# Chapter 9
# Micro-impact Assessment of Guangdong ETS

## 9.1 Assessment of ETS Operational Efficiency

The ETS is an organic system that requires an all-round assessment from the perspective of systematology. In order to evaluate the administration efficiency of Guangdong ETS, our research team computed the relative efficiency of Guangdong ETS with DEA Model. The outcome is considered as a key criterion for judging appropriateness of Guangdong emissions allowances allocation. For employing this model, we used the 31 provinces/municipalities as the study samples, and 26 of them were defined Decision Making Unit (DMU) through screening.

In light of the *Notice of the State Council on Issuing the Work Plan for Greenhouse Gas Emissions Control during the 12th Five-Year Plan Period* released in 2012, there are 31 Chinese provinces/municipalities are about to cut carbon emissions, though to a different extent. After preliminary screening, we removed 6 of them (Inner Mongolia, Hainan, Tibet, Qinghai, Ningxia, and Xinjiang) from our study samples, since they do not need to cap the total amount of emissions, while the remaining 26 (Shenzhen Municipality and 25 provinces/municipalities due to cut emissions) are defined as DMU for model-based evaluation. We used $C^2GS^2$ Model to evaluate the administration efficiency of the 26 areas [1, 2].

### 9.1.1 Model Building

Assumption:

Each ETS represents a unit, called as $\mathrm{DMU}_i (1 \leq i \leq 26)$. Each DMU is constituted by six input factors ($X$) and four desirable output ($Y$)—$Y$ is generated from ETS operation, then the Production Possibility Set (PPS) is defined as follows [3]:


D. Zhao et al., *A Brief Overview of China's ETS Pilots*,
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$$P = \{(X, Y), X > 0, Y > 0; X \in E_t, Y \in E_m\}$$

The input and output vector of the $i$th DMU is

$$X_i = (x_{1i}, x_{2i}, x_{3i}, \ldots, x_{ti})^{\mathrm{T}} > 0 \quad (1 < t \leq 6)$$
$$Y_{\mathrm{i}} = (y_{1i}, y_{2i}, y_{3i}, \ldots, y_{mi})^{\mathrm{T}} > 0 \quad (1 < m \leq 4) \ \ (1 \leq i \leq 26)$$

$x_{ti}$ denotes the $t$th input indicator of the $i$th DMU; $y_{mi}$ denotes the $m$th output indicator of the $i$th DMU. Both $x_{ti}$ 和 $y_{mi}$ are observed values calculated on the basis of historical statistics or predictions.

Based on the rationale of $C^2GS^2$ Model, bring non-Archimedean infinitesimal $\varepsilon(\varepsilon = 10^{-6})$ into the linear programming equation, then convert the equation into the Dual Model of LP:

$$\min \left\{\theta_k - \varepsilon \cdot (\widehat{e^T} S^- + e^T S^+\right\}$$
$$\text{s.t.} \begin{cases} \sum_{i=1}^{26} \lambda_i \cdot X_i + S^- = \theta_k \cdot X_k \\ \sum_{i=1}^{26} \lambda_i \cdot Y_i - S^+ = Y_k, \\ \sum_{i=1}^{26} \lambda_i = 1, \lambda_i \geq 0 \\ S^+ \geq, S^- \geq 0 \end{cases} \tag{9.1}$$

where $\widehat{e^T} = (1, 1, \ldots, 1) \in E_n$, $e^T = (1, 1, \ldots, 1) \in E_m; S^-, S^+$, respectively, denote slack variable of input and output.

When $\theta = h(X_k, Y_k) = 1$, the input $X_k$ can no longer decrease by the same ratio $\theta$, then DMU has a technical efficiency (weak DEA efficiency); when $\theta = h(X_k, Y_k) = 1$ and $S^{k-} = S^{k+} = 0$, then DMU has DEA efficiency, indicating PPS is at the effective production frontier.

If $\theta \neq 1$, it indicates that technical efficiency of DMU is available for further improvement, then use a distance function to figure out the "projection" of DMU at the effective production frontier:

$$\widehat{X}_k = \theta X_k - S^-, \quad \widehat{Y}_k = \theta Y_k + S^+ \tag{9.2}$$

In order to obtain the adjusting information for converting it to technical efficiency. Through statistical analysis of adjustment vector, we will find out the major problems that affect the efficiency of DMU:

Adjustment vector of input: $\Delta X_k = X_k - \widehat{X}_k = (1 - \theta) X_k + S^-$
Adjustment vector of output: $\Delta Y_k = \widehat{Y}_k - Y_k - S^+$

### 9.1.2 Input–Output Indicator Design

Choosing appropriate indicators for assessment based on characteristics of study samples is one of the crucial steps for developing models. While considering the characteristics and construction objectives of ETS, we designed the input–output indicators used for $C^2GS^2$ calculation in this report. After a preliminary estimation and expert review, we sorted out the following six input indicators and four output indicators.

(1) **Input indicators**

We designed input indicators for the efficiency evaluation model based on the major components of an ETS. Through literature analysis, we have found eight indicators that are closely related to ETS operational efficiency: regulated emissions quantity, allowances total quantity and allocation, MRV, transaction system, offset mechanism, legal framework, and linkage with external carbon markets. We visited and consulted the stakeholders (ETS designers, researchers, government officials, and corporate representatives) in the pilot areas, and found that the current ETS pilot programs only involve the former six indicators, and they are at the beginning to link with each other. Among the six indicators, allowances allocation plan occupies the core position. Most pilot areas adopt the "top-down" and "bottom-up" approaches for determining the total amount of allowances, and the latter is closely related to allowances allocation. It is believed that the allocation plan somewhat affects allowances total quantity, carbon price, companies' efforts in emissions reduction and economic efficiency.

According to the on-site surveys of Guangdong and other ETS pilot areas, we learned that they have roughly the same frequency of allowances allocation. Guangdong was the only one that exercised mandatory allowances purchase in 2013 but turned to voluntary purchase in 2014. Moreover, through an initial model calculation, we found that the two factors (allocation frequency and mandatory/voluntary purchase) have no significant direct impact on evaluating the allocation efficiency with DEA Model. After removing these two factors, the model-based evaluation outcome turned out to be significant, so we used the following six indicators as input factors for model calculation.

$X_1$ percentage of the carbon emissions from ETS-regulated industrial sectors in local total emissions in year $t_0$ (2010);
$X_2$ comprehensive emissions reduction rate of ETS-regulated industrial sectors (criterion for allowances allocation);
$X_3$ percentage of the IVA of ETS-regulated industrial sectors in local total GDP;
$X_4$ allowances trading price;
$X_5$ percentage of CCER for offsets;
$X_6$ fines for excessive emissions.

The ETS framework in the pilot areas also covers newly built projects. The national industry development plan has presented requirements for the scale and technical norms of newly built projects, e.g., their $CO_2$ emissions per unit of production shall be lower than their existing counterparts, meaning that these projects only account for a small share in local total emissions. Therefore, all pilot areas usually allocate free and sufficient emission allowances to these projects, which exert limited impact on the ETS efficiency evaluation. So the newly built projects are excluded from the input factors for evaluation.

(2) **Output indicators**

Under the restraint of the same total amount of emissions, the ETS-regulated companies have lower emission reduction cost than those nonregulated companies, which is an essential benefit of the ETS; therefore, relative decline rate in emission reduction cost is a key output indicator for evaluating ETS. During the investigations, we also found that local governments are especially caring about the impact of ETS on local overall emission reduction target, GDP growth, and development of low-carbon service sector, which concerns the sustainable development of the ETS in China. Based on the above considerations, we took the following four output indicators for measuring the ETS efficiency.

(i) Relative decline rate in emission reduction cost ($Y_1$): The ETS features “lower cost in achieving emission reduction”, thus making $Y_1$ an important factor for measuring the effect of the ETS in all pilot areas. Theoretically, $Y_1$ is calculated through comparison between the homogeneous companies within or outside the ETS framework.

$$Y_1 = \sum_{k=1}^{n} \frac{\overline{c_k}(a, e, p)}{\overline{C_k}(m, e, r)}$$

Under the prerequisite of control over carbon intensity and gross energy consumption, $\overline{C_k}$ 和 $\overline{c_k}$, respectively, denote the sectoral average emission reduction cost of sector $K$ and the average emission reduction cost of ETS-regulated companies within sector $K$.

The parameters $a$, $e$, $p$, $r$, and $m$, respectively, stand for the amount of allowances, level of emissions, carbon price, potentials in emission reduction, and intensity of environmental constraint. However, when the ETS is yet officially operated, it is hard to compute $Y_1$ of ETS-regulated companies. As such, the above formula is better converted into the following formula:

$$Y_1' = \frac{\sum_k^n \overline{\mathrm{ac}_k}}{\overline{\mathrm{AC}}} = \frac{\sum_{k=1}^n (10.9 - 108 * \ln(1 - R))_k}{\overline{\mathrm{AC}}} \tag{9.3}$$

In Formula 9.3, $\overline{\mathrm{ac}_k}$ denotes the average emission reduction cost of the ETS-regulated sector $K$, $\overline{\mathrm{AC}}$ denotes the social average emission reduction cost, and $R$ denotes the emission reduction rate of sector $K$. If the upper limit on emissions of ETS-regulated companies is above the social emission reduction target, then

$\overline{ac_k} > \overline{AC}$. In light of the ETS design rationale, the ETS-regulated companies are able to trade allowances to lower $\overline{ac_k}$ which may finally level off $\overline{AC}$. In this section, we use Formula 9.3 to expound the advantages of the ETS in cutting emission reduction cost.

(ii) ETS economic efficiency ($Y_2$): Measure $Y_2$ by comparing the growth rate of IVA of ETS-regulated companies and local GDP growth rate. $Y_2 > 1$ indicates ETS economic efficiency is higher than the sectoral average economic efficiency, which proves that the ETS is of small negative impact on the local economy.

$$Y_2 = \frac{\left(\sum_{k=1}^{n} \mathrm{GDP}_{k(t_1)} - \mathrm{GDP}_{k(t_0)}\right) / \sum_{k=1}^{n} \mathrm{GDP}_{k(t_0)}}{\left(\mathrm{GDP}_{(t_1)} - \mathrm{GDP}_{(t_0)}\right) / \mathrm{GDP}_{(t_0)}} \tag{9.4}$$

(iii) Developments of low-carbon sectors ($Y_3$): The design of ETS aims to foster new economic growth points, create more job opportunities and promote the development of low-carbon sectors. $Y_3$ is measured by a third-party verifier or carbon trading service agency on basis of the quantity ($q$), scale ($s$), and human sources ($h$) of new companies that are directly related to the ETS.

$$Y_3 = \frac{w_1 q_{i1} + w_2 s_{i2} + w_3 h_{i3}}{3} \quad i = 1, 2, \ldots, n \tag{9.5}$$

(iv) ETS contribution ratio to local emission reduction target ($Y_4$): Compare the decline rate in carbon intensity of the ETS-regulated sectors $(\Delta e_k)$ and the local carbon intensity reduction target $(\Delta e)$, we can figure out $Y_4$.

$$Y_4 = \frac{\Delta e_k}{\Delta e} = \frac{\sum_{k=1}^{n} \frac{E_{k(t_1)}}{\mathrm{GDP}_{k(t1)}} - \frac{E_{k(t_0)}}{\mathrm{GDP}_{k(t0)}}}{\frac{E_{t_1}}{\mathrm{GDP}_{t_1}} - \frac{E_{t_0}}{\mathrm{GDP}_{t_0}}} \tag{9.6}$$

### *9.1.3 Input–Output Indicators*

In reference to the information and data in relevant statistical yearbooks and websites of competent authorities [4–12], as well as the industry materials and our survey findings, we used Formulas 9.3, 9.4, 9.5, and 9.6 to process and compute the data about 26 DMUs which are needed for model evaluation. Considering the limitations of coverage, we only introduced the input–output indicators in Table 9.1.

**Table 9.1** Input–output indicators of ETS

| Input indicators | Output indicators |
|---|---|
| Percentage of ETS-regulated emissions | Decline rate in emission reduction cost |
| Carbon intensity reduction target | Economic efficiency |
| Percentage of IVA of ETS-regulated companies | MRV employees |
| Percentage of CCER | Contribution ratio to emission reduction |
| Carbon price | |
| Fines for excessive emissions | |

### *9.1.4 Model Solving*

After being processed and computed, the input–output data are plugged into Formula 9.1, then we can apply EXCEL Programming Solver Function to resolve the respective operational efficiency of the 26 pilot areas:

Take Guangdong ETS for instance, the equation set for evaluating the impact of the allowance allocation plan on ETS operational efficiency is shown as follows:

$$\text{Objective function: } \min\left\{\theta_1 - \varepsilon\cdot\left(s_1^- + s_2^- + s_3^- + s_4^- + s_5^- + s_6^- + s_1^+ + s_2^+ + s_3^+ + s_4^+\right)\right\}$$

$$\text{Constraint condition}\begin{cases} 54\lambda_1 + 45\lambda_2 + 40\lambda_3 + 53.7\lambda_4 + + \cdots + 38\lambda_{26} + s_1^- = 54\theta_1 \\ 33\lambda_1 + 26.59\lambda_2 + 21\lambda_3 + 20\lambda_4 + + \cdots + 32\lambda_{26} + s_2^- = 33\theta_1 \\ 49\lambda_1 + 20\lambda_2 + 48\lambda_3 + 46.8\lambda_4 + \cdots + 59\lambda_{26} + s_3^- = 49\theta_1 \\ 44.3\lambda_1 + 59.2\lambda_2 + 20.3\lambda_3 + 59.3\lambda_4 + \cdots + 60.2\lambda_{26} + s_4^- = 44.3\theta_1 \\ 10\lambda_1 + 5\lambda_2 + 10\lambda_3 + 5\lambda_4 + \cdots + 10\lambda_{26} + s_5^- = 10\theta_1 \\ 132.8\lambda_1 + 50\lambda_2 + 60.9\lambda_3 + 59.2\lambda_4 + \cdots + 114\lambda_{26} + s_6^- = 132.8\theta_1 \\ 1.58\lambda_1 + 1.39\lambda_2 + 1.08\lambda_3 + 1.04\lambda_4 + \cdots + 1.53\lambda_{26} - s_1^+ = 1.58\theta_1 \\ \lambda_1 + 0.67\lambda_2 + 0.94\lambda_3 + 0.77\lambda_4 + \cdots + 1.07\lambda_{26} - s_2^+ = \theta_1 \\ 101\lambda_1 + 245\lambda_2 + 75\lambda_3 + 96\lambda_4 + \cdots + 318\lambda_{26} - s_3^+ = 101\theta_1 \\ 1.69\lambda_1 + 1.48\lambda_2 + 1.11\lambda_3 + 1.05\lambda_4 + \cdots + 1.64\lambda_{26} - s_4^+ = 1.69\theta_1 \end{cases} \tag{9.7}$$

Similar equations are applicable for evaluating the ETS operational efficiency of other pilot areas, but the right-hand side of the equations shall be replaced with the factors and $\theta_i$ of the concerned area.

### *9.1.5 Outcome of Model Evaluation*

Tables 9.2 and 9.3 show that among the 26 DMUs, 15 have DEA efficiency, 2 have weak DEA efficiency, and 9 have non-DEA efficiency.

Among the seven ETS pilot areas, Beijing, Shenzhen, Chongqing, and Hubei have DEA efficiency, and the optimal solution of their ETS operational efficiency is given as follows:

**Table 9.2** Calculation results of ETS operational efficiency and slack variables

| Areas | $\theta$ | $S_1^-$ | $S_2^-$ | $S_3^-$ | $S_4^-$ | $S_5^-$ | $S_6^-$ | $S_1^+$ | $S_2^+$ | $S_3^+$ | $S_4^+$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Guangdong | 0.87 | 0.21 | 0.82 | 0.00 | 0.00 | 0.00 | 78.44 | 0.02 | 0.17 | 0.00 | 0.00 |
| Beijing | 1.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 |
| Tianjin | 0.88 | 0.00 | 0.25 | 5.69 | 0.00 | 3.80 | 0.00 | 0.00 | 0.00 | 2.83 | 0.01 |
| Hubei | 1.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Shenzhen | 1.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Shanghai | 0.90 | 17.33 | 0.00 | 0.03 | 0.00 | 0.00 | 0.00 | 0.00 | 0.05 | 0.00 | 0.04 |
| Chongqing | 1.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Hebei | 0.95 | 0.27 | 0.00 | 4.39 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.02 |
| Shanxi | 0.94 | 0.69 | 0.00 | 6.92 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 6.68 | 0.00 |
| Liaoning | 0.99 | 0.60 | 0.00 | 3.62 | 0.72 | 0.00 | 0.72 | 0.00 | 0.00 | 0.00 | 0.01 |
| Heilongjiang | 1.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Jiangsu | 1.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Zhejiang | 1.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Anhui | 1.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Fujian | 1.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Jiangxi | 0.93 | 0.00 | 0.00 | 0.00 | 0.25 | 0.00 | 0.21 | 0.01 | 0.00 | 0.00 | 0.00 |
| Shandong | 1.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Henan | 1.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Hunan | 1.00 | 0.45 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Guangxi | 1.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Sichuan | 1.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Guizhou | 1.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Yunnan | 1.00 | 0.05 | 0.00 | 0.00 | 0.02 | 0.00 | 0.02 | 0.00 | 0.00 | 0.22 | 0.00 |
| Shanxi | 0.97 | 0.00 | 0.17 | 5.97 | 0.00 | 0.12 | 0.00 | 0.00 | 0.00 | 1.42 | 0.01 |
| Gansu | 0.99 | 2.63 | 0.04 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 51.98 | 0.00 |

**Table 9.3** Emission reduction cost of 300 MW generating units

| Carbon price (yuan/t$CO_2$) | Percentage of paid allowances | | | | Overall cost (yuan) |
|---|---|---|---|---|---|
| | 3% | 5% | 10% | 100% | |
| 5 | 38 | 63 | 125 | 1251 | 1,094,210,000 |
| 60 | 451 | 751 | 1502 | 15,017 | 1,094,210,000 |
| 120 | 901 | 1502 | 3003 | 30,035 | 1,094,210,000 |

$\theta_1 = \theta_2 = \theta_{21} = \theta_{26} = 1$, $s_1^- = s_2^- = s_{21}^- = s_{26}^- = 0$, $s_1^+ = s_2^+ = s_{21}^+ = s_{26}^+ = 0$; therefore, $DMU_2$ (Beijing), $DMU_4$ (Hubei), $DMU_5$ (Shenzhen), and $DMU_7$ (Chongqing) have DEA efficiency ($C^2GS^2$), i.e., maximized output in contrast to input, and all of them lie at efficient production frontier.

