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Redesigning a cap-and-trade program for air emissions by agent-based modeling

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Abstract

This paper establishes a virtual model based on the concept of agent-based method and cost-effectiveness analysis to determine the feasibility of reviewing and improving the cap-and-trade program, using the air emission program in Taiwan as a case study. We adjusted the emission baseline, reduction target proportion, and trading platform under the scheme and simulated the emission reduction and trading behavior of each type of pollutant in different cases.

Based on the comparative results of the modeling schemes analyzed in this paper, it is suggested that to improve the distribution of reduction targets without including trading systems can result in the most reduction amount in the study regions. Compared with an approach that includes a trading system, the proposed method provides a simple approach without any obvious increase in the reduction objects' average cost per unit of reduction. However, this approach makes it difficult for newly proposed investment projects to settle in the region to acquire the offset; therefore, an alternative measure should be designed for this purpose in such a case. When policy-makers default on making decisions based on air emission caps, a reduction scheme based on a supported trading system will be more adaptable for economic development. It is recommended to consider the maximum emission of the previous 7 years as a baseline, along with a trading platform, for making the market more effective and ensuring a smaller impact on the reduction target of the polluters.

Keywords: Air emission cap-and-trade program, Emission trading, Agent-based model, Cost-effectiveness analysis

1 Introduction

The air emission cap-and-trade program has been implemented in America for years, from the earliest "USEPA Acid Rain Program" issued in 1996 [1] for controlling over NO_x to the subsequent "New Source Review" "NO_x Budget Trading Programs," [2] "Clean Air Interstate Rule," and "Regional Clean Air Incentives Market" [3] that played a facilitating role. It has been widely popularized as a management strategy for preventing and controlling various pollutants, which shows that cap control is a cost-effective policy for reducing air pollution emissions, as they can be implemented with a trading market to encourage polluters to reduce emissions by themselves and improve air quality eventually.

In Taiwan, the air emission cap-and-trade program is implemented to control air pollution initially in 2015. According to the report issued by the Taiwan Environmental Protection Administration (TEPA) [4], the biggest problem with the air emission cap-and-trade program since its implementation across these regions to date is that despite a sufficient offset amount for the polluters to trade, the trading amount accounts for only 12% of the actual allowable offset amount since 2015. It can be seen that the polluters in question chose to reduce their emissions in response to the program rather than obtaining the credit to offset, indicating a failure of the trading market in executing its role as planned. It's important to find good methods that could review implementation of the cap-and-trade program for policy makers. So the

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aim of this paper is to build a method that could evaluate trading and reduction behavior of polluters in order to find planning ways of revising the program.

The previous economic models for the emission trading system were established using the top-down mathematical static analysis mode [5]. Scholars such as Hahn [6], Rose et al. [7], and Cramton and Kerr [8] have conducted relevant investigations on the initial distribution and application of emissions credit. However, instead of gradually analyzing with the dynamic viewpoint [9], this top-down holistic mathematical programming model only deals with the analysis results of some stage in the static state (economic equilibrium—the optimal point for supply and demand balance). Besides, to obtain the analytical solution, the heterogeneity of the research subject will be simplified dramatically, and the interaction effect will not be analyzed. The trading system pertains to the behavioral interaction relationship among agents and belongs to the dynamic and nonlinear complex system [10]. Therefore, recently, there are many relevant trading systems conducting studies by changing to the bottom-up methodology of Agent-based model (ABM) [11–13].

ABM has the feature that the agent studied has self-consciousness and behavior, which adopts the bottom-up mode for simulation. To understand and explore the influence of the behavioral pattern of the agent discussed in the system on the system environment, individual intelligent viewpoints have been produced, and the agents discussed in the system have been enabled to have self-behavior pattern so as to further conform to the scenario characteristics of a real system and develop the ABM theory [11].

Aiming at the discussion on the trading market system, ABM model focuses on how the trading decision behavior among traders affects the overall economic situation [11, 12]; it transforms from the rational solving and decision-making process with traditional mathematical functions into the process of regulating microscopic behavior of decision makers and participants for the trading market environment [13]. Compared with the mode of mathematical equations, the simulation system lays more emphasis on the heterogeneity of agents, whose macroscopic simulation results are determined by the individual behavior of these microscopic individuals [14].

For evaluating the effectiveness of trading market, while ABM can be set to provide elastic modes by virtue of adjusting the trading decision of traders [15], with the trading results being determined by both parties. Therefore, through discussion it is able to determine the influencing factors of trading system, for example, the influence of emissions credit distribution modes [16] and the influence of other supporting strategies such as trade fee and emission discharge fee [17, 18]; in addition to purely discussing the trading system market, the influence of the trading market on commodity economy market [19] and power supply market [20] can be further analyzed. It is also suggested to discuss the trading system utilizing the simulation results via scenario setting [21, 22].

However, these studies emphasize on the trading process and evaluate the efficiency of the trading market; they rarely discuss the efficiency of the cap-and-trade program rules. Moreover, polluters have rights to choose their baseline year and whom to deal with according to the rules of the cap-and-trade program in Taiwan. Therefore, in this paper, we used the bottom-up method to set the behavioral rules for the controlled industries with respect to their choice of the baseline year and their trading negotiation in order to simulate their decisions under the program in a way that was closer to what would happen in the real system. Moreover, this paper's aim is to develop a model to predict the emission reduction and trading behavior of polluters in different cases after adjusting the program setting, and evaluate trading and reduction status in order to find planning ways of revising the program, and compared the system with no trade allowed, which refers to a command-and-control measure. The structure of this paper is as follows. Section 2 describes study case and ABM methodology used to develop the model. Section 3 discusses and analyses the simulation results. Section 4 concludes with a summary of the main findings and recommendations for revising the cap-and-trade program and further research.

This paper aims to determine the feasibility for reviewing and improving the system further. The development of the modeling tools and methods discussed in this paper will facilitate policy makers to establish new methods when studying and discussing the methods for providing a sustainable development strategy for air quality management.

2 Materials

2.1 Study area

We chose the Kaohsiung and Pingtung regions, the first places to implement the air emissions cap-and-trade program in Taiwan, for the case study. Several important rules of this program in Taiwan are that the polluters' annual emission benchmark of SO_x, volatile organic compounds (VOCs), NO_x, and particulate matter (PM) would be chosen by themselves from any of the annual emissions in the previous 7 years. Then the polluters are requested to reduce at least 5% of the emission compared to the annual emission benchmark. If the polluters can't reduce more than the reduction goal, they have to purchase 1.2 times the reduction amount from others that own offset permits to offset the same pollutant (for example, offset permits of SO_x are limited to offset SO_x) [23].

2.2 Study methods and purpose

2.2.1 Model concept

The boundary of the system proposed in this paper included the Kaohsiung and Pingtung regions of Taiwan. In all, 557 polluters were managed by the program, including manufacturing industries, hospitals, waste treatment and recycled industries, among others, and we set these polluters as the agents. The collected data included emissions, industrial categories, and pollution control costs. The pollution emission data and the related information of the polluters were obtained from the TEPA open data [24], and the data on the marginal abatement cost was based on TEPA's related study report [25, 26] and the green national income account statistical tables in Taiwan [27]. We primarily collected the emission data and basic information of pollution source control in study cases of the region and set the judgment modes of behavior decisions before establishing the framework of ABM model (see Fig. 1).

Thereafter, we performed simulations under different situation settings, analyzed and discussed the influence of the implementation of cap-and-trade program, and further studied other recommended methods. The study process and mode architecture are shown in Fig. 2.

2.2.2 Settings of model simulation

In the first step, the model simulated that each polluter how to choose the annual emission benchmark and then calculated polluters' reduction or offset amounts. In the second step, the model considered that each polluter needed to reduce emissions as one opportunity to bargain. Before the bargain, each polluter did not have clear information about prices of the others' offset permits, so the model let the polluter find the three dealers at random to negotiate the trading price [28]. The detailed steps of the trading decision process are described below (details show in Fig. 2):

1. Step of evaluating the trading: The polluter evaluated trading is practicable when its marginal abatement cost (MAC) was higher than the sellers' offset permit price (equal to the sellers' MAC). Otherwise, if the polluter negotiated with the dealers whose offset permit prices were all higher than the polluter's MAC, the trading would not proceed.
2. Bargaining step: If the trade could proceed, the trading price (TPijk) was determined as somewhere between the polluter's MAC (MCik) and dealer's offset permit price (MCjk), and then the model simulated the offset amounts that could be traded.
3. Trading step: The model would calculate the total cost of each trade and then let the polluter trade with the dealer with the lowest trading cost. Based on the program rules, it restricted that polluters from purchasing 1.2 times the reduction amount to offset and let them purchase only the same pollutant of offset permits to offset. The polluter's total trading cost (TCijk) was calculated by the following equation:

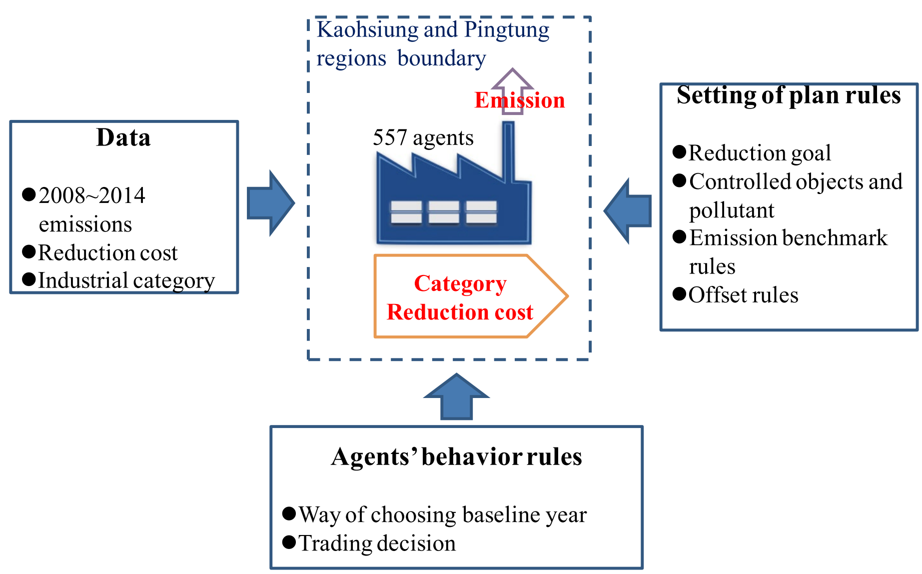

Fig. 1 Agent-based model's conceptual framework

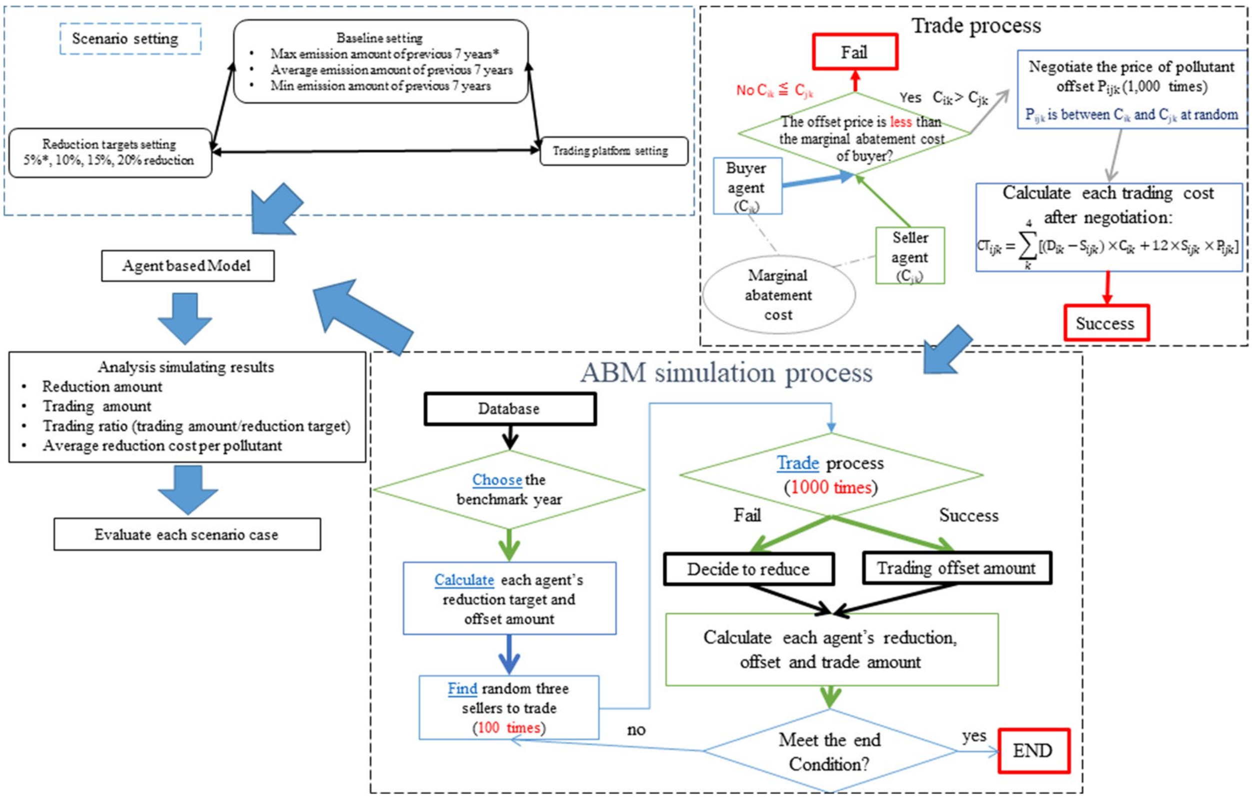

Fig. 2 Architecture of research and mode processes

$$TC_{ijk} = \sum_{k}^{4} \left[(DM_{ik} - SM_{ijk}) \times MC_{ik} + 1.2 \times SM_{ijk} \times TP_{ijk} \right]$$

where DM_{ik} was the pollutant reduction amounts of buyer, SM_{ijk} was buyers' purchased offset amounts for the pollutant from sellers, TP_{ijk} was the trading price of the pollutant by buyers negotiating with sellers, and MC_{ik} was buyers' MAC of the pollutant.

Because the random settings of the model, such as free opportunities of finding dealