A Knapsack Model Based Approach to Measure the Carbon Reduction Space of Industry Sector: A Case Study of Shenzhen, China

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***Abstract*—Top-down and bottom-up models are the two most widely used approaches to determine the amount or proportion of carbon emissions that can be abated. In this paper, a new bottom-up approach based on Knapsack model is used to calculate the carbon reduction space of Shenzhen industry sector. The result shows that over 20% of total industrial emissions could be saved in present emission level when unit reduction cost reaches 100 $/t-$CO_2$. And when the cost is below 20 $/t-$CO_2$, about 5% of industrial emissions can be saved. The mainstay industries of the city such as Manufacture of Communication Equipment, Computers and Other Electronic Equipment (MCCO) will be less affected due to the larger reduction spaces.**

***Index Terms*—carbon emissions, reduction space, industry sector**

I. Introduction

A question of consequence for climate and energy policy analysis is the amount or proportion of carbon emissions that can be abated. In this paper, the proportion of carbon emissions that can be saved is defined as carbon reduction space. There has been a wide range of models developed to determine the potential or space of carbon reduction. The models provide insights into this issue under their respective assumptions. Despite the different scientific paradigms, the models could be categorized into two approaches, the top-down approach and the bottom-up approach [1]. In brief, a typical top-down approach focuses on market interactions within the whole economy and has little technological detail and a typical bottom-up approach focuses on the substitutability of individual technologies and their relative costs. Top-down models like AIM, E3MG etc. are mainstream approaches and they provide comparable outcomes [2]. Other top-down approaches could also be found in regional studies [3]-[5] and some studies aiming at industrial parks [6], [7]. While bottom-up models vary due to the different study objects [8]. Generally, the bottom-up models are more suitable for an industry that has similar products and process such as steal [9] and cement [10]. Such example can also be found in the study of ammonia industry [11] etc.

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In this study, a bottom-up approach based on Knapsack model is applied to calculate the carbon reduction space of industry sector. And Shenzhen, one of the seven pilot cities or provinces of carbon trading of China, is taken as a case study.

As planned, Shenzhen is to establish its carbon trading system in the middle of 2013. Due to the different pricing mechanisms of electricity, the power plants in China have no right to adjust the price under carbon control [12], which suggests that the carbon price has almost no impact on the consumer side of electricity. In response, the indirect emission from electricity consumption is put under the mandatory carbon control of Shenzhen government. The first period of the carbon trading system from 2013-2015 operates CO_2 emission associated with energy use only. So no carbon emission other than that from energy consumption is discussed here. 2011, the first year of the Twelfth Five Year Plan is selected as the base year of the study. By convert energy consumption into carbon emission, the emission from industry sector by energy sources is showed in Fig.1. All the emission factors used in the passage are illustrated in Table I.

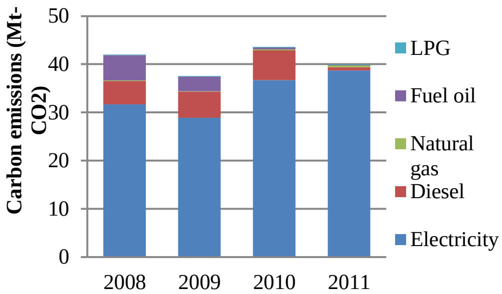

Figure 1. Carbon emission of industry sector by energy sources, Shenzhen statistical yearbook, 2011 [13].

By examining all the 30 sub-sectors, Manufacture of Communication Equipment, Computers and Other Electronic Equipment (MCCO), Manufacture of Electrical Machinery and Equipment (MEE), Manufacture of Plastics (MP) and Manufacture of Metal Products (MMP) are identified as the 4 biggest emitters within industry sector. All the other sub-sectors left are treated as a remainder.

Carbon emissions by energy sources of the top 4 emitters and the remainder are showed in Fig. 2.

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TABLE I. EMISSION FACTORS

Emission factors	2008	2009	2010
Electricity（tCO_2/MWh）[1]	1.0634	0.9987	0.9762
Diesel(tCO_2/t)[2]	3.1		
Fuel oil(tCO2/t)[2]	3.17		
LPG(tCO_2/t)[2]	3.1		
Natural gas(tCO_2/m^3)[2]	0.0022		

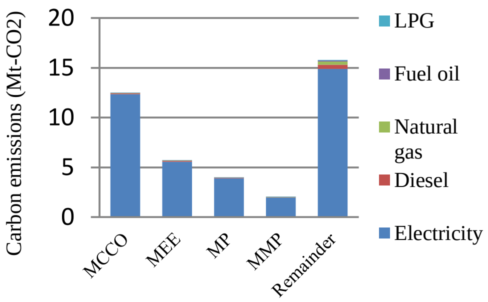

Figure 2. Carbon emissions by energy sources of top 4 emitters and the remainder within the industry sector.