As for the ETS in Guangdong, Shanghai, and Tianjin, they have input–output slack variable >0, indicating that the efficiency of both input and output shall be improved. Among the 19 DMUs, 11 have DEA efficiency, 6 have non-DEA efficiency, and 2 have weak DEA efficiency. The efficiency value of non-DEA efficiency is $\theta_1 < 1$, indicating that Hebei, Shanxi, Liaoning, Jiangxi, Shaanxi, and Gansu are now at the stage of progressively increasing scale. The ETS in Hunan and Yunnan have technical efficiency and weak DEA efficiency (Figs. 9.1 and 9.2).

Through analysis of the ETS operational efficiency of 26 DMUs, we found that Guangdong ETS had non-DEA efficiency over 2013–2014, which exhibits in the following three aspects:

(1) The $CO_2$ emissions covered by Guangdong ETS are overly high. In 2013, the regulated emissions accounted for 54% of Guangdong total emissions, and 12% points higher than the optimal efficiency point;
(2) In case of a high coverage of $CO_2$ emissions, the fines for excessive emissions will be on the high side, which further lowers allowance allocation efficiency. Through comparisons, we find that at the state of optimal efficiency, the fines for excessive emissions are around 37 yuan/t. In light of the carbon trading implementation plan of Guangdong, if an ETS-regulated company has excessive emissions, an amount of allowances that are twice more than the extra portion of emissions will be deducted from its next year's total allowances; in other words, it will be imposed a fine at 88 yuan/t which is two times more than carbon price and remarkably higher than efficiency value;
(3) Under the scenario that Guangdong ETS targets to reduce carbon intensity by 33%, covered enterprises will find the decline rate in emission reduction cost

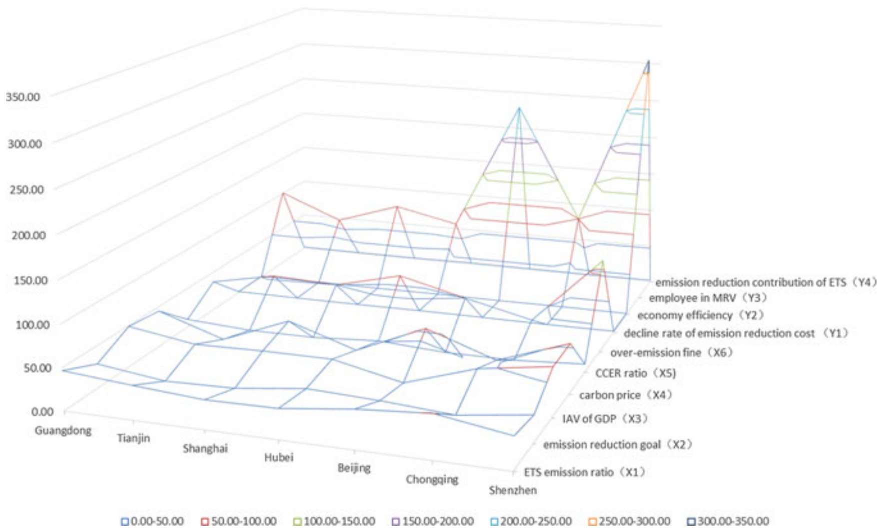


**Fig. 9.1** Efficient production frontier of ETS operational efficiency of seven pilot areas

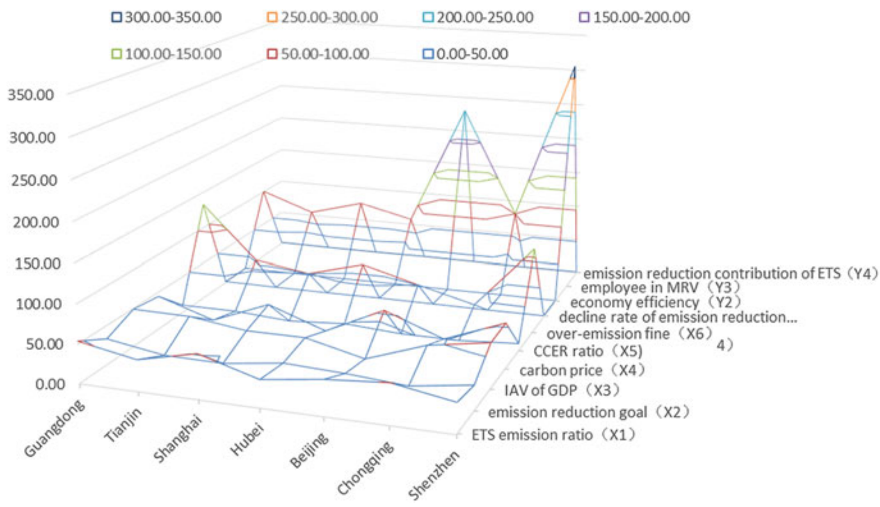


**Fig. 9.2** Actual efficiency of seven pilots ETS

and economic efficiency deviate from efficiency value. The carbon intensity is about to be cut by 21.5%, then there will be higher economic efficiency (Fig. 9.3).

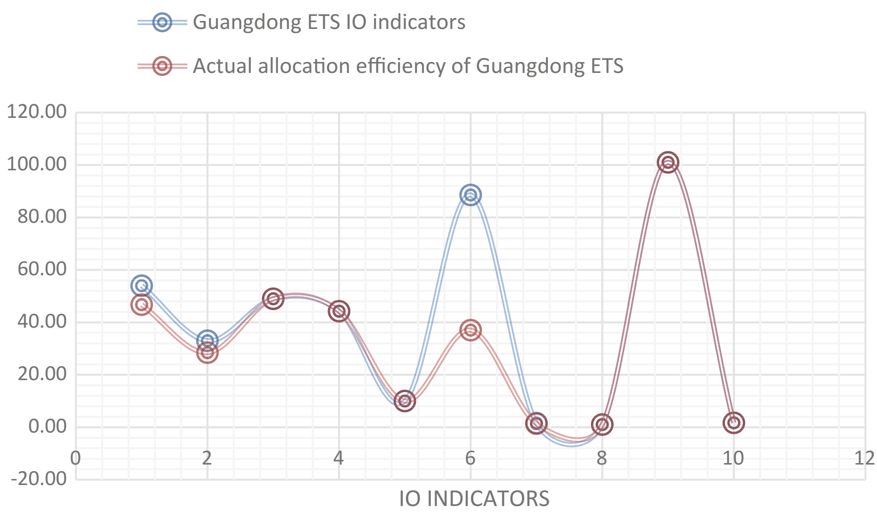


**Fig. 9.3** Comparison between Guangdong ETS actual allocation efficiency and efficient production frontier

### 9.1.6 Analysis and Suggestions

Regarding the influencing factors of ETS operational efficiency, the quantity of regulated emissions, upper limit of emission allowances, covered enterprises' profitability and potentials in emission reduction play a crucial role in determining ETS operational efficiency. ETS operational efficiency is determined by its input–output scale and various factors, meaning that the operational efficiency of DMU is affected by various factors. For some DMUs, their regulation coverage is so wide that weighs on operational efficiency; for others, the covered enterprises are bearing overly high task for cutting emissions, which presses down the efficiency; or some loose allowance supply which is hard to restrict emissions.

Various input factors are closely correlated and interlocked, which means that an adjustment of the appropriateness of an input factor is related to other factors, there shall be no horizontal comparison of single factors or placing it under standardized processing. Take Guangdong and Chongqing, for instance, their ETS has similar input factors, and input–output value exceeding the average level, but Chongqing ETS has DEA efficiency, while Guangdong ETS has efficiency loss since it covers a large quantity of emissions. For the ETS of Guangdong and Chongqing, their regulated emissions account for more than 50% of local total emissions, and they have the same-level carbon prices and IVA of regulated companies, but as for the fines for over emissions, Guangdong ETS is twice more than Chongqing ETS, such a severe penalty deviates Guangdong ETS operational efficiency from its optimal scale. Therefore, all input factors of ETS are mutually confined and linked, so the ETS design shall closely focus on the characteristics of covered enterprises, and prepare for scale design of input factors (Fig. 9.4).

Percentage of CCER is closely related to allowance price, the percentage of available CCER is better adjusted down. Owing to sufficient supply and lower emission reduction cost, CCER price is usually lower than the allowance price. In a relatively closed market, if covered enterprises are able to buy a large quantity of CCER, they will have less demand for allowances, which will then bring down allowance price. Gloomy allowance price is sure to hold back the ETS from exhibiting its intrinsic advantage in saving emission reduction cost, because the companies that are highly potential in cutting emissions will lack motivation in investing emission reduction technologies or selling allowances amid low carbon prices, while the companies that are less potential in cutting emissions may purchase CCER for compliance in case of inadequate allowances, which will discount the ETS advantages and meaning of existence. Table 9.2 demonstrates that the ETS of Tianjin and Shanxi has a lower percentage of CCER projection value than its designed value at efficient production frontier. As mentioned above, a wholly applicable percentage of CCER does not exist, but it is feasible to adjust down (rather than instead of vice versa) such percentage.

The emissions covered by the ETS shall be no more than 50% of local total emissions at the preliminary stage. The emission reduction tasks assigned to the covered enterprises shall be properly designed in light of their characteristics,

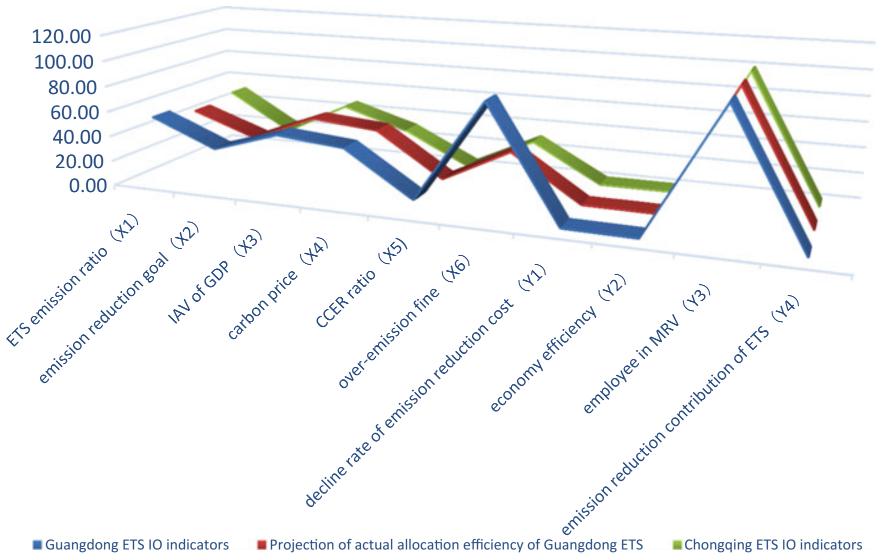


**Fig. 9.4** Comparison between Guangdong and Chongqing ETS IO indicators

safeguard their normal development while urging them to save energy and cut emissions, so as not to dampen local economic growth.

Link allowance administration with CCER offset mechanism, i.e., in case of tight allowance supply, allow the covered enterprises are to turnover more CCER for offsetting their emissions; conversely, adjust down the percentage of available CCER. Set up an allowance reserve, motivate third-party institutions to join in the ETS so as to vitalize the carbon market.

In case the regulated industrial sectors function as an economic pillar of a given area, the upper limit on $CO_2$ emissions (emission reduction rate) should not be too tight, otherwise, it may discourage the sustainable development of local economy.

Any excessive emission shall be fined to demonstrate the deterrent effect of the ETS. In this sense, severe punishment helps to achieve the ETS objectives. However, when the ETS covers a large quantity of emissions, sets a tight upper limit on total emissions and has low percentage of available CCER, then the penalty mechanism for excessive emissions will not only be the sword of Damocles, but a sharp device for increased cost in emission compliance. An overly high amount of fine may inflict development of the real economy.

Fostering new economic growth, especially developing low-carbon service sector, is another important function of ETS. The operation of ETS calls for a large number of MRV institutions and professionals, which will create job opportunities and optimize local economic structure. Theoretically, more employees working for MRV prove that ETS is able to promote the development of the local low-carbon sector. But the employment scale of MRV differs among different areas with disparate labor cost, because the expenses on MRV are finally borne by the companies under verification. For the central and western regions where the per capita wage is relatively low, more personnel shall be trained to join in MRV; moreover, most of the employees in these regions lack of advanced knowledge or technical skills, cultivating more professional verifiers is able to enhance the accuracy of verification. For the eastern and other developed provinces, the scale of MRV should not be too large.

## 9.2 Impact of Allowance Allocation on Companies' Cost and Economic Efficiency

Under the condition of limited $CO_2$ emission space, the emission allowance allocation is actually a distribution of potential resources and wealth, which will exert an impact on macro-economy and companies' production cost from different dimensions. The design of the emission allowance allocation system shall take account of local emission reduction target, industry development demand, energy consumption mix, companies' technical strength and bearing capacity. Companies, being micro-economic agent, are the most directly under the impact from emission allowance allocation. Therefore, this section focuses on evaluating the impact of Guangdong ETS emission allowance allocation on companies' cost and economic efficiency [13].

### *9.2.1 Comparative Analysis of Companies' Operational Cost*

The electricity and heat generation–supply sector (hereinafter briefed as "electricity sector") is a dominant GHG emitter and also a major ETS-regulated object. So all of the seven ETS pilot areas have included electricity sector into their regulation, and a study focused on this sector is widely representative. This sector, with Guangdong-based coal-fired electricity generating units as study samples, will evaluate the impact of the emission allowance allocation system on companies' economic efficiency, and sum up the crucial factors of the system that impact companies' operational cost.

There are four types of coal-fired generating units that are regulated by Guangdong ETS: <300, 300, 600, and 1000 MW. The $CO_2$ emissions from these four generating units were used as a benchmark for defining the allowances for Guangdong's total regulated coal-fired generating units in 2013. The 300 MW generating units have the largest number, the 600 MW generating units have the largest aggregated installed capacity; both the quantity and aggregated capacity of 1000 MW generating units are on the rise; the generating units less than 300 MW are being phased out. As such, the 300, 600, and 1000 MW generating units become study sample in this section. With a view to actual production, the power plants, for the sake of stable production and maximized efficiency, usually operate two generating units or more at the same time; and the production parameters and cost of the two generating units are assessed together. Therefore, in this sector, we make two generating units as one analytical unit for evaluating the ETS impact on the production cost of power plants.

(1) Operational cost breakdown of Guangdong-based regulated electricity companies

Our research team investigated the $CO_2$ emissions from Guangdong-based power plants, and consulted with the *Reference Construction Cost Index for Quota Design of Fossil Fuel-based Power Plant projects*, and found out that in 2014 the coal prices were about 800 yuan/tce, the limestone prices were about 100 yuan/t, the annual utilization hours of generating units were 4500 h, the electricity price was 0.502 yuan/kWh, the economic operational cycle of power plants were 20 year, the loan accounted for 80% of total static investment, the loan term averaged at 15 year, the loan interest rate averaged at 6.55%, the depreciable life was 15 year and the residuals rate was 5%, insurance and reparation expenses, respectively, held 0.25 and 2% of total investment, the employees' average wage was around 50,000 yuan/year (plus an additional 60% of welfare). The working efficiency of the sample generating units is an average efficiency of homogeneous generating units, the coal consumption per unit electricity output is converted from the benchmark value of allowances.

Power plants with 2 × 300 MW generating units: unit investment of 4394 yuan/kW; number of employees at about 234; material expense at about 6 yuan/kWh; other expenses at about 12 yuan/kWh; limestone consumption at 8 t/h (sulfur content of coal at about 2%); discharging fee of $SO_2$, $NO_X$ and dust was, respectively, 1.43 million yuan/year, 1.62 million yuan/year, and 80,000 yuan/year. Based on our estimation, such power plants have an overall cost of about 1094.21 million yuan.

Power plants with 2 × 600 MW generating units: unit investment of 3367 yuan/kW; number of employees at about 247; material expense at about 5 yuan/kWh; other expenses at about 10 yuan/kWh; limestone consumption at 16 t/h (sulfur content of coal at about 2%); discharging fee of $SO_2$, $NO_X$ and dust was, respectively, 2.60 million yuan/year, 2.93 million yuan/year and 150,000 yuan/year. Based on our estimation, such power plants have an overall cost of about 1913.10 million yuan.

Power plants with 2 × 1000 MW generating units: unit investment of 3334 yuan/kW; number of employees at about 300; material expense at about 4 yuan/kWh; other expenses at about 8 yuan/kWh; limestone consumption at 8 t/h (sulfur content of coal at about 0.9%); discharging fee of $SO_2$, $NO_X$ and dust was, respectively, 3.60 million yuan/year, 4.10 million yuan/year and 240,000 yuan/year. Based on our estimation, such power plants have an overall cost of about 3032.55 million yuan.

The cost breakdown of the above three generating units is respective shown in Figs. 9.5, 9.6 and 9.7:

As shown in the above figures, the expenses on coal, depreciation, loan interest, reparation, and other items account for more than 95% of power plants' overall cost. Among all cost items, the expenses on coal rank first, which are about

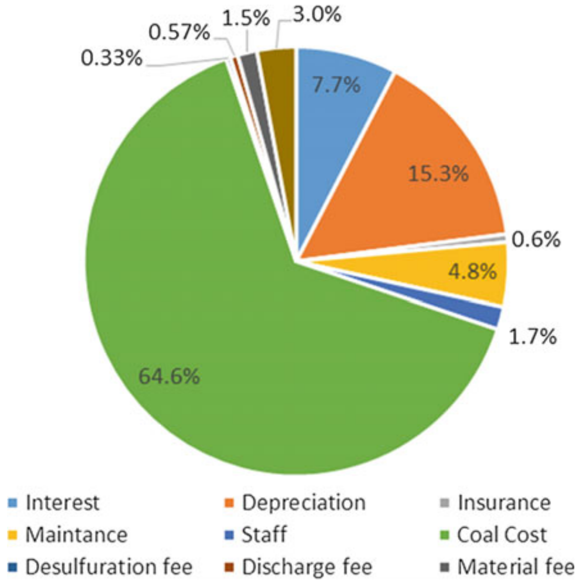


**Fig. 9.5** Cost breakdown of 300 MW generating units

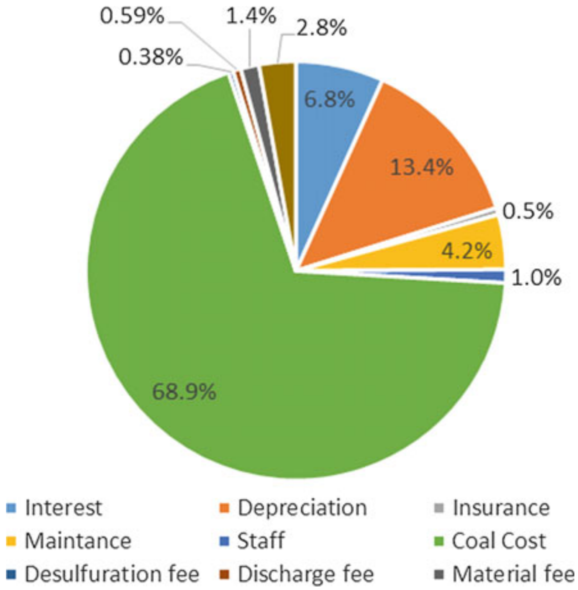


**Fig. 9.6** Cost breakdown of 600 MW generating units

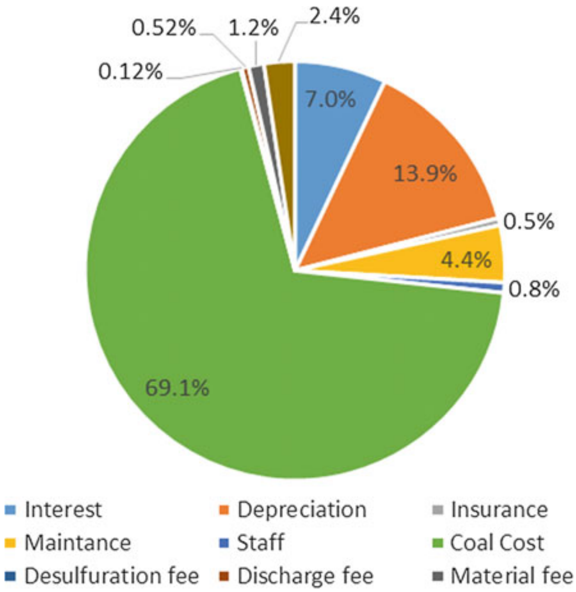


**Fig. 9.7** Cost breakdown of 1000 MW generating units

two-thirds of overall cost, indicating that coal consumption quantity and coal price are key factors that determine production cost of power plants. Along with expanding installed capacity, the marginal cost for labor force, material and administration has been decreasing progressively under the scale effect. Moreover, since the 1000 MW generating units require higher for feed coal quality (with much lower sulfur content), the percentage of desulfurization and discharge expenses are significantly lower than the other two generating units. However, coal consumption has kept increasing, holding an increasing share in the overall cost.

(2) Impact of allowance administration on the cost of Guangdong-based regulated electricity companies

Being an external environmental governance mechanism, ETS will bring a series of influences, both short term and long run, on covered enterprises. These companies may receive benefit from carbon trading, but pay for extra expenses in the meantime. In the short term, the companies have to increase manpower and material resources for making accounting of carbon emissions and taking care of carbon assets; purchase additional allowances if their actual emissions are much higher; or sell surplus allowances to gain profit in case of significant emission reductions, so as to offset all or partial of reduction cost. Different allowance allocation plans will incur different compliance costs upon covered enterprises. If 100% of the allowances are allocated for free, and the allowance benchmark is industrial average emissions, the ETS will exert a small impact on the cost of the power plants with production efficiency on industry average, such impact is almost ignored. While the emission administration is going deeper and carbon emissions are about to enter the peak time, the upper limit on aggregate emissions tends to be tightened, so as to ensure the fulfillment of the established reduction target. Meanwhile, the total amount of allowances shall be strictly managed. When the allowance benchmark remains unchanged, the percentage of free allowances shall be reduced; in this case, for the covered enterprises, if their quantity of emissions remains unchanged or the emission cutbacks are lower than the reduction in allowances, they have to purchase additional allowances from government or market, which will, of course, increase their cost.

In light of Guangdong carbon emission allowance allocation plans, and based on the study samples of selected power plants, we analyzed the impact of ETS on their production cost under different scenarios. We made the following assumptions:

(i) The emission reduction cost discussed in this section is limited to the direct expenses for the purchase of allowances, while disregard of such invisible cost for manpower and material resources injected into carbon trading;

(ii) Regarding the study samples, the energy consumption for electricity generation is an average level of the same generating units. When the allowance benchmark is based on the average energy consumption of the same generating units, the total allowances granted to the companies shall be equal to their actual emissions;

(iii) If the free allowances are lower than companies' actual emissions, they have to adopt certain emission reduction technologies to cut emissions or purchase additional allowances on market in order to fulfill their reduction obligation. But they have to pay for the expenses no matter what option they choose. There are diversified emission reduction technologies, which complicate the cost accounting, so we prefer estimating their reduction cost from the purchase of additional allowances;

(iv) The *Interim Measures for Carbon Emissions Administration in Guangdong Province* state that "the emission allowances granted to covered enterprises/institutions are based on free and paid allocation, with the percentage of free allocation reduced gradually," "electricity companies will receive 95% of free allowances, while iron and steel, petrochemical and cement companies will receive 97% of free allowances separately." In reference to the foreign experiences, e.g., EU ETS cancels free allowances to electricity sector (during Phase 2 and 3), and US RGGI never distributes allowances to electricity sector for free, so we estimate that Guangdong will gradually cut the percentage of free allowances, the electricity companies will have to buy 3, 5, 10, and 100% of allowances step by step;

(v) In 2013, Guangdong set the carbon price at 60 yuan/t$CO_2$ for auction. The carbon prices vary greatly among the seven pilot areas, some top at 120 yuan/t$CO_2$ (China Shenzhen Emission Exchange), while some lower at 5 yuan/t$CO_2$ (Shanghai Environment and Energy Exchange). As for Guangdong-based electricity companies, the carbon prices for different scenarios are set as 5, 60, and 120 yuan/t$CO_2$.

In light of the above assumptions and the characteristics of electricity sector, we developed a formula for calculating the emission reduction cost:

$$\text{Emission-reduction cost} = \text{installed capacity} \times \text{generating hours} \times \text{allocation benchmark} \times \text{percentage of paid allowances} \times \text{carbon price}$$

The computed emission-reduction costs of the above-mentioned three generating units are shown in Tables 9.4 and 9.5 and Figs. 9.8, 9.9, and 9.10.

**Table 9.4** Emission reduction cost of 600 MW generating units

| Carbon price (yuan/t$CO_2$) | Percentage of paid allowances | | | | Overall cost (yuan) |
|---|---|---|---|---|---|
| | 3% | 5% | 10% | 100% | |
| 5 | 70 | 117 | 234 | 2336 | 1,913,100,000 |
| 60 | 841 | 1401 | 2803 | 28,026 | 1,913,100,000 |
| 120 | 1682 | 2803 | 5605 | 56,052 | 1,913,100,000 |

**Table 9.5** Emission reduction cost of 1000 MW generating units

| Carbon price (yuan/t$CO_2$) | Percentage of paid allowances | | | | Overall cost (yuan) |
|---|---|---|---|---|---|
| | 3% | 5% | 10% | 100% | |
| 5 | 111 | 186 | 371 | 3713 | 3,032,550,000 |
| 60 | 1337 | 2228 | 4455 | 44,550 | 3,032,550,000 |
| 120 | 2673 | 4455 | 8910 | 89,100 | 3,032,550,000 |

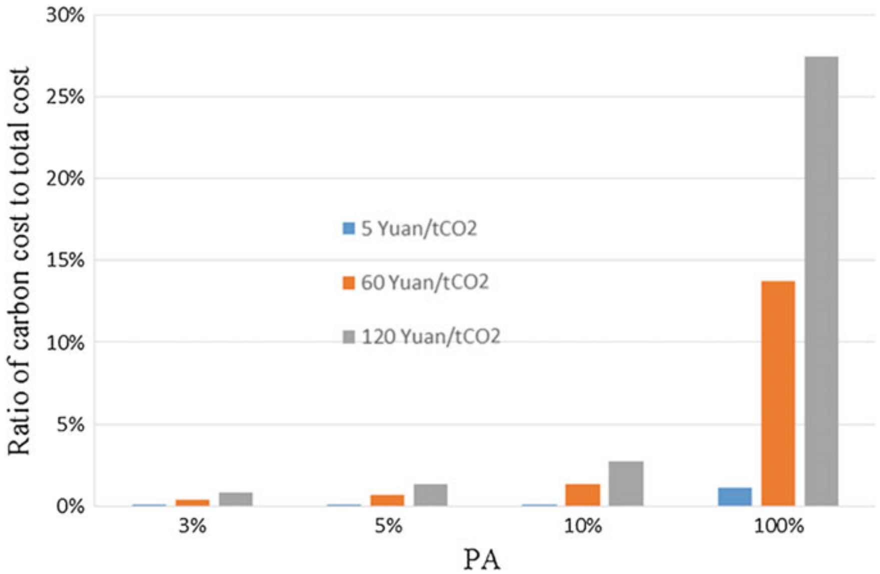


**Fig. 9.8** Share of emission reduction cost in overall cost of 300 MW generating units

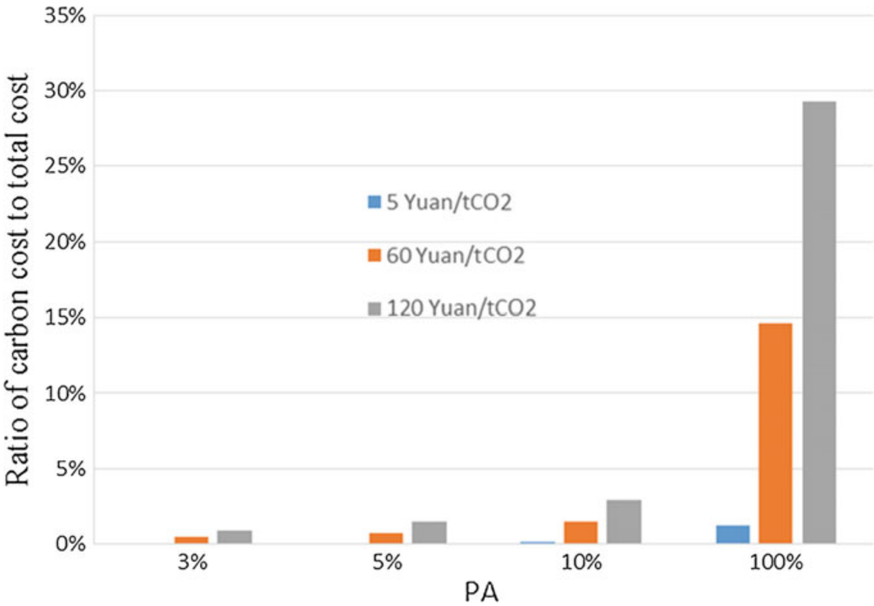


**Fig. 9.9** Share of emission reduction cost in overall cost of 600 MW generating units

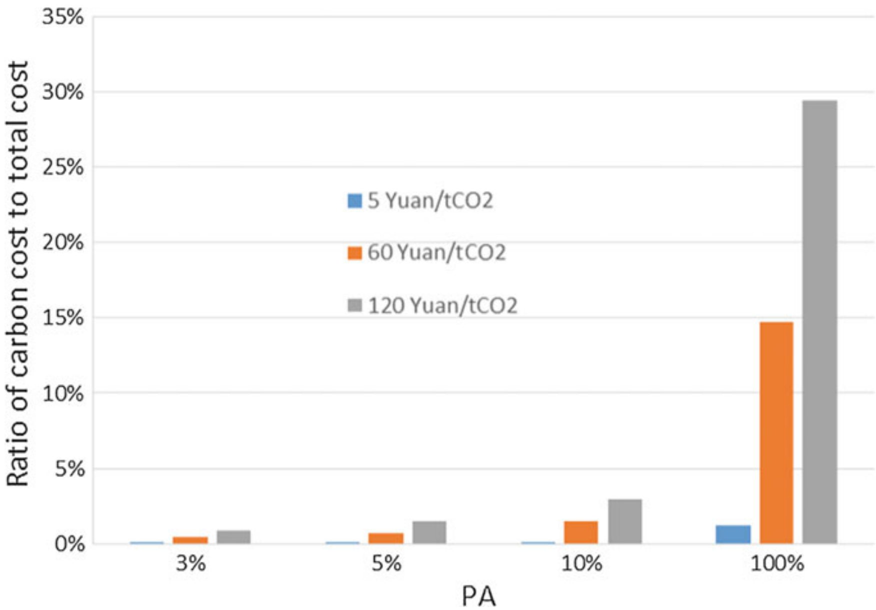


**Fig. 9.10** Share of emission reduction cost in overall cost of 1000 MW generating units

We can draw up the following conclusions from the above emission reduction costs:

In case of low carbon price (5 yuan/t$CO_2$), the emission reduction cost accounts for a small share in overall electricity generation cost. Even if the company has to buy 100% of allowances, the emission reduction cost only holds around 1% of the overall cost, indicating that the ETS is of limited impact on the overall cost of electricity companies.

In case of high carbon price (120 yuan/t$CO_2$), the emission reduction cost accounts for a larger share in overall electricity generation cost. If the company has to pay for 3% of allowances, the emission reduction cost only holds around 1% of the overall cost; if the company buys 100% of allowances, then the share of the emission reduction cost will rise to one-third, becoming the second largest cost item next to coal consumption, indicating that the ETS is of significant impact on the overall cost of electricity companies. It can be seen that the impact of ETS on the cost of companies is closely related to the carbon price and amount of free allowances. When the level of emissions is fixed, less free allowances will force the companies to buy more allowances; at this point, the expenses on allowances are decided by carbon price: low carbon price saves the emission reduction cost and exerts limited impact on companies' overall cost; on the contrary, high carbon price greatly affects companies' overall cost. In the case of high carbon prices and the company needs to buy a large quantity of allowances, its production cost will increase sharply, which may even alter its production decisions. In light of the Guangdong allowance allocation plan, the electricity companies only access to a certain portion of free allowances, they have to pay for an additional 3–5% allowances. The carbon price in 2013 and 2014 start was set at around 60 yuan/t$CO_2$. Based on such price and the demand for allowances, for Guangdong-based regulated electricity companies, their emission reduction cost accounts for around 0.5% of their overall cost, such proportion levels off that of desulfurization and discharge expenses, which is of limited impact on their overall cost.

Since electricity sector is the largest emitting source, their free allowances are less than the other three sectors. The ETS-based cap on total allowances may have the most significant impact on the electricity sector. Based on the above analysis, under Guangdong ETS framework, electricity companies have to pay for certain emission reduction cost, which is of limited impact on their overall cost. Such conclusion accords with our investigations of Guangdong-based electricity companies.

### *9.2.2 Impact on IRR of Generating Units*

Subsection 9.2.1 analyzes the static impact of emission reduction cost on companies' overall cost. For understanding the dynamic impact of emission reduction cost on the entire production cycle, we hereby use Internal Rate of Return (IRR) to compare and analyze the changes on IRR of the power plants with three types of generating units (2 × 300 MW, 2 × 600 MW, 2 × 1000 MW) based on the assumptions (i), (ii), and (iii) in Subsect. 9.2.1, in an aim to find the acceptable emission reduction cost which sustains normal profitability of different power plants. In order to gain an insight into the ETS impact on companies' economic benefit under different upper limits on carbon emissions, we split the percentage of paid allowances into seven grades (3, 5, 10, 20, 30, 50, and 100%) and divide the carbon prices into 36 multistep prices from 5 to 300 yuan/t$CO_2$, i.e., a price range split by 5 yuan/t$CO_2$ below 60 yuan/t$CO_2$ and a price range split by 10 yuan/t$CO_2$ above 60 yuan/t$CO_2$.

Based on above-mentioned parameters of generating units, we estimated the cash inflow and outflow of the electricity companies within their operating cycle, and then used EXCEl tools to figure out the IRR of different power plants (2 × 300 MW, 2 × 600 MW, 2 × 1000 MW) without ETS, i.e., 8.72, 15.58, and 17.65%. According to the *Reference Construction Cost Index for Quota Design of Fossil Fuel-based Power Plant projects*, the Baseline IRR of fossil fuel-based power plants is 8%, which is to say that if IRR > 8%, the power plant has economic viability. This shows that, without emission reduction cost, these power plants have an IRR > 8%, which is worthy of investment. In contrast, the implementation of ETS incurs emission reduction cost upon the power plants and affects their IRR. Based on different carbon prices and percentage of paid allowances, we compared calculated and analyzed the changes in IRR of these power plants.

In light of the assumed percentage of paid allowances (PA) and carbon prices, we can figure out the emission reduction cost of a power plant under a given situation. Based on the increase in emission reduction cost and changes on cash flow, we can compute the IRR of this power plant under such scenario. See the calculation results in Tables 9.6, 9.7, and 9.8.

Tables 9.6, 9.7, and 9.8 demonstrate that for the power plants with 300 MW generating units, in case of PA = 3%, carbon price >180 yuan/t$CO_2$; PA = 5%, carbon price >110 yuan/t$CO_2$; or PA = 10%, carbon price >55 yuan/t$CO_2$, their IRR is lower than Baseline IRR. In another case, for the power plants (600 and 1000 MW), based on PA = 3%, PA = 5% or PA = 10%, even if the carbon price is as high as 300 yuan/t$CO_2$, their IRR is much higher than the Baseline IRR.

In case of PA = 20%, carbon price >262 yuan/t$CO_2$, the 600 MW power plants have an IRR lower than the Baseline IRR, but the 1000 MW power plants still have economic viability. In case of PA = 30%, carbon price >236 yuan/t$CO_2$, the 1000 MW power plants will have an IRR lower than the Baseline IRR.

In case of PA = 100%, the 300 MW power plants (carbon price > 5.5 yuan/t$CO_2$), 600 MW power plants (carbon price > 52 yuan/t$CO_2$) and 1000 MW power plants (carbon price > 71 yuan/t$CO_2$) will have an IRR lower than the Baseline IRR and lost economic viability.

Through illustration of the changes on IRR based on different PA–carbon price portfolios, we have funded the relationship between carbon price, the percentage of paid allowances, and IRR, which reflect the ETS impact on companies' IRR.

Figures 9.11, 9.12, and 9.13 demonstrate that companies' IRR declines along with increasing emission reduction cost.

**Table 9.6** IRR of 300 MW generating units with varied PA and carbon price portfolios

| Carbon price (yuan/ $tCO_2$) | IRR | | | | | | |
|---|---|---|---|---|---|---|---|
| | PA = 3% | PA = 5% | PA = 10% | PA = 20% | PA = 30% | PA = 50% | PA = 100% |
| *5* | *8.7%* | *8.7%* | *8.7%* | *8.6%* | *8.5%* | *8.4%* | *8.1%* |
| 10 | 8.7% | 8.7% | 8.6% | 8.5% | 8.3% | 8.1% | 7.4% |
| 15 | 8.7% | 8.6% | 8.5% | 8.3% | 8.1% | 7.7% | 6.7% |
| 20 | 8.6% | 8.6% | 8.5% | 8.2% | 7.9% | 7.4% | 6.0% |
| 25 | 8.6% | 8.6% | 8.4% | 8.1% | 7.7% | 7.1% | 5.3% |
| 30 | 8.6% | 8.5% | 8.3% | 7.9% | 7.5% | 6.7% | 4.5% |
| 35 | 8.6% | 8.5% | 8.3% | 7.8% | 7.3% | 6.4% | 3.7% |
| 40 | 8.6% | 8.5% | 8.2% | 7.7% | 7.1% | 6.0% | 2.9% |
| 45 | 8.5% | 8.4% | 8.1% | 7.5% | 6.9% | 5.6% | 2.1% |
| 50 | 8.5% | 8.4% | 8.1% | 7.4% | 6.7% | 5.3% | 1.2% |
| 55 | 8.5% | 8.4% | 8.0% | 7.3% | 6.5% | 4.9% | 0.2% |
| 60 | 8.5% | 8.3% | 7.9% | 7.1% | 6.3% | 4.5% | -0.8% |

*Note* The figures (italic) represent the PA–carbon price portfolio under the scenario IRR > 8%

**Table 9.7** IRR of 600 MW generating units with varied PA and carbon price portfolios

| Carbon price (yuan/ $tCO_2$) | IRR | | | | | | |
|---|---|---|---|---|---|---|---|
| | PA = 3% | PA = 5% | PA = 10% | PA = 20% | PA = 30% | PA = 50% | PA = 100% |
| *5* | *15.6%* | *15.5%* | *15.5%* | *15.4%* | *15.4%* | *15.2%* | *14.9%* |
| *10* | *15.5%* | *15.5%* | *15.4%* | *15.3%* | *15.2%* | *14.9%* | *14.2%* |
| *15* | *15.5%* | *15.5%* | *15.4%* | *15.2%* | *15.0%* | *14.6%* | *13.5%* |
| *20* | *15.5%* | *15.4%* | *15.3%* | *15.0%* | *14.8%* | *14.2%* | *12.8%* |
| *25* | *15.5%* | *15.4%* | *15.2%* | *14.9%* | *14.6%* | *13.9%* | *12.1%* |
| *30* | *15.5%* | *15.4%* | *15.2%* | *14.8%* | *14.4%* | *13.5%* | *11.4%* |
| *35* | *15.4%* | *15.3%* | *15.1%* | *14.6%* | *14.2%* | *13.2%* | *10.7%* |
| *40* | *15.4%* | *15.3%* | *15.0%* | *14.5%* | *14.0%* | *12.8%* | *9.9%* |
| *45* | *15.4%* | *15.3%* | *15.0%* | *14.4%* | *13.7%* | *12.5%* | *9.2%* |
| *50* | *15.4%* | *15.2%* | *14.9%* | *14.2%* | *13.5%* | *12.1%* | *8.1%* |
| 55 | 15.4% | 15.2% | 14.8% | 14.1% | 13.3% | 11.8% | 7.6% |
| 60 | 15.3% | 15.2% | 14.8% | 14.0% | 13.1% | 11.4% | 6.7% |
| 70 | 15.3% | 15.1% | 14.6% | 13.7% | 12.7% | 10.7% | 5.0% |
| 80 | 15.3% | 15.0% | 14.5% | 13.4% | 12.3% | 9.9% | 3.1% |
| 90 | 15.2% | 15.0% | 14.4% | 13.1% | 11.8% | 9.2% | 0.9% |
| 100 | 15.2% | 14.9% | 14.2% | 12.8% | 11.4% | 8.0% | -1.6% |

*Note* The figures (italic) represent the PA–carbon price portfolio under the scenario IRR > 8%

**Table 9.8** IRR of 1000 MW generating units with varied PA and carbon price portfolios

| Carbon price (yuan/ $tCO_2$) | IRR | | | | | | |
|---|---|---|---|---|---|---|---|
| | PA = 3% | PA = 5% | PA = 10% | PA = 20% | PA = 30% | PA = 50% | PA = 100% |
| *5* | *17.6%* | *17.6%* | *17.6%* | *17.5%* | *17.5%* | *17.3%* | *17.0%* |
| *10* | *17.6%* | *17.6%* | *17.5%* | *17.4%* | *17.3%* | *17.0%* | *16.4%* |
| *15* | *17.6%* | *17.6%* | *17.5%* | *17.3%* | *17.1%* | *16.7%* | *15.8%* |
| *20* | *17.6%* | *17.5%* | *17.4%* | *17.1%* | *16.9%* | *16.4%* | *15.1%* |
| *25* | *17.6%* | *17.5%* | *17.3%* | *17.0%* | *16.7%* | *16.1%* | *14.5%* |
| *30* | *17.5%* | *17.5%* | *17.3%* | *16.9%* | *16.5%* | *15.8%* | *13.8%* |
| *35* | *17.5%* | *17.4%* | *17.2%* | *16.8%* | *16.3%* | *15.4%* | *13.1%* |
| *40* | *17.5%* | *17.4%* | *17.1%* | *16.6%* | *16.1%* | *15.1%* | *12.5%* |
| *45* | *17.5%* | *17.4%* | *17.1%* | *16.5%* | *15.9%* | *14.8%* | *11.8%* |
| *50* | *17.5%* | *17.3%* | *17.0%* | *16.4%* | *15.8%* | *14.5%* | *11.1%* |
| *55* | *17.4%* | *17.3%* | *17.0%* | *16.3%* | *15.6%* | *14.1%* | *10.4%* |
| *60* | *17.4%* | *17.3%* | *16.9%* | *16.1%* | *15.4%* | *13.8%* | *9.6%* |
| *70* | *17.4%* | *17.2%* | *16.8%* | *15.9%* | *15.0%* | *13.1%* | *8.0%* |
| 80 | 17.3% | 17.1% | 16.6% | 15.6% | 14.6% | 12.5% | 6.5% |
| 90 | 17.3% | 17.1% | 16.5% | 15.4% | 14.2% | 11.8% | 4.8% |
| 100 | 17.3% | 17.0% | 16.4% | 15.1% | 13.8% | 11.1% | 3.0% |
| 110 | 17.2% | 17.0% | 16.3% | 14.8% | 13.4% | 10.4% | 0.9% |
| 120 | 17.2% | 16.9% | 16.1% | 14.6% | 13.0% | 9.6% | -1.6% |

*Note* The figures (italic) represent the PA–carbon price portfolio under the scenario IRR > 8%

If PA = 3%, the IRR curve tilts slightly when carbon price <150 yuan/$tCO_2$, it still look likes a straight line, it does not tilt downwards until carbon price >150 yuan/$tCO_2$.
If PA = 5%, the IRR curve tilts slightly when carbon price <100 yuan/$tCO_2$, it does not tilt downwards until carbon price >100 yuan/$tCO_2$.
If PA > 10%, the slope of IRR curve changes notably along with rising carbon price.

The impact of ETS on IRR is related to the installed capacity of generating units. Our calculations show that the larger the installed capacity is, the smaller the IRR slope will be; a higher initial IRR (IRR without implementation of ETS) marks the company is able to bear higher emission reduction cost.

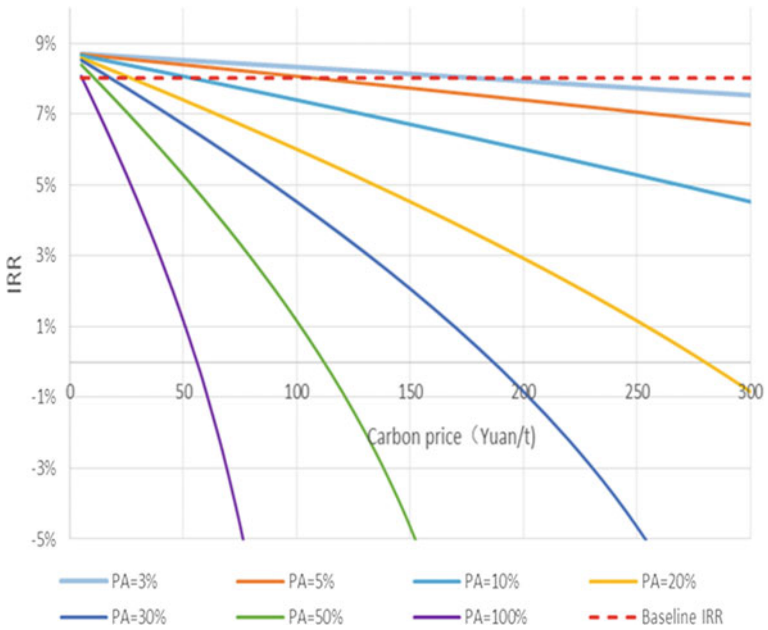


**Fig. 9.11** Impact of emission reduction cost on IRR of 300 MW power plants

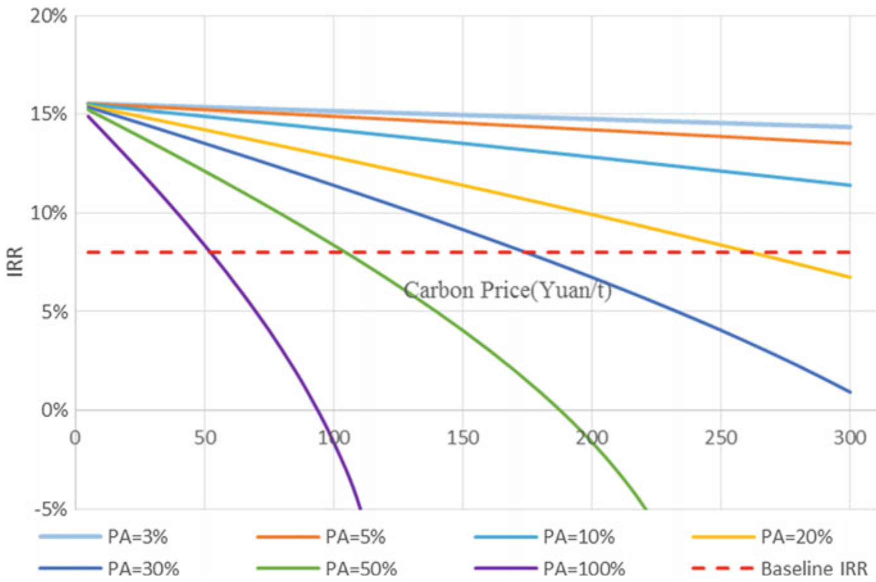


**Fig. 9.12** Impact of emission reduction cost on IRR of 600 MW power plants

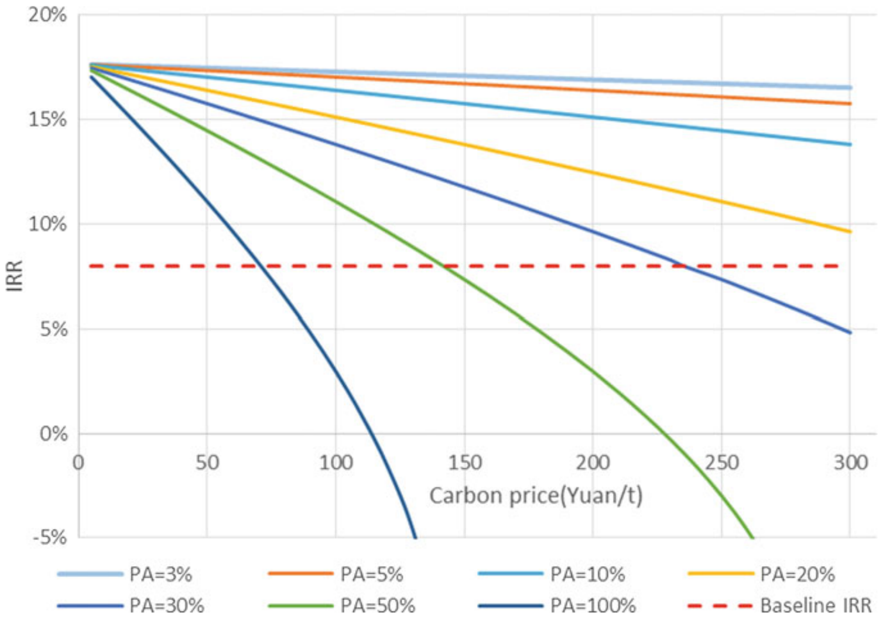


**Fig. 9.13** Impact of emission reduction cost on IRR of 1000 MW power plants

### *9.2.3 Critical Threshold of Electricity Companies for Bearing Emission-Reduction Cost*

In reference to the above analysis about the power plants (300, 600, and 1000 MW), given the paid allowances (PA) and carbon prices, the IRR of the three types of power plants can operate economically (IRR = 8%) and drew up Fig. 9.14 to exhibit the critical point where the emission reduction cost could affect companies' profitability.

For the 300 MW power plants, the PA–carbon price portfolios are set as (3%, 180 yuan/t$CO_2$), (5%, 110 yuan/t$CO_2$), (10%, 55 yuan/t$CO_2$), (20%, 27 yuan/t$CO_2$), (30%, 18 yuan/t$CO_2$), (50%, 11 yuan/t$CO_2$), and (100%, 5.5 yuan/t$CO_2$), and IRR as 8%. The dots on the curve indicate the maximized acceptable PA for maintaining IRR > 8% at a carbon price. The dots on the bottom left curve indicate the PA–carbon price portfolios, where the IRR > 8%; the dots on upper right curve indicate the PA–carbon price portfolios where the IRR < 8%.

By analogy, for the 600 MW power plants, the PA–carbon price portfolios are set as (20%, 262 yuan/t$CO_2$), (30%, 175 yuan/t$CO_2$), and (50%, 105 yuan/t$CO_2$), and IRR as 8%. For the 1000 MW power plants, the PA–carbon price portfolios are set as (30%, 236 yuan/t$CO_2$), (50%, 142 yuan/t$CO_2$), and (100%, 71 yuan/t$CO_2$), and IRR as 8%. Based on these dots, we are able to draw curves that depict the impact of emission-reduction cost on companies' economic efficiency (see Fig. 9.14).

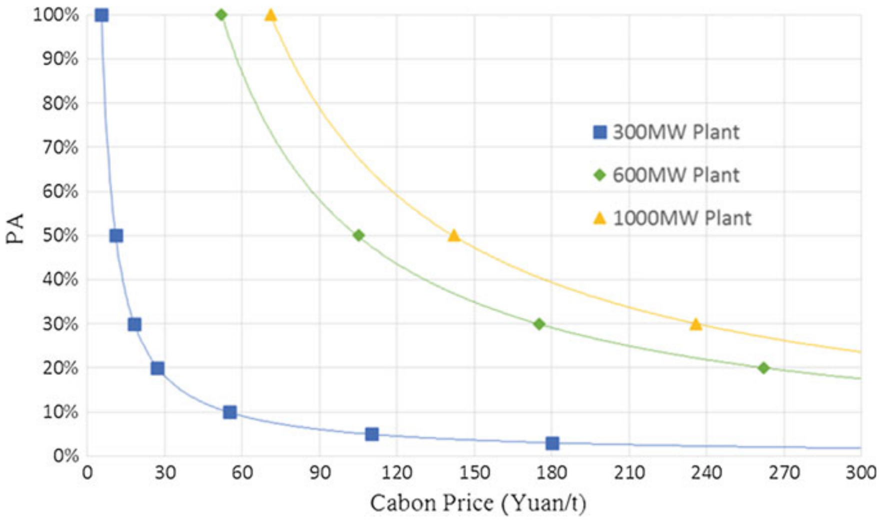


**Fig. 9.14** Bearable PA of different generating units

We can use the above curves to compare the impact of emission-reduction cost on different power plants with varied PA–carbon price portfolios. In order to sustain normal profitability in case of carbon price = 90 yuan/t$CO_2$, the 300 MW power plants can buy no more than 7% of allowances, such percentage for the 600 and 1000 MW power plants is 58 and 79%, respectively. If a power plant has to buy 30% of allowances and maintains profitability in the meantime, the 300 MW power plants can bear a carbon price at no higher than 20 yuan/t$CO_2$, such price for the 600 and 1000 MW power plants is 175 and 238 yuan/t$CO_2$, respectively.

Moreover, Fig. 9.14 also demonstrates that the power plants with smaller installed capacity and higher unit energy consumption are harder to maintain IRR > 8%, and weaker to bear high emission reduction cost. From 300 to 1000 MW, the generating units have increasing generation efficiency, and a critical curve farther away from the axis, a wider range of profitability, and stronger to bear high emission reduction cost. If carbon price $\leq 60$ yuan/t$CO_2$, the PA shall be lower than 10% to ensure economic viability of all generating units. Along with increasing carbon price, PA shall decrease accordingly.

The allowance allocation adopted by US RGGI is similar to the PA = 100% scenario discussed in this subsection. From 2010 to 2015, the average auction price set by RGGI was $1.86, $1.89, $1.93, $2.92, $4.72, and $6.10. Through comparison, we found that the RGGI auction prices at the preliminary stage are similar to the bearable carbon price (5.5 yuan/t$CO_2$) of Guangdong-based 300 MW power plants. From 2013 to 2015, the RGGI auction prices are similar to the bearable carbon price (52 yuan/t$CO_2$) of Guangdong-based 600 MW power plants. An evaluation report shows that the RGGI-regulated emissions over 2011–2013 dropped 19.8% from the 2006–2008 period, with unit emissions decreasing

141 $kgCO_2$/MWh. Such fact tells that within the RGGI framework, the unit emissions shall decrease along with an annual reduction in total emissions. As for Guangdong-based power plants (300, 600 MW), their unit emissions also demonstrate a year-on-year downward trend, which proves that our analysis of the bearable carbon price of power plants is reasonable on the whole.

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