future development strategies made by the leaders of the enterprises.

#### **4.4 Enterprise management to enhance energy efficiency**

The productivity of enterprises is decided by human behavior, which plays a key role of the transformation of enterprises rather than machinery. To increase the efficiency, effective management is essential (Deming 1990). Sola and Xavier(2007) indicate that decision of enterprise strategy, establishment of management system as well as training scheme of the employees are important aspects of enterprise management, and related analysis shows that there is a strong correlation between enterprise management and energy efficiency, that is, better management will cause less energy loss.

The interviews in nine enterprises in Jiangsu province shows that the management of energy efficiency of an enterprise depends heavily on the administrator's emphasis on this issue. There is no significant difference related to the scale of the enterprises. According to the head of the energy departments in these enterprises, the importance of management is acknowledged because the enterprise can benefits from effective management. Besides, barriers to energy efficiency related to bad management and concern with good management were of great concern to the

administrators. This will be discussed in the next chapter.

*“We have built a sound Energy management system, set up a leading group for energy conservation, and established a three-level energy management network of group, firm and branch plants. (Enterprise B, large-scale)*

*“Management is very important, after all, a good technology cannot work without the control of human being, and so scientific and refined management can contribute to efficiency, especially when the technique and equipment in most enterprises have been improved to almost the same high level, management will be more influential in improving the efficiency.” (Enterprise D, medium-scale)*

*“Our company is encouraging the establishment of an energy system which is helpful for reducing energy loss and increasing efficiency. We have done a lot on technology improvement, benchmarking and resource utilization. Last time the advisor indicated that our resource optimization is weak, to be exact, the single tasks are good, while there are problems in the process of connecting these tasks. So processes such as network transmission can be improved because it is used in the whole company and not belongs to any single task. Our system optimization is taking this issue into consideration. Such as our gas-electric set, as a system, it has to be well planned by the company. The energy system can evaluate the equipment and technique to find energy-saving space, including data benchmarking. Benchmarking and process carding can be used to find the energy-saving space and equipment that should be eliminated, and to estimate the energy factors that will cause energy loss and control them, in order to save energy during the management processes. Factors that have strong effect on energy saving or that are more possible to be improved will be regard as priority to improve. By rectification, both efficiency and management level will be improved.” (Enterprise C, medium-scale)*

*“The human factor is one of the most fundamental factors in enterprise management, and talent technicians are brought along such as our vice president. Enterprise would lose competitiveness if it does not introduce new talents. Technical skills and management style of the managers are both important. As a manager, I should be familiar with the key technique, besides I should take good use of this technique, which calls for a good management method. Managers often have different management ideas. Good leaders will make excellent team.” (Enterprise H, small-scale)*

From the description of enterprise C, it can be seen that the improvement of management can effectively increase energy efficiency, which is also agreed and valued by the other enterprises. It is difficult to judge that whether the large-scale or medium/ small scale enterprises have a better management method, because it is related to the structure of the organization as well as managers' emphasis. During the interview, when answering the question about what effects different management

methods can cause, enterprises in different scales have different emphasis. To be exact, large enterprises focus on what methods they have chosen and what achievement they have attained, and they also suggest the urgency and necessity of good management. Medium and small scale enterprises tend to express the leaders' emphasis of management methods and their positive attitude of study and improvement, and they also show a sense of pride when talking about the improvement of efficiency by scientific management. In contrast, small enterprises show a more positive attitude on improving the management method, which is because the leaders can pay more attention in almost every aspect of the enterprises, and the leaders' concern about energy efficiency can affect other employees. While in large enterprises, management is more complex and the effect of energy management is less obvious than that in small enterprises (Rohdin, Thollander and Solding 2007).

#### **4.5 The relative importance of factors enhancing energy efficacy**

The various factors that contribute to energy efficiency have been discussed separately. In general, technology progress, market competition, policy and enterprise management can improve energy efficiency to some extent. However, the enterprises do not have the same recognition of the importance and effects of the various factors. In the process of research, I asked companies to rank the factors according to importance.

Due to the differentiated views on the encouraging and restrictive effects of policies, the policy factor is divided into an enhancing part and a constraining part when enterprises rank the relative importance of factors. In the same vein, the technology improvement factor is divided into the technology adoption part and R&D part. The enterprises grade six factors according to importance. The most important factor gets 6 points while the least important factor gets 1. The result is shown in Table 4.2



Table 4.2 Ranks of enhancing factors for energy efficiency

Enterprise Code	Technology Adoption	Market Competition	Restrictive policies	Enterprise Management	Encouraging policies	R&D
A	6	5	4	3	2	1
B	6	5	3	4	2	1
C	6	5	2	4	3	1
D	6	5	4	3	2	1
E	6	4	3	5	2	1
F	6	4	5	2	3	1
G	6	3	5	4	2	1
H	6	5	3	4	2	1
I	5	3	4	6	2	1

As we can see from the sorted result, technology adoption is the most important factor considered by enterprises, while R&D also as a technology factor is considered the least important because technologies used by enterprise are designed mainly by designing institutes rather than themselves. Market competition ranks in the second place in most enterprises and restrictive policies and enterprise management follows behind market completion. The relatively low scores of the restrictive policy are consistent with enterprises' argument that 'Even without government's regulation, we will still carry on the improvement of energy efficiency for survival'. Moreover, although the government offers support such as subsidies, these policies were not appreciated by enterprises because the subsidy is relatively small compared to the investment and small enterprises even cannot get subsidy most of the time. Hence its importance was ranked the fifth and the score is much lower than the fourth one.

It can be found from Table 4.2 that there are obvious differences on rank of factors among the large, medium and small-sized enterprises. According to the almost all the interviewees in large and medium-sized enterprises, the importance of market competition is only less than technological introduction, while some small-sized enterprises even ranked this factor at the fourth place. There are two reasons explaining this difference. The first reason is that there are other options, such as improve productive technique and product quality, available to raise competitiveness for the small enterprises and the improvement of energy efficiency is not the first option. Thus the effect of energy-efficiency on competition is weak in small

enterprises. But in large-size enterprises, the technologies of both energy efficiency and production are constantly upgraded and what they do is seizing every chance to raise their competitiveness and the competition is their best ‘supervisor’. Facing different competitors are another reason to explain the difference. The competitors of small-sized enterprises are usually small-sized and their overall level of energy efficiency is low and therefore the motivation of enhancing energy efficiency is weak among them, while large enterprises are facing the challenge from large ones with similar technology and they are sensitive to any variation of energy efficiency of their competitors.

The scores of restrictive policies in small-sized enterprises are relatively high and two of them rank this factor in the second place, that is to say, the importance of government constraints is only less than technology adoption for them. This is because many energy efficiency standards of small-sized enterprises just reach the national limit value and if restrictive policy adjusts slightly, the influence is huge for them. For medium-sized enterprises, the room to improve energy efficiency through technology improvement is bigger than that of larger-sized enterprises, in addition, the policy adjustment could not affect them obviously because their standards related to energy efficiency perform better than what the policy requires and they are actively improving energy efficiency to enhance their competitiveness. Therefore the effect of restrictive policies is weaker to medium-sized enterprises. Besides, the score given to restrictive policies by large enterprises is different from my expectation. Large-sized enterprises attach more importance to policy constraints although I thought they produced and chose without the burden of the restrictive policies. Large-scale enterprise have adopted almost all the technology that central government requires and encourages to use and hence the room to improve is relatively small, however the governments set tighter goals for large-sized enterprises year by year, thus the influence of restrictive policies is obvious for them.

The effect of supportive policies is weaker than regulatory pressure in most large and medium scale enterprises. The present form of the supportive policies mainly is subsidizing the adoption of energy efficiency technology. However, almost all

technologies the government subsidizes have been applied years ago in large-sized enterprises. Hence, they benefit little from the supportive policies while the medium enterprises C can better enjoy the subsidies because there is bigger room for it to improve efficiency through continual adoption of technology and they are trying to apply new technologies. Therefore the policies are indeed supportive for it. Besides, small-sized enterprises also give a low score on this indicator because they have low energy efficiency and their speed of promoting energy efficiency is slower than the speed of replacement of governmental subsidy lists and thus they hardly enjoy the governmental subsidies especially national and provincial ones.

The ideas in large-sized enterprises and medium-small enterprises are divided over the management effect on energy efficiency. The effect of enterprise management is more obvious in medium-small enterprises than in large ones, which may be caused by the difference of management complexity in these enterprises. Enterprises management in small-sized is relatively simple and the managing effect on energy efficiency is easier to be reflected, while in large-sized enterprises, management is complicated and energy management need to combine with administrative system in other fields to achieve the energy-efficiency improvement, and thus its importance is easy to be ignored.

#### **4.6 Summary**

In this chapter, I discuss the relations between energy efficiency and technological progress, policy-making, market competition and enterprise management in Jiangsu nine iron and steel enterprises. Similar to previous findings, the nine enterprises generally recognize the enhancing role of these four factors; however, they rank the importance of the factors differently especially in terms of market competition, business management and policy constraints.

Government regulatory pressure gives a greater impact on energy efficiency in small enterprises but market competition has less power, while in large enterprises, the impact of market competition is greater than government constraints. Besides,

medium-sized enterprises are influenced by these two factors at an intermediate level.

In terms of enterprise management, the effect of management is relatively obvious in small and medium-sized enterprises due to their simple corporate structure while its importance has a lower score in large enterprises although they also stress the promoting role of management in energy efficiency.

## 5 Constraining energy efficiency in the Jiangsu iron and steel industry

Based on the classification of energy efficiency made by Weber (1997), Sorrell (1996) and Trianni and Cagno (2011) as mentioned in the Literature Review (Chapter 2.3 above), I analyze the constraining factors of energy-efficiency according to the framework presented in Table 5.1:

Table 5.1 Research framework on constraining factors for energy efficiency

Primary index	Secondary index	Possible constraining factors involved
Economic non-market failure	Capital	Insufficient capital; little economic benefit
	Risk	Production interruption; Long payback time; ineffective of technology
	Hidden costs	High cost of information gathering and testing.
	Heterogeneity	Ineffective method of energy efficiency improvement
Market failure	information	Unaware of energy-efficient measures; Imprecise information; Unreliable information
	externality	The externality of risk and technology
	Principal-agent problem	Different interest between the principals and agents
Organizational	Status	Low status of energy department
	Incentives	Confused mission; Lack of incentives
	Culture	Poor energy efficient atmosphere
Behavioral	Non-rational choice	Choose energy-efficient measures by rule of thumb.
	Value	Ignorance of energy efficiency by managers
	Inertia	Unwilling to change the current condition
	Existing level of operating skills	Low existing level induces difficulty of applying new method.

Source: Weber (1997), Sorrell (1996) and Trianni and Cagno (2011)

## 5.1 Economic non-market failure

In this paper, the constraining factors of energy efficiency improvement are divided into four categories: capital, risk, hidden-cost and heterogeneity. This section describes the responses of 9 steel enterprises on the issue of constraining factors and analyzes the differences of responses among the three types of enterprises.

### 5.1.1 Insufficient capital

In Chapter 4, competition, technology, management and policy are proved to be the contributing factors of energy efficiency improvement, that is, enterprises could improve their energy efficiency through the improvements of technology and management; however, the improvements on technology and management require a large amount of capital, which is not easy for some enterprises. Anderson and Newell (2004) investigated 50 Greek manufacturing-type enterprises and they found that most of the participants (76%) considered insufficient capital as one of the biggest barrier to energy efficiency improvement. Rohdin, Thollander and Solding (2007) obtained a similar result through the research on Swedish cast industry. However, most of enterprises interviewed do not take capital as a problem as long as the pay-back period of new technology or equipment is acceptable. A short pay-back period on new technology is stressed especially in medium-small-scale enterprises because they are less capable of financing new technology and more likely avoid risk. However, even small-scale enterprises with similar financial strength have different attitudes to capital issues. Some small-scale enterprises recognize capital as a barrier to energy efficiency, while other small ones do not, which is probably due to different attitudes of managers on energy efficiency. If the managers actively support energy-efficiency they will approve sufficient capital to energy-efficient improvements and therefore the heads of energy department would not deem the capital as a problem. The attitude issue will be discussed in detail in latter section.

*“Capital is not a problem for us... .. There are two reasons why we do not (apply)*

energy contract management system<sup>8</sup>: on the one hand, we are not in lack of capital; on the other hand, we prefer to buy technology and equipment rather than let the energy service companies buy them and rent them to us. Our boss said if the technology is splendid, why should I share it (the benefit brought by technology application) with you? I will buyout it on my own.” (Enterprise A, large-scale)

“If payback is confirmed, money is usually not a problem. The situation is not ideal for this year but we will not cut the energy-saving fund..... The sales revenue decides whether or not we have money to invest on energy-efficient technology. Take the coal moisture control budget as an example: it is not easy for this budget to be approved although the payback of this technology is confirmed, for it requires quite a lot of money. Several million could not be a problem but if technology needs sixty or seventy million at current situation, boss would think where this amount of money should be used. Investing too much money on a technology itself is a risky behavior even the payback of technology is verified. ” (Enterprise D, medium-scale)

“Money is not a problem, we focus on the payback. If the payback period of a technology is too long, we will consider postponing the adoption of the technology. The speed of capital turnover is also an important point we need to consider in current situation.. ” (Enterprise E, middle-scale)

“Our enterprise needs some investment on energy efficiency. It depends on the cost of this program and the payback period.” (Enterprise G, small-scale)

“It is tough for iron and steel industry since the 2008 financial crisis and it is difficult for us to put forward an energy-saving program. Where is the money? We are trying to compress our cost! And you want me to invest on this? Only if we are in the golden period, the capital is not a problem. We care about the payback. If a technology can pay back for sure, we will apply it.” (Enterprise F, small-scale)

“Well, on this problem, money is not a problem only if there will be a. Our enterprise has nothing but money! I am not bragging. Since it saves money, our boss will sign it immediately.” (Enterprise H, small-scale)

It can be inferred from the investment philosophy of these enterprises that they would not consider investment on environment-friendly technology if the technology cannot bring benefits for them, which is supported by the interview results about desulfurizer. Sintered smoke contains lots of environmental pollutants like sulfur oxides, dust, nitric oxide and Tetrachlorodibenzo-p-dioxin (TCDD) and the National Ministry of Industry suggests that enterprises equip desulfurizer on sintering machines.

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<sup>8</sup>energy contract management system: Energy Company helps enterprise to invest in an energy-saving programme. The energy-saving benefit will be shared at a certain proportion between the Energy Service Company and the iron and steel enterprise the first years after the programme is established in the enterprise. After this period, all of the benefits will accrue to the enterprise.

The desulfurizer is gradually accepted by large and medium-size enterprises. While not all of the sintering machines in the large-medium-scale enterprises have been equipped with a desulfurizer, none of the small-size enterprise equips desulfurizer on sintering machines.

*“About the environment, well, we now own a big enterprise and we have to focus on corporate image and social responsibility. People care about the environment they live in and they may complain if it is polluted. So we are avoiding making extra pollution even if sometimes we want to. We still choose to use some new measures although they may have small negative effects on the profits, such as desulfurization. In big enterprises like ours, profit is crucial, we shall take social responsibility as well; for those small enterprises, things are different. They can’t afford it.” (Enterprise A, large-scale)*

*“We won’t focus on the project like desulfurization if there’s not restriction from the government. However, government order us to do this, we followed. At least we can get some subsidy for it and it is a tide of development. There is restriction from environmental protection agency too. We can save some pollution discharge fees if we make effort on desulfurization. ” (Enterprise E, middle-scale) “It (using new technology) will improve profit. If it brings little benefit, we won’t accept. Like desulfurization, it brings nothing good for us but power consumption, but we have to do it because government asks so. ” (Enterprise E, middle-scale)*

*“We won’t accept the technology if it cannot bring us benefit.” (Enterprise G, small-scale)<sup>9</sup>*

Although enterprises mostly say that capital is not a problem as long as technology and equipment are profitable, they also express the difficulties in applying technology or equipment effective in terms of environmental protection but extremely costly or not profitable under the currently low profitability condition in the iron and steel industry. Therefore, we can infer that insufficient capital is still a barrier to energy-efficiency improvement, especially when the conceptualization of energy efficiency used in this study includes the environmental protection cum reduction of pollution element.

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<sup>9</sup> In fact the citations also show how important governmental policies and regulations are. (see more in Section 4.2)



### 5.1.2 The high risk of applying new measures

Production is the main task in the iron and steel industry and if energy-efficient measures disturb the stability of production, enterprises would refuse to adopt those measures as loss caused by using new measures may largely surpass its benefits. In the Swedish paper industry, the potential risk of interruption of production is deemed the most important barrier to enhance energy efficiency (Thollander and Ottosson 2008), and in my study, the department managers in the nine enterprises all claim that no negative impact on production is the precondition of applying new energy-efficient measures, which indicate the higher priority of smooth production.

*“The precondition of applying energy-efficient measures is that the measure would not influence our production, but if it only has a small negative impact on production, we probably use it..... Take waste heat recovery in the sintering process for example, we can only produce 30 ton steam and we can get 40 ton if we adjust some process of production. However, the adjustment may affect many aspects of production, so we abandon the goal of getting 40 ton steam. Production is most important thing in a manufacturing enterprise after all. Although there is a big gap between the 30 ton and 40ton, we do not want to risk production and 30 ton is enough according to our own circumstances.” (Enterprise A, large-scale)*

*“No negative effect on production is the most important thing, which is more important than short payback period.....we can accept several days for adjustment of new energy-efficient measures, but we cannot allow production interruption when take account of adoption of new measures.”(Enterprise D, medium-scale)*

*“Of course we need to take account of the stability of production. Some equipment we introduced before are indeed good in other enterprises; however some of them are not effective in ours. So we do not rush into applying new technology even some energy-efficient measures recommended by energy services companies are free. The managers of the production department usually discuss the feasibility of new measures with us, and we would not try to use new measures if they influence production.....we may suffer huge loss if big equipment introduced for energy saving goes wrong.” (Enterprise E, medium-scale)*

*“The main risk of applying new technology is the immature of technology. If new technology cannot go with safe and smooth production, we do not dare to use it.”(Enterprise G, small-scale)*

*“We only use mature technology and send skilled workers to inspect technology before confirming the adoption of energy-efficient measures. The preparation for applying new measures usually takes a long time. We do not accept big change in*

*production conditions due to applying energy-efficient measures because the change may lead to accident. ” (Enterprise F, small-scale)*

All of the large-scale, medium-scale and small-scale enterprises deem the potential risk of as the main barrier of applying new more energy-efficient technology. However, the actions conducted by the three types of enterprises to cope with the potential risk are not the same. Large-scale enterprises may still try to use new technology although there are potential risks, but they sometimes make adjustments on energy-efficient technologies in order to assure the stability of production, and thus those new technologies do not fully release potentials. In medium and small scale enterprises, they usually avoid applying the technologies with potential risks due to the weaker risk tolerance.

The purpose of assuring production in enterprises is to make profits and therefore, the risk of low rate of return on investment or long payback time, which may play a negative impact on profits, is another main reason why enterprises hesitate to apply new technologies. As mentioned in previous section that ‘investment can pay off’ is the precondition for adopting new measures. However, the payback period is different in different types of enterprises. Small-scale enterprises require short payback period that usually is about one year and no more than two years while large-scale enterprises are not that sensitive on the payback period. For medium enterprises, the requirements on payback period are varying according to their earning performance: payback period can be long when enterprises have good returns while the period is short when enterprises have poor performance.

*“We currently do not apply new measures as long as there are no requirements. The industrial policies are changing these years and the steel market has been saturated in the south of Jiangsu. We may face removing of the whole enterprise due to the large operating cost because our enterprise isn’t near the Yangtze River. If our enterprise really moves to another place or close down in these two years, we definitely cannot get all the benefits of energy-efficient technology with long payback period. So we can only conduct some projects that can pay back in a short time” (Enterprise H, small-scale)*

*“The payback period depends on the technology conditions. If we know the technology is indeed good, we mainly discuss the operating cost of the technology with the supplier when we plan to use it and we do not require specific payback*

*period as long as the technology can smoothly run.” (Enterprise A, large-scale)*

*“We should not require all the technologies have same payback period because large projects cannot payback in two years and we still need to apply it. However, we sometimes postpone adopting new measures if the payback periods are too long.” (Enterprise D, medium-scale)*

*“The payback period is related to the economic performance of our enterprise. We can accept relative long payback period if the enterprise earns well these years but we will defer the long-payback-period projects when the economic performance is not good enough.” (Enterprise C, medium-scale)*

### 5.1.3 Heterogeneity

Besides the risk of production interruption or long payback period, the effect of energy-efficient technology constitutes another factor influencing the choice of technology adoption in the enterprise. Technology performs differently in various circumstances and a technology operating highly effective in some enterprises may be ineffective even burden imposed in others, especially in small and medium enterprises.

*“CCPP (Combined Cycle Power Plant) is one method in electric power generation. Due to its relatively higher requirement for the stability of the power load, CCPP has not been applied yet..... Using the redundant gas, whose fluctuation is associated with production, results in the occasional going up and down of the power load. Furthermore, the high expense on investment and maintenance all together, contribute to the non-adoption of CCPP as well.” (Enterprise D, medium-scale)*

*“With all the technologies being applied, the disappointing result is far away from the designed index and intended goal. Namely, the technology needs adaptation when it is applied into the project.” (Enterprise E, middle-scale)*

*“Many new technologies are cost-wasting and unachievable in power saving, and have to been paused due to its failure to achieve the expected results. Take the elimination of the automatic technology of Bomb-Dropping in BOF for example, it should save money, but after we use we found it waste our money. Perhaps, it is a good technology for large-scale enterprises because the technology itself has size limitation. Namely, it is more economical when the furnace is much larger.” (Enterprise H, small-scale)*

*“Enterprise’s scale is critical. While a technology made profits in other enterprises, its output wasn’t proportional to its input after we invested in it. The cost large enterprises invested may be recovered in 5 to 8 years on a cost-recovery basis,*

*but in our enterprise, a full-recovery of the cost may be impossible even in 20 years. All that leads to the abortion of the further investment. Coking is a good example to make explanations. Coke dry quenching technology is not applied in our enterprise because we only have 0.4-0.5 million tons of coke that can be used to generate power and the investment on coke dry quenching technology cannot be returned even in ten years.....You can only get benefits when your enterprise reaches a specific scale, otherwise your investment is worthless. So even the technology is mature, we still cannot apply it. (Enterprise G, small-scale)*

It can be found from the above that, technologies are more effective in large-scale enterprises. To improve the energy efficiency in small-scale enterprises, a choice should be made between the specific design of energy efficient technology for small-scale enterprises and further enterprise mergence into larger group. After every possible constraining factor involved being discussed, a comprehensive answer will be given to solve the problem of heterogeneity in small-scale enterprises.

#### 5.1.4 **High hidden cost**

It has been demonstrated that adoption of feasible technology is key to improve energy efficiency and enterprises try to fully understand new technology to assure the effectiveness and feasibility of the technology. In the process of understanding, enterprises need to spend money to search for information about new technology and test the reliability of the technology. Because the money spent on searching or testing are usually calculated separately from the cost of buying technology, it is called hidden cost and does not included in to total cost of applying new technology. Hein and Blok (in Mirza et al. 2009) calculated the cost of searching and verifying energy-efficient information in 12 Dutch enterprises and found that, the searching cost accounted for 2-6% of the total investment and the verifying fee accounted for 1-2% of total investment. Apart from that, the money spent on adjusting previous productive structure and training to skilled workers to apply new technologies also belong to hidden cost. In order to save cost, some enterprises especially those that lack capital may neglect gathering of energy-efficiency information, which reduce the possibility of applying energy-efficient measures. However, the hidden cost does not constitute barriers to energy-efficiency improvement in the 9 interviewed enterprises. There are

two reasons to explain this: the fierce market competition force technology suppliers to continually offer energy-efficiency information to enterprises for free and help enterprises calculate benefits or train workers to use new technology; government and industry associations also supply a good information exchange platform for enterprises and therefore it is not difficult to search information and verify stability of technology for enterprises.

*“We confirm the effectiveness of new technology through comparison. When suppliers introduced some technologies, we definitely ask them whether the technologies operate successfully in some other enterprises. Moreover, we go to other enterprises applying new technologies to investigate the effectiveness of technologies. We need to clearly know the reason why technology did not fully release its potential..... there are many companies designing energy-efficient technologies and they are also facing fierce competition, which force the technology suppliers to calculate the rate of payback carefully for enterprises. When the technology supplier says that the technology adoption can help us save 20% energy consumption, we usually require that he or she point out the specific source of energy saving and we won't believe them if they cannot tell us the source of energy saving in detail. ”*  
(Enterprise D, medium-scale)

## **5.2 Market failure**

In this paper, imperfect information, negative externality, split incentives and principal-agent problems are the four aspects of market failure that hinder the energy-efficiency improvement. Because there is overlap between imperfect information and hidden cost, this section does not repeat the part already discussed. The overlapping part between negative externality and low payback rate of technologies will also not be discussed again.

### **5.2.1 Imperfect information**

The cost of gathering energy-efficiency information discussed above can reflect whether information communicate freely. Generally speaking, the less smooth the information channel is, the higher the cost of gathering information of energy-efficient technology is and the information is mastered by minority, while the

unimpeded information can reduce the information cost. Most of the enterprises interviewed claim that they can easily get energy-efficiency information and information is not a barrier to energy-efficiency improvement. Except two small-scale enterprises, the enterprises had good information on domestic energy-efficiency. However, only in one large-scale enterprise, managers told that they go aboard to gather new energy-efficiency information. Medium-scale and small-scale enterprises hardly care about the latest energy-efficiency information from abroad.

*“We applied Combined Cycle Power Plant early compared to other enterprises. This technology is invented by foreign country and we introduced it through going abroad to study practices of foreign countries. The relevant department of central government popularizes energy-efficient measures based on the experiences of enterprises. For example, big enterprises recommended some good technology first and then the relevant department of NDRC certify those technology and form a technological promotion list to encourage enterprises use the new measures.....we mainly get information on our own and we also go to aboard to study new technology.” (Enterprise A, large-scale)*

*“I think the foreign information channel is not smooth not only for enterprises but also for domestic technology suppliers. Take the indicator system for example, they (iron and steel enterprises in foreign countries) are using the new measures that may be invented in 2012 but our country can only get the indicators from 2010 of foreign countries and we cannot know the latest level of their energy efficiency. Bureau of Metallurgical Industry communicates with Japanese relevant department every two years and popularize some new technologies. The relevant department of central government also communicates with other countries and the new information get through communication delivered to enterprises by industrial association. Apart from that, we get information from technology suppliers or study from other enterprises when we find energy-efficiency gap with others. So most energy-efficiency information we get comes from domestic government departments or other iron and steel enterprises as well as energy services companies, but we still cannot know the latest technologies used aboard.” (Enterprise D, medium-scale)*

*“We know most domestic technologies and we often send skilled workers out to study new technologies used in other enterprises that have similar productive structure and equipment with us, but we do not know much about latest technologies in foreign countries.” (Enterprise C, medium-scale)*

*“We know some energy-efficient technologies used in our country, but we do not know all of them. I think the information channel is not smooth.....I get the energy-efficiency information via websites” (Enterprise G, small-scale)*

It is obvious that the abilities of gathering energy-efficiency information are

different among these enterprises. Large-scale enterprises not only go aboard to find new energy-efficient technology but also ‘assume the responsibility’ of transferring energy-efficiency information to others, however, although large-scale enterprises are more capable of gathering information, lack of access to get foreign technology postpones the further improvement of energy efficiency of large-scale enterprises. With regard to medium-scale enterprises, they take the large-scale enterprises as their example and what they want to do is bridging the gap on energy efficiency with large-scale enterprises, and therefore the information they want to get is mainly on the technologies used effectively in large-scale enterprises. As mentioned above, the domestic information is available to most enterprises and thus the energy-efficiency improvement in medium-scale enterprises will not be influenced by limited information. For the small-scale enterprises with poor performance on energy-efficiency improvement, they even cannot grasp all the domestic information of energy-efficient technology because not all of them join the industrial association and they have fewer chances to attend industry conferences organized by central or provincial government and thus face the problem of imperfect information which hinder the energy-efficiency improvement.

### 5.2.2 **Externality**

Externality of pollution, risk of applying new technology and R&D are three factors hindering the energy-efficiency improvement. The externality of pollution is mainly caused by free pollutant emission. The emission of polluting gas has not been priced in China and the cost of disposing pollution is shared by the whole society, and therefore enterprises tend to use more energy and do not recycle emissions without supervision in order to save cost. Take desulfurizer for example, there is no incentive for enterprises to dispose sulfide without coercive policy and charge on sulfide emission. Thus, no benefits is not an adequate explanation for avoiding adopting environment-friendly technologies and enterprises will have a new understanding on the efficiency of the desulfurizer after the responsibility of disposing pollutant

emission being internalized.

We know from the section 5.1.2 that risk caused by applying new measures is an important barrier to energy-efficiency improvement and the first tries are facing more risks while the latter ones are facing less risks, moreover, the first tries cannot get any benefits because of their ‘courage’ and because of that, enterprises tend to wait for others to try the new measure first and thus slow introduction of the new measures.. Medium-scale and small-scale enterprises are more likely to wait to share the experimental results of others and use new measures until most enterprises say ‘good’ on those measures, which can explain their lower pace of enhancing energy efficiency than the large-scale enterprises’.

*“We will not apply technologies unless they are mature” (Enterprise D, medium-scale)*

*“We take account of new energy-efficient measures and sometimes we are the first enterprises to try the new measures.” (Enterprise E, medium-scale)*

*“We couldn’t be the first enterprises to try the new measure.....We usually use the technologies after we know that they are running effectively in many enterprises, otherwise, we would not use them.” (Enterprise H, small-scale)*

The pollution externality and risk externality mentioned above are negative externalities, while the R&D externality is a positive externality. Although this positive externality makes many enterprises improve energy efficiency it also fosters inertia for the enterprises in developing their own new energy-efficient measures. Research and development on energy-efficient measures usually need input of large amounts of capital and human resources but the achievements are not exclusive, they are shared with other enterprises that get access to the knowledge without many efforts. Thus most enterprises, especially the small-scale enterprises choose to wait for others to develop new technology although they know where energy efficiency needs to be improved. This may postpone the further improvement of energy efficiency of enterprises.



### 5.2.3 The principal-agent problem

Managers (agents) usually have more knowledge on specific investments and profits than enterprises owners (principals), that is, information mastered by principal and agent is asymmetric. Under this circumstance, managers have stronger incentives to make choices combined with their own interest rather than in the owner's sake. For example, managers usually do not choose energy-efficient projects with long pay-back period although they are effective because that the benefits brought by conducting these projects may not be owed to managers if the pay-back period is longer than the term of managers' service. The owners of the enterprises are also the managers in all of the interviewed enterprises except one. Therefore, only one enterprise reflects the principal-agent problem.

*“Although I'm the head of the energy department, but I really do not know whom I should report to when I want to introduce an energy-efficient measure. If I report to the owner of our group company, the managers of this enterprise may blame me for short-circuiting the hierarchy, but if I report to the manager, they often refuse to reform these years because the head office do not pay much attention to the our energy efficiency. The head office only appoints ten people to guide the production in our company and no one of them joins our energy department and what the managers of the enterprises do is catering to the concern of the head office and avoiding conducting energy-efficient projects with less profit because this enterprise may close down in two or three years and the managers do not want to invest some technology that cannot pay back in their service term.” (Enterprise H, small-scale)*

## 5.3 Organizational factors

Both the structure and the energy efficient atmosphere of an organization have impact on the improvement of energy efficiency. In this section, the position of the energy department, the priority of energy efficiency and organization culture will be overviewed in order to discuss the negative impact that business organization might have on the improvement of energy efficiency.

### 5.3.1 The low status of the energy department

The previous studies have found that high-level decisions have more influence. Consequently, it can be deduced that the advanced standard of energy efficiency is bound up with the energy department and its position in the whole enterprise. If the department is in a high position, it will enjoy influential decisions and strong execution. However, if the department is in relatively low position, the improvement project of energy efficient technology will be denied because of other programs like the manufacturing processes (Sola and Xavier 2007). Hence the position of energy department and the priority of energy efficiency build upon each other.

*“We have set up a specialized department which research on energy efficiency of our enterprise, such as the center of administrative control over energy... Our department does not have the decision rights to introduce some technique. (Enterprise B, large-scale)*

*“Though our energy department has no decision rights, we would report several techniques which we think are important this year to a superior and rank them. All the approved techniques will be demonstrated by the quality department. After the demonstration, these techniques will be reported to the planning and development department, which will consider and make the decision. We will do the technical demonstration, and the quality department will also organize other department to take all the factors into account and make the comprehensive argument. The superior will mainly calculate the benefit. Our previous short-flat-fast project paid back in one year, which was approved in spite of financial difficulties... Several million Yuan might be alright, but if it will cost 60 or 70 million Yuan, the leader will think about what to do with the money.” (Enterprise D, medium-scale)*

*“With enhanced status, our energy department is energy counterpart department. If an energy company or an energy conservation company wants to find us, they will find us. However, our leader will take production into account and make the final decision. (Enterprise E, medium-scale)*

*“Our company has a department functioning as an energy department. We have no decision rights except for offering advice. Our leader will make the decision.” (Enterprise F, small-scale)*

In all the above enterprises, the energy department belongs to a function. Although the status of the energy department has been raised in recent years, its position is not high in general even in a large enterprise. The department only has the

rights to gather and demonstrate data without decision rights. When introducing efficiency measures, other aspects, especially production should be taken into consideration. Judging from the interview, we find that the steel industry is in a bad situation with more emphasis on production control and less priority on energy efficiency because the energy department is lack of decision rights. Therefore, energy department, in particular those in a small company often act as monitoring energy consumption.

### 5.3.2 Lack of incentives

The improvement of energy efficiency needs not only the support of the corporate management but also the coordination of different departments. As for steel companies, executive support is important for deciding whether some large high efficient methods will be adopted. However, small reforms within a department also matter a lot, because on the one hand the introduced methods once digested would better meet the enterprise's requirements, and on the other hand, those reforms lay the foundation for enterprise innovation. Therefore, motivating the enthusiasms of all departments is an effective means to promote energy efficiency. If the company promotes the department to boost energy efficiency while cannot properly quantify the performance of those departments in efficiency improvement or provide appropriate rewards, then the enthusiasms of front-line employees cannot be aroused, even causing objection to the introduced energy efficient measures. Among all of the 9 iron and steel enterprises, it is those sub-factories (sintering, ironworks, steel works, rolling plants) who operate high-energy-efficient technology equipment and put forward small reforms. The enterprise adopts the approach that enables the factories to self-control the energy efficiency, which means every factory or even every workshop can measure its energy consumption. Meanwhile, even small-sized enterprises establish reward and punishment institution in order to encourage each workshop to control energy consumption and propose program to solve low energy efficiency.