As the industry as well as the high technology center of China, Shenzhen showed significant differences compared with traditional industrial cities in the structure of carbon emission, especially when indirect emission from electricity consumption is taken into account. The features are:

1) The industry sector covers 30 sub-sectors and has a wide range of products. Even within the top emitter MCCO, the products differ dramatically
2) High-tech sub-sectors like MCCO and MEE are the major emission sources of industry sector. Traditional energy intensive sub-sectors addressed by previous studies like iron and steel (part of metal products manufacturing) or cement (part of non-metallic mineral products manufacturing), however, contribute much smaller.

II. METHODOLOGY

The general method used in this study can be summarized as the following steps:

1) Select target enterprises according to exampling method and gather the information needed including the energy-consuming facilities, the energy consumption structure etc..
2) Select applicable reduction technologies for the enterprises and determine the reduction potential of each of them.
3) Derive the aggregated reduction potentials of the industry sector and its sub-sectors.

[1] Source: Baseline Emission Factors for Regional Power Grids in China, National Development and Reform Commission, 2008, 2009 and 2010.

[2] Source: Provincial Greenhouse Gas Inventory Guidelines, National Development and Reform Commission, 2011.

A. Sampling Method

Stratified sampling is applied according to the features of industry sector. First determine the sample size. Then determine the sub-sample size according to the contribution of carbon emissions of each sub-sector. And finally sample independently from each sub-population to target the enterprises.

The sample size is set at 104 according to the availability of data. The sample covers 25 sub-sectors. 5 sub-sectors are excluded due to small contributions.

B. Reduction Technologies of Industry Sector

The reduction technologies addressed in the study are generally categorized into two types, energy-saving reconstructions of buildings and efficiency improvements of facilities. Reconstruction of lighting and air-conditioning, installation of small solar power system and intelligentizing of distribution system are included in the former type. The technical enhancements of energy efficiency for individual facilities such as frequency transformation and waste heat recovery are included in the later one. In total, over 80 technologies are specifically addressed in the study.

C. Model Description

An industrial enterprise, no matter which sector it belongs, has to take two essential factors into consideration while making energy-saving (or carbon reduction) decisions: the cost and the benefit. The cost of a reduction technology includes the prices of the facilities, installation fees, use cost like operation and maintenance costs, fuel cost etc. The benefit is the carbon reductions during its useful life. The use cost is not considered because a certain technology varies when applied to different enterprises. The useful life of technologies is not considered either.

So an individual technology can be seen as $N_i(w_i, e_i)$, where $w_i \sim U(a_i, b_i)$ is the cost of an individual technology and $e_i \sim U(c_i, d_i)$ is its yearly energy saving or carbon reduction.

Assuming an enterprise A is willing to invest W for carbon reduction, it must maximum its benefit within the budget W. So it becomes a process of selecting available technologies to achieve the maximum reduction. The process could be illustrated as equation (1):

$$\begin{cases} \max \sum_1^n x_i E(e_i) \\ st. \\ \sum_1^n x_i E(w_i) \leq W \\ w_i \sim U(a_i, b_i), e_i \sim U(c_i, d_i) \\ x_i \in \{0,1\} \end{cases} \tag{1}$$

Thus the decision-making process of an enterprise can be described as the 0-1 knapsack model.

In order to make the results more relevant and comparable, linear transformation is made to formula 1 so that the constraint of an overall budget is transformed into the one of unit reduction cost. The transformation is shown as follows:

$$\sum_{1}^{n} x_i E(w_i) \leq W$$

$$\frac{\sum_{1}^{n} x_i E(w_i)}{\sum_{1}^{n} x_i E(e_i)} \leq \frac{W}{\sum_{1}^{n} x_i E(e_i)} = \mathrm{U}$$

$$\sum_{1}^{n} x_i E(w_i) \leq \mathrm{U} \sum_{1}^{n} x_i E(e_i)$$

$$\sum_{1}^{n} x_i [E(w_i) - UE(e_i)] \leq 0$$

Equation (2) is obtained through the transformation:

$$\begin{cases} \max \sum_{1}^{n} x_i E(e_i) \\ st. \\ \sum_{1}^{n} x_i [E(w_i) - UE(e_i)] \leq 0 \\ w_i \sim U(a_i,\ b_i), e_i \sim U(c_i,\ d_i) \\ x_i \in \{0,1\} \end{cases} \quad (2)$$

where U ($/t-$CO_2$) is the unit reduction cost.

III. Results and Conclusions

A. Carbon Reduction Space

As is shown in Fig. 3, the reduction space rise with unit reduction cost. When the unit reduction cost is below 10 $/t-$CO_2$, the reduction space is 1.56%. When the unit reduction cost reaches 100 $/t-$CO_2$ and above, more than 20% of the carbon emissions can be saved every year. Larger slope appears when the unit reduction cost is above 20 $/t-$CO_2$ and below 100 $/t-$CO_2$. This might results from a wider distribution of technologies within this cost range. And the slope dropped when the unit reduction cost surpasses 100 $/t-$CO_2$, which may suggest the insufficiency of technologies.

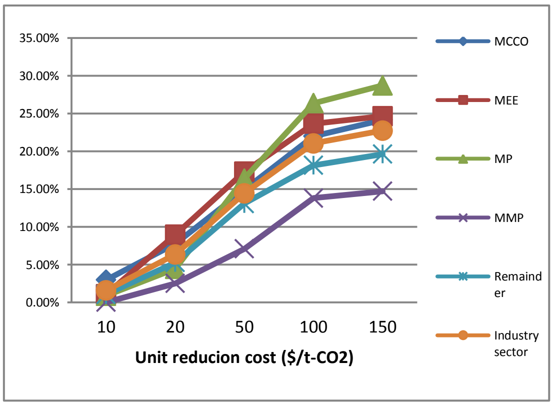

Figure 3. Reduction space of industry sector and its sub-sectors.

Apart from the four biggest emitters, the reduction space of the remainder is below the overall level of industry sector, which could explain its disproportion between contribution of emission and reduction. On the contrary, reduction spaces of top emitters including MCCO, MEE, and MP are larger than the average level especially when unit reduction cost grows higher.

Fig. 4 shows that MCCO, the biggest emitter of all sub-sectors, contributes over 50% of the total reduction when unit reduction cost is below 10 $/t-$CO_2$. The reduction space exceeds 30% when the cost is over 20 $/t-$CO_2$. And as the second and the third biggest emission sources, MEE and MP contribute similarly especially when unit reduction cost is above 50 $/t-$CO_2$. The contribution of MP is relatively small due to its lower emissions and little reduction space. But it increases with the cost. All the other sub-sectors contribute around 30% of total reduction, which is not proportionate to their share of emissions (see Fig. 2).

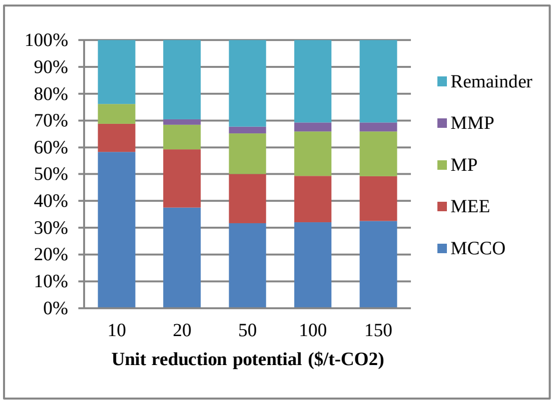

Figure 4. Contribution of reduction under different costs.

B. Conclusions

This study uses a bottom-up approach to calculate the carbon reduction potential of Shenzhen industry sector. The method applied is suitable for industries with a wide range of products and processes. Compared with former studies, more technologies are taking into account and more data has been manipulated. Overall, from this study the following conclusions can be drawn:

1) The result shows that 21.3% of carbon emissions may be reduced at cost below 100 $/t-$CO_2$. At costs less than 20 $/t-$CO_2$, only 6.33% of emissions may be abated.
2) Compared with some studies of industry sector using bottom-up approaches, the reduction potential of Shenzhen's industry sector is relatively higher. This is because the application of reduction technologies is restricted by costs and concepts. After the carbon trading system is established, however, carbon price would make enterprises seriously consider about their reduction plans.
3) As the mainstay industries of Shenzhen, the sustainable development of MCCO and MEE is a priority. The result of the study shows that their reduction spaces are above the average level, which suggests that they may surfer from less stress when the trading system is established.

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