*“We examine those factories separately and we make plans every year which*

*will examine on the comprehensive energy consumption and small indicators such as focal ratio and coal recovery... those factories will get more money if they manage well and get less if they do not, which depends on the examination. Our small firms would allocate some money for rewarding... high bonus...in June this year, a five-yearly innovation competition was held, which mainly focused on minor modifications. The award was selected according to the number of involved projects and how much these modifications come into play. This time we listed over 90 people, who win the first, second and third prize respectively (first prize is 108,000 Yuan, second prize is 72,000 Yuan, third prize is 36,000 Yuan, consolation prize is 10,000 Yuan) We have set up the 1, 2, 3, 4, 5 prize for minor modifications with less reward, which will probably increase every year and allocated by all participants according to how much these modifications come into play (first prize is 30,000-40,000 Yuan, fourth prize is 10,000 Yuan, consolation prize is 5,000 Yuan)... People are willing to participate in the competition, even with such less incentive. ” (Enterprise A, large-scale)*

*“Energy efficiency is linked to salary, which is calculated in accordance with the number of people. For instance, the each extra 0.1 of blast furnace gas will be fined 50 Yuan while you will be rewarded if the rate of BFG is decreased. However, the disadvantage of modification in each quarter is that the better people perform the more they have to cut down the BFG. Later on, the employees proposed that they don’t want to reduce the BFG or any reward or punishment; rather, they want to maintain the status quo. Minor modification and labor emulation will be rewarded separately. There will be a small group, through project application, probably getting more incentives. Without pressure, they will win the prize so long as they work hard and finish it. Even those proposals which are not applied into use, employees who presented them will be rewarded.” (Enterprise E, medium-scale)*

*“The employees will never be content with the company’s reward. Because the salary is low in our company and the incentive is not much which is a little bit better than no reward. But even that does not mobilize our employees. ” (Enterprise F, small-scale)*

*“The employees are satisfied with the incentives and actively develop energy-saving techniques. Each member of the group will get several hundred Yuan. One cannot complete the group work. We provide forms for rational suggestions, if your advice is reasonable and save energy, we will save some even if you save 1 Yuan for each ton of materials provided that we have large amount of resource. Every company will reward for energy saving, and we reward much.” (Enterprise H, small-scale)*

*“Our company leaders support for the improvement of energy efficiency very well and reward much. In such a good atmosphere, the employees are willing to join in it. Therefore, the company’s motivation is of great importance.” (Enterprise I, small-scale)*

Overall, each enterprise has incentive system for the department and the

individual in place, but the level of reward is different owing to the differences in the economic strength of the enterprises. Probably the large enterprise would reward much and consequently the employee's enthusiasm is high. However, this has much to do with the emphasis of the management rather than the scale of a company. For example, the reward level of Enterprise E and F is not satisfactory. However, the reward level of Enterprise H and I greatly improved employee's enthusiasm. In addition, it can be realized from Enterprise E's answer that the reward and punishment system of a company should be rational; otherwise the employees would lose their heart and ignore the improvement of energy efficiency. Dynamic measurement should be applied to the system, never letting those running faster be punished more. Secondly, there should be a difference between the amount of reward and punishment, which means that the reward should be more than the fine. In this way, the employees have something to look forward to that their efforts paid off.

### 5.3.3 Weak energy efficient atmosphere

The energy department is the guide of the company to raise energy efficiency while it is up to each department and employee to practice it. The aim of building an energy-efficiency culture is to change the current situation of 'low priority of energy efficiency' and to encourage workers to apply energy-efficient approach in every step of the production. From the available data, all of the enterprises are at an early stage in building a cultural atmosphere and what they do is spreading the concept of energy efficiency and examining energy consumption in every step of production, such as producing coke, iron and steel.

*"We should enhance the propaganda of energy-saving awareness and measurement and audit." (Enterprise B, large-scale)*

*"There is not a widespread awareness of energy saving in our company, except for some ads of energy saving and strengthening the awareness of plants in energy saving mainly focusing on examining its indicators." (Enterprise E, medium-scale)*

*"The cultural atmosphere is poor... the departments keep to themselves, only the leaders would pay attention to energy efficiency." (Enterprise H, small-scale)*

## 5.4 Behavioral factors

The behavior of the owners of the enterprises, the heads of the energy departments, the line supervisors and workers all influence the application of energy-efficient measures. This section tries to explain how their behaviors hinder the energy-efficiency improvement from four aspects: the way to make choice, the value of managers, behavioral interior and the existing level of operating technology.

### 5.4.1 Choosing by the rule of thumb

No matter managers, supervisors or workers do not always choose rationally, they sometimes choose by the rule of thumb and refuse to apply new energy-efficient measures although technological information channel is unimpeded and technologies are available (Simon 1979). In my study, department heads have expressed that they usually send some people in charge of energy efficiency out to study new measures before introducing the measures. It is in the process of studying that the people get experiences that provide a reference for future plan. For instance, people form impression that energy-efficient measures are ineffective after they observed that many enterprises cannot operate the measures well and when a new measure appears next time, people tend to judge the effectiveness of the measure according to the average performance of the measure in many enterprises rather than scientific evaluation combined the condition of the enterprises and thus miss the energy-efficient measures that is effective for some specific enterprises. Large and medium-scale enterprises interviewed argue that they do not have the problem of choosing by the rule of thumb while small enterprises have this problem.

*“It may be the management problems that lead to the ineffectiveness of the energy-efficient measures and the skill level of the workers also influence the effect of the measures, so we still conduct scientific evaluation according to our own condition rather than totally listen to others. We do not abandon a technology because many people say it’s bad and we also do not apply a technology blindly because others say it’s effective. ” (Enterprise A, large-scale)*

*“If everybody says the effect of energy-efficient measure is modest, we may not*

*apply it, but we will try if there are some people say it is good. We carefully take account of new measure as long as there is success case. ” (Enterprise E, medium-scale)*

*“We only use new measures when their effectiveness is 100% guaranteed.” (Enterprise F, small-scale)*

*“If seven out of ten enterprises do not recognize the effectiveness of a technology, we would not do further study and directly abandon that technology.” (Enterprise H, small-scale)*

#### **5.4.2 Lack of energy-efficiency awareness**

Low energy-efficiency awareness of managers weaken the energy-efficiency atmosphere, lower the priority of energy-efficient project, and cause the lack of energy-efficiency institute and thus reinforce the constraining effect of the factors mentioned above on the improvement of energy efficiency (UNEP 2006). In my study the department heads only recognized the importance of the managers’ awareness, however, none of them mentioned that lack of energy-efficiency awareness hinders the energy-efficiency improvement according to their own circumstances.

*“We improve energy efficiency because we want to do that, not just to achieve the task assigned by governments.” (Enterprise B, large-scale)*

*“We have to improve energy efficiency because governments enforce strict administration. If the value of our energy index exceeds the national standard, the government officer will come..... So our manager put a high value on energy efficiency. ” (Enterprise C, medium-scale)*

*“What the manager care about is profit so he support the improvement of energy-efficiency as long as the energy-efficient project bring profits.” (Enterprise E, medium-scale)*

*“Our managers strongly support energy-efficiency improvement.” (Enterprise H, small-scale)*

*“Managers indeed pay attention to energy efficiency, which is partly forced by the current economic situation. You can ignore this (energy efficiency) if you want to close down the company. I think every manager both in our enterprise and other enterprises value this thing but the approaches of coping with efficiency improvement may be different among enterprises.” (Enterprise G, small-scale)*

The attitudes of the managers on energy-efficiency improvement can be divided into active and passive pattern according to the responses of department heads.

Moreover, the attitude of the managers is not directly related to enterprise scale: there are managers in large enterprises taking the attitude of achieving tasks while there are managers in small-scale enterprises, such as enterprises H and I, who strongly support energy-efficiency improvement although they have weaker economic ability than large and medium-scale enterprises.

#### 5.4.3 Behavioral inertia

The inertia of maintaining the status quo makes it difficult to apply new measures. In terms of energy efficiency, the application of new energy-efficient technology usually needs coordination with change of the operators' working habits and adjustments of current productive equipment. Enterprises do not optionally change the current situation in order to keep production levels consistent, especially when enhancing energy efficiency is only supplementary means to increase profits. According to the department heads interviewed, enterprises usually store some important equipment in case the current equipment break down and replace the storage according to enterprise policies rather than adopting new measures as soon as possible. This is in line with the argument that the behavior inertia could hinder the energy-efficiency improvement. Moreover, there are also managers and workers who are reluctant to change existing equipment because they are used to what they have in place. This also may constrain energy efficiency improvement.

*“The main energy-efficient equipment is motor and fan in the production. We will replace the new ones because the central government has published the new elimination list of equipment. The equipment department will buy new motor and fan but we cannot be sure whether they are the most energy-efficient ones..... sometimes we buy same type of equipment to replace the broken one in order to guarantee the consistence of production although we know some better equipment. We introduction of new equipment should be approved by the decision makers first and we cannot change them whenever we want. ” (Enterprise A, large-scale)*

*“We have storage of important equipment. We usually replace the same type of equipment unless the enterprise has approved new energy-efficient equipment and facility division has bought that equipment. Some new equipment needs to be ordered in advance and it takes time to coordinate the application of new equipment with the current production, so we would rather use the current model.” (Enterprise E, medium-scale)*



*“We change the models that have been listed in the elimination dictionary; otherwise, we keep on using the same type. Workers have operating inertia and new equipment may not run smoothly if workers cannot adapt to the new operation environment. Therefore, taking human factors into consideration, we would rather use the current equipment to keep the stability and safe of production. Moreover, the idea of the leader is also important. The elderly people are less capable of taking in new things and they tend to maintain the status quo and thus hinder the energy-efficiency improvement.” (Enterprise F, small-scale)*

#### **5.4.4 Low operating skill**

Enterprises introduced new energy-efficient measures according to specific conditions in their own production, such as equipment they currently use. However, the workers' operating skills often be ignored in the process of discussing the feasibility of new measures, which lead to the fail of efficiency improvement even if energy-efficient measures has been applied. The workers' performances in some of the interviewed enterprises reflect the constraining effect of low operating skill on energy-efficiency improvement.

*“The equipment level doesn't hinder the adoption of energy-efficient measures but the workers' operating skill indeed influences the application of the measures. Some workers do not invest too much to improve their skill because they are job-hoppers and although they are trained on some operating skill, they only know how to use the new equipment but do not know why they need to operate like this. For example, they know what they should do when the needle arrives at certain points but they do not know why. So it is hard to require their (workers) autonomous activities in energy-efficiency improvement.” (Enterprise D, medium-scale)*

*“We have built up a Dispatch Center of Energy Management, but it is not in full operation because we doubt the ability of the operators. We do not know whether the dispatchers acknowledge the system well and are capable of operating switches” (Enterprise E, medium-scale)*

*“The operating skill of workers indeed influences the application of energy-efficient equipment. We spent 6 million Yuan to maintain the equipment of TRT a while ago. Although we throw the blame on the technology supplier, we know it is the inappropriate operating by the workers that caused the damage.” (Enterprise H, small-scale)*

*“The operating skill can hinder the improvement of energy efficiency, but it is not the main barrier.” (Enterprise G, small-scale)*

## 5.5 The relative importance of factors constraining energy efficiency

This chapter analyzes the practical effect of 14 potential factors hindering energy efficiency based on the interview records of the nine iron and steel enterprises. This chapter finds that every factor except hidden cost obstructs improvement of energy-efficiency, but the constraining effects of the factors differ in degree according to the responses of department heads. In order to identify the main barriers, I asked the department heads to rank the factors according to their influence. Hidden cost, externality, principal-agent problems, inertia and choosing by the rule of thumb are not shown in the sorted result because these factors are mentioned in at most two enterprises and thus excluded from the rank list. The factor of 'lack of awareness' is also not included because managers are under strict administration and they pay much attention to energy efficiency whether they have to or not. Hence, the awareness of the managers does not hinder energy efficiency in the opinions of the department heads. However, it is interesting that one of the department heads does not rank this factor, although he mentioned that lack of awareness *does* influence their energy efficiency more or less, which may be explained by his worry about the disclosure of interview records. Moreover, I divided the 'heterogeneity' into two parts: poor performance and limited applicability of energy-efficient measures according to the idea of the interviewees. Enterprises grade nine factors according to influence. The factor with greatest influence gets 9 points and the least influential factor gets 1. Zero in Table 5.2 means that department head does not think the factor constrains energy-efficiency improvement. The results are as following:

Table 5.2 Ranks of constraining factors for energy efficiency

Enterprise Code	risk	lack of capital	Limited applicability (technology)	Poor performance (technology)	Imperfect information	Low status of department	Weak energy-efficiency atmosphere	Lack of incentives	Low operating skill
A	9	0	8	7	0	0	0	6	0
B	9	0	8	7	0	0	0	0	0
C	9	0	0	0	7	0	0	8	0
D	9	0	0	8	0	0	0	0	0
E	9	0	0	7	6	8	0	5	4
F	8	9	3	4	0	5	5	7	6
G	8	9	4	3	6	0	0	7	5
H	9	0	4	5	0	7	8	0	6
I	9	0	8	7	0	0	0	0	0

It can be found in Table 5.2 that the enterprises agree that risks, including interruption of production and long payback period are a very important factor constraining energy-efficiency. Seven of the nine department heads give this factor a score of 9. However, the high score does not mean that all of the enterprises are currently hindered by factor. It rather reflects that they consider risk is the most important factor influencing their decision-making. Hence, if technology suppliers and governments want to popularize new energy-efficient technology, the first thing they should do is helping enterprises reduce potential risk.

Poor performance and limited applicability of energy-efficient measures are the main factors constraining improvement of energy efficiency in many enterprises, which, together with the findings in section 4.1 that technology application contributes most to energy-efficiency improvement, demonstrate the importance of technology in energy-efficiency improvement.

The influence of the factor ‘lack of incentives’ just follows the factors ‘limited applicability’ and ‘poor performance technology’. And one large-scale enterprise and four medium-small-scale enterprises give a high score to this factor. Besides, small-scale enterprises primarily concern the factor ‘low operating skill’. Moreover, only two and three enterprises grade factors ‘low status of department’ and ‘weak energy-efficiency’, but the scores given by these enterprises on the two factors are

high.

We can see from Table 5.2 that some factors get high scores in some of the enterprises but in other they are low. Therefore it is necessary to discuss how different the enterprises rank these factors. The 'risk' factor is excluded from the difference analysis because its influence is undisputed.

In terms of quantity of barriers, large-scale enterprises are influenced by fewer barriers including limited applicability and poor performance of technology and lack of incentives, while small-scale enterprises are influenced by all the barriers. For medium-scale enterprise, there are two more barriers, i.e. low status of the energy department and low operating skill, constraining their energy-efficiency improvement compared to large-scale enterprises. The quantity of barriers can partly explain why large-scale enterprises perform better on energy efficiency.

The influences of barriers are different in three types of enterprises. Lack of capital is a main barrier in small-scale enterprises. In comparison, none of the large-scale enterprises give scores to this factor.

The different information required by enterprises can explain the different influence of imperfect information in small and medium enterprises. Small-scale enterprises except one do not have problems of imperfect information, while two medium-scale enterprises rank this factor in the third and fourth place respectively. A possible explanation is that the technologies required by small-scale enterprises are mature and thus the information is shared and reliable while the technologies required by medium-scale enterprises are not mature enough and thus the information is less shared and reliable. Similar reasoning can explain differences in scores given to limited applicability and poor performance of technology among large, medium and small scale enterprises. Large-scale enterprises deem the limited applicability and poor performance of technology as the second and third constraints to energy efficiency because the technologies they have or have not adopted are more advanced but new to them. Hence, they still need time to adjust the production system or improve operating skills to better apply the technologies. Small-scale enterprises in contrast, do not give high scores to these two factors since the technologies they apply

are mature and repetitively tested by large and medium scale enterprises. Factors such as lack of incentives or weak energy-efficiency atmosphere may be more influential to small enterprises. Medium-scale enterprises do not grade 'limited applicability of technology' but two of three enterprises give high scores to the constraints of 'poor performance of technology' because they only use technology tested by large-scale enterprises. However, due to their insufficient level of management or operating skill, the performance of technology is not that good and they sometimes have to suspend some technologies, which influence their energy efficiency.

The problem of low operating skills mainly exists in small-scale enterprises because replacement rate of backward technology and equipment is slow and the operating skills of workers are hard to improve in practice. Moreover, small-scale enterprises are in lack of capital and therefore they seldom offer professional training to their workers. Last but not least large-scale enterprises are often more attractive workplaces than small scale enterprises and can more easily attract skilled workers. Although the large enterprises and two of the three medium enterprises do not rank this factor, we cannot say the operating skill is of no problem to them. From Chapter 5.4 we know that the workers in some medium enterprises only know how to operate but do not know why they do what. This may result in little initiative among the workers, which may in turn constrain improvement of energy efficiency in the longer run.

Lack of incentives, low status of the department and a weak energy-efficiency atmosphere are mainly related to individual enterprise culture, therefore the ranks of these three factors not only differ between different types of enterprises but also within same types of enterprises. More than half enterprises grade 'lack of incentives', even the large and medium scale enterprises give high scores on this factor, but there are still some other large and medium enterprises that do not grade or give low score to this factor. Similarly, two small-scale enterprises rank this factor in the third place while the other two small-scale enterprises do not grade it. For the factor 'low status of department', only one medium-scale and one small-scale enterprise give a main

place to this factor. Only two small-scale enterprises rank ‘weak energy-efficiency atmosphere’. Compared to larger enterprises, small-scale enterprises still have a large room to improve production and enhance their competitiveness; therefore the energy-efficiency atmosphere is weaker than the production atmosphere in many small-scale enterprises.

## **5.6 Summary**

This chapter has discussed the relations between energy efficiency and market failures and economic barriers, organizational and behavioral aspects based on interviews in nine iron and steel enterprises in Jiangsu province, China. This chapter finds that all of the 14 factors except hidden cost belonging to market failures are considered obstructing to the improvement of energy-efficiency. Economic barriers followed by organizational and behavioral barriers have greatest influence while market failure influence least according to the rank results. Moreover, differences of enterprise scale lead to the differentiated ranks of these barriers. Fewer barriers constrain the energy-efficiency improvement in large-scale enterprises than small-scale enterprises where ‘lack of capital’ and ‘low operating skill’ that were not recognized in other enterprises have high scores.

## **6 Conclusions and policy advices**

In this thesis, I have examined issues relating to energy efficiency both in developed and developing countries. I especially looked at the factors influencing energy efficiency and used the 9 iron and steel enterprises in Jiangsu province to studies these questions. Why and how these enterprises improve their energy efficiency and what difficulties they are facing in the process of energy efficiency improvement have been presented and analyzed. Based on the informants' response, this study answers the research questions mentioned in the first chapter:

*Which factors enhance and constrain energy-efficiency improvement in China's iron and steel industry?*

*How do large, medium and small enterprises respond differently to the influencing factors and why?*

### **6.1 Main conclusions**

When seeing the two chapters of analysis, it is evident that access to technology and capability to upgrade and apply technology are the most important factors enhancing energy efficiency, which is in accordance with the quantitative results that technology contributes most for energy efficiency in China (Tan and Zhang 2010). However, R&D undertaken in the enterprises contributes little in these enterprises although some advanced iron and steel enterprises in developed countries take the R&D as an important part to enhance energy efficiency (Yuan 2011). Almost all the nine enterprises claim that they can only take some small modification on the equipment but they do not have ability to research on their own. The energy-efficient technology they use is mainly recommended by governments and designed by designing institution, which confirm the current reality in China that the governments and institutions substitute enterprises as the mainly developers of energy-efficient technology (Yuan 2011). This study divides the governmental policies into restrictive policies and supportive policies, and analyzes their effects on energy efficiency rather

than only describing governmental policies or using energy price policies to evaluate the effects of governmental policies (Tan and Zhang 2010, Zhou, Levine and Price 2010). The finding shows that restrictive policies are much more effective than supportive policies on energy-efficiency improvement, especially in smaller enterprises due to their currently lower level of energy efficiency. Although the energy efficiency of large-scale enterprise is not lower than medium-scale enterprise, they feel stressed to accomplish the task assigned by governments because they already applied all the technology required or recommended by governments and their room to improve energy efficiency is smaller than medium-scale enterprises. This result sheds a light on designing and implementing a differentiated policies to different types of enterprises. The recognition of market competition in these enterprises is not only in line with the argument that market function make enterprises care more about efficiency and innovation and thus improve energy efficiency (Shi 2006) but also reflect the different effects of market competition in large, medium and small enterprises that previously be skipped in China . Large-and-medium-scale enterprises more likely to be forced by market competition to improve energy efficiency than small ones because small enterprises have other aspects such as improving product quality to deal with market competition. Combined with the scores of restrictive policies, this finding indicates that the restrictive policies are more effective than market competition to force small enterprises to enhance energy efficiency. In line with Sola and Kovaleski (in Sola and Xavier 2007), this study also finds enterprise management has a positive effect on energy-efficiency improvement. Moreover, the effectiveness of this factor is more obvious in small-scale enterprises. This may be because it is easier to manage the productive system and in small-scale enterprises due to relatively less management complexity than larger enterprises.

The classifications of constraining factors of energy efficiency made by Sorrel (2004) and Trianni and Cagno (2011) are a suitable backbone for the conceptual framework in this study. With the framework, this study provided many useful insights for understanding and analyzing why enterprises do not actively improve



their energy efficiency and how these enterprises perform differently. The constrains analysis in this study also strengthens the approaches within the energy efficiency literature that emphasizes the need to have a comprehensive approach and take social factors into account when analyzing the influencing factors of energy efficiency (Callon 1991 ) and supply a new perspective for energy efficiency study in China. Except hidden cost, all the constraining factors mentioned in Sorell's and Trianni's framework, such as insufficient capital, high risk of applying technology, heterogeneity of technology, imperfect information, negative externality, principal-agent problem, low status of energy department, lack of incentives, weak energy-efficiency atmosphere, non-rational choice, ignorance of energy efficiency, unwilling to change current condition and low operating skills are recognized by one or several enterprises in this research. However, the influences of these factors in this study are different due to their specific conditions.

Most of the enterprises choose new technology mainly depend on others' experiences of applying technology. Besides, they have low R&D level and they can do little to adjust new technology. Therefore the limited applicability and poor performance of technology becomes a main barrier to energy efficiency.

Unlike 50 manufacturing enterprises in Greece (Anderson and Newell 2004), capital generally is not a main problem to these enterprises except small ones. However, the argument of 'sufficient capital' is based on the premise that investment on energy-efficient measures can pay back. The non-profitable measures such as desulfurizer still make a financial pressure even for large-scale enterprises.

As mentioned in introduction part, the number of the iron and steel enterprises are large and the competition among them is fierce, which lead to the energy efficiency information diffuse fast especially in large-and-medium-scale enterprises. Except two small-scale enterprises reflect the difficulties to get information, other enterprises do not have the problem of getting energy efficiency information. But because advanced enterprises in developed countries usually keep the latest energy-efficient measures as a secret for a while, the lack of access to foreign information still plays a role in constraining energy efficiency of the enterprises, such

as the large-scale enterprises in this study, that partly rely on innovations in developed countries.

Although all the informants said that the awareness of their managers does not hinder energy-efficiency improvement, the scores they give to ‘lack of incentives’ and ‘weak energy-efficiency atmosphere’ indirectly reflect the attitudes of managers on energy efficiency. More than half informants think their enterprises are lacking incentives and these enterprises are not limited small-scale enterprises while one large-scale enterprise also gives an important position to this factor. This result again confirms that China is in an early stage of obtaining energy efficiency.

The theoretical factors in Sorrell’s framework (Sorrell 2004) such as principal-agent problems, inertia and choosing by the rule of thumb are not the main barriers to energy efficiency in these enterprises and risk of applying technology is a potential most important constraining factor of energy efficiency even though it is not currently influencing energy efficiency in these enterprises.

This study was conducted in the most energy-intensive industry in the worldwide largest energy consumption country. The insights from this study supply a new research approach in energy efficiency for other studies relating energy efficiency in China. There are many industries in China are energy-intensive, such as power industry and textile industry. For these industries, the qualitative research using the similar framework can obtain more knowledge the influencing factors of industrial energy efficiency. The insights and findings in this study might also be useful for the China’s energy efficiency policy discussion as the advices are proposed according to the real conditions of enterprises and the findings in different sized enterprises indicate that differentiated policies are needed. In the end, this study describe the research context, method, theory and findings in detail in order to make it easier for readers to assess the transferability of this study to other contexts.

## **6.2 Advices**

### **Encouraging R&D and research on technological applicability**

According to the feedback of the nine enterprises, technological change is necessary to enhance energy efficiency, but the challenge is how to make this happen, by developing new technology or to get access to new technology and have the capacity to use it adequately when one gets access to it? If technology cannot be effectively used in production, its constraining effect on energy efficiency is also obvious. The most advanced energy-efficient technologies that the iron and steel enterprises in China currently are using mostly imported from abroad, but it is hard for the enterprises to get the latest information of energy-efficient technology, which slows down the pace of China's improvement on energy efficiency. Therefore, both of the central government and provincial governments should encourage enterprises to take R&D on new energy-efficient technologies, which in line with the advice of improving R&D ability most mentioned in previous Chinese studies. However, strengthening research on technological applicability is also important according to feedback that limited applicability and poor performance of technology are main barriers to energy efficiency. In this respect, besides the financial reward on energy-efficiency improvement, government should establish specialized fund for R&D on both new energy-efficient technologies and technological applicability to encourage enterprises to supply the fund and conduct R&D.

### **Formulating and implementing strict energy-efficiency standards**

Due to the sensitivity of large and small enterprises to policy constraints, realistic execution of energy efficiency standards has a positive effect on stimulating R&D in large enterprises and applying energy-efficient measures in small enterprises. In addition, it can also strengthen energy-efficient awareness in iron and steel enterprises. However, according to a large-scale enterprise, even an enterprise does not reach the standards, the local government does not force the enterprise close down because an iron and steel enterprise usually input huge amount of money and employ many local workers. To guarantee the effective implementation of criterion in enterprises, not only local government should step up system of punishment aiming at those do not reach energy-efficiency standards, and central government also should strengthen supervision on local government and severely punish non-compliance behavior taken

by local governments only considering economic development.

Besides, environmental responsibility should be involved in the evaluations on energy efficiency and government can collect environmental taxes and carbon-emission taxes through taxation lever.

### **Increasing subsidies**

Raising energy efficiency is a gradual process, but China has to accelerate the efficiency improvement due to the strong request of decreasing carbon emissions from the international community. The overall level of energy efficiency is not high in Chinese iron and steel industry and it is stressful for enterprises to arrive at a high level of energy efficiency in a short time. Without government subsidies, especially the subsidies on environmental protection technologies, the competitiveness of some enterprises may be challenged because of adopting nonprofit measures in a short time. Both large-scale enterprises and small enterprises in this study reflect the problems that subsidies are insufficient compared to investment or it is hard to get subsidies.

Government subsidies should be distributed based on the characteristics of the enterprise, especially paying more attention to the proportion of subsidy in small and medium-sized enterprises. Moreover, subsidies implementation should adopt the stepwise method considering the difference of enterprises' performances. For instance, giving more subsidies to enterprises that use energy efficiency technology first and giving fewer to those left behind rather than only supply subsidies on a technology at a specific period. This will not only help more enterprises to enjoy subsidies, but also stimulate an early use of energy-efficient measures in enterprises.

### **Providing training environment**

Low managerial level of managers and low operating skills of workers are identified as barriers to energy-efficiency improvement. However, enterprises have insufficient incentives to change this problem because they want to save the cost of training. In this regard, government can play a role in workers' training through supplying subsidies on trainings related to energy efficiency or requiring iron and steel association to take a lead in organizing training for managers and staffs on a regular basis. Besides, the training content for managers should focus on theories and

practices of systematically improving energy efficiency, while the training content for workers should give priority to principles and practices of specific energy efficiency technologies.

### **Encouraging the enlargement of enterprises**

One of the reasons to explain the low energy efficiency in small-size enterprises is the miniaturization of both equipment and plants. There is obvious scale effect in steel industry and the small equipment is ineffective in itself and further hinder enterprises taking part in regular competition. Aiming at this problem, the government can play a role in encouraging acquisition and reorganization in iron and steel industry guided by industry association. In the process of reorganization, association should press corporations to make complete integration plan to achieve the true sense of enterprise integration avoiding simply joining together.

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# **Apendix**

## **Interview guide**

### **Background**

Name of the enterprise being studied.

When was the company established?

Ownership structure and changes in ownership over time.

Size: number and turnover rate of employee.

### **Products**

The composition of products.

The changes in the composition of products over time.

### **Inputs**

#### **Capital**

How did you raise the necessary capital?

How do you use the capital? The distribution of the capital.

#### **Machinery & technology**

What machinery and equipment do you require in the production?

Describe generations of machines used in the company from the beginning of its production.

Who are your suppliers and why you selected them?

#### **Energy**

What is the main demand of the energy and how does it change?

How much energy do you consume over time and the production of the company in the same period? The changes and why?

Who are your energy suppliers? Has the relationship changed over time?

Is there any subsidy on the energy price from the central or provincial government?

How does it influence your energy choice?

The ratio of the energy cost in the total cost and the changes.

### **Labor**

Composition of the workforce today. (Skilled, unskilled, contract workers, male, female, supervisors, office workers, R&D)

What skills are required of the workers and what educational level do they have?

Changes in the qualifications of the workers over time.

Is it difficult to recruit workers with required skills?

Do you offer any training for your employees?

### **Markets**

Who are your main competitors? And where are they located?

What are your main strength and (weakness)?

What is the regular profit margin in your type of business and has this changed over the past five years? Why?

Are you part of any industrial association or network to fight competition and what has the organization achieved?

What strategies do you apply to meet increasing competition?

### **Driving forces for energy efficiency**

How do you define the energy efficiency?

### **Policies**

Is the energy consumption in the production subject to the 'Quota of energy consumption per unit in main process of crude steel production' and 'quota of energy consumption per unit of coke'?

How the Energy standards influence the energy efficiency?

How the policy of 'differential power prices' influence the energy efficiency?

Does the local government implement the policy of 'differential power prices' strictly?

Does the local government still offer subsidy on the power price?

How the changes of the export rebate policy influence the energy efficiency and profit

in your enterprise?

Do you obtain financial incentives due to the adoption of the energy-efficient technique? Does the local government offer more financial incentives than the central government? How?

If the company participated in any related program, does it accomplish the aim of the conservation? What energy-efficient measures did the company use during that period? What kind of support did the company get in the program?

Do other policies influence your adoption of the energy-efficient technique? What are they and how?

How do you evaluate the policies encouraging improvement of energy efficiency?

### **Technology**

What is the main technology and equipment for the steel making in the enterprise?

What are the effective volumes of Blast furnace, Converter, Electric furnace?

Do you apply pulverized coal injection system, TRT, Gas recovery device, coal moisture control technique, coke dry quenching device, desulphurization equipment?

The process of the elimination of backward equipment.

Are you imputing new equipment to improve energy efficiency? What's the scale of the input?

What is the gap between your present equipment and foreign developed equipment?

How the adoptions of the new equipment influence the energy efficiency and profit of the company?

Have you ever applied any R&D fund related to energy efficiency?

1. Have businesses like yours closed down in recent years because the strict policies?

### **Collaboration**

Foreign or local collaborators of the company.

Type and period of collaboration (technical, financial, marketing, management)

Chinese steel industry has forged alliance with several countries, do you benefit directly or indirectly and how?

Are you the member of any industry association? What is the name and size of the association? The geographical distribution of the members.

Description of the activities in the industry association. Do you have any technical discussion and sharing?

### **Competition**

Do you know what energy-efficient technique do your competitors use?

The advantages and disadvantages of your energy-efficiency technology compared to your competitors.

Do you think the energy efficiency is a key factor in the competition in steel industry?

Does the energy-efficiency improvement of your competitor drive you improve energy efficiency?

### **Self-innovation**

Do you have any innovation on the energy-efficient technique?

Have you put the innovation into practice?

How much do you invest for the improvement of energy efficiency every year? The change of the figure. The ratio of the investment in the energy-efficient technique compared to the production input.

What is the ratio of the investment in the technological purchase compared to the self-innovation?

What is the most important factor driving the improvement of energy efficiency? How do you rank them?

Other factors driving the improvement of energy efficiency.

Does the productivity improve after the adoption of the energy-efficient technique?

How about the profit?

### **Management**

Do you have any strict management measures on energy efficiency?

### **Barriers to energy efficiency**

#### **Market failure**

What is the source of the energy-efficient technique? (government, suppliers, other companies, active collection)

Which country or area are the techniques produced?

Do you know clearly about the characteristics like costs and saving potentials as well as the actual energy consumption of the technique in place?

Is the information on the energy-efficient technique credible?

How do you test the credibility of the information?

Is the information specific, vivid and simple?

The cycle of information collection?

Do you have specific personnel in charge of searching for energy-efficient technique?

The cost of the information collection.

Is the credibility of information one barrier of the adoption of energy-efficient technique?

Which sectors have effective role in the improvement of energy efficiency?

Does the company evaluate the energy efficiency in every sector?

Would the sectorial enthusiasm be suppressed if the energy efficiency evaluated in terms of the whole company other than sector efficiency.

Does the company give any awards to the energy-efficient sector? How?

Does your manager drop energy efficient measures due to the profit of the measures cannot payback in his service period?

### **Economic but non-market failure factor**

Capital related: what are the main parts of the reinvest and the priority of these parts.

The average amount of investment in energy-efficient technique.

Is the capital sufficient for the input of the energy-efficient technique?

The change of the investment over time.

What are the other capital sources for energy-efficient technique other than the surplus of the company?

Risk-related: Do you have good internal technical skills to apply the advanced technique?

Payback period of the present energy-efficient technique.

What is the payback criterion of the company?

Which technique is refused by the company due to the long payback period?

Does the adoption of the new technique bring the production disruption? If it does,

how would you choose?

Does the present energy-efficiency technique influence the quality of products? If it does, how would you choose?

What is the quality of the energy-efficient equipment? Does it accord with the information you got?

What is the inconvenience in production brought by the energy-efficient technique?

What is the main risk of the adoption of energy-efficient technique?

Do you use any measures to avoid the negative effects?

How do you think about the energy price in future? Does it influence the technical choice?

How does the price of the technology influence the present technical choice?

Is there any other uncertainty influencing the technological choice at present?

### **Behavioral & organizational factors**

Do you have a sector in charge of the energy efficiency?

Is the energy sector the key sector or assistant department?

Which sector decides the investments in the energy-efficient technology? What is the role of the energy sector in the decision-making?

Are the decision made by rule of thumb or based on scientific evaluation?

When you need to replace some equipment due to the aging, do you first choose the equipment with similar characteristic of previous equipment or consider choosing the energy-efficient equipment?

The attitudes of the staff on the energy efficiency.

The attitudes of the managers on the energy efficiency.

Do you apply any non-productively energy-efficient measures?

Does the company make strategies for the improvement of the energy efficiency?

What is that?

How do you sort these barriers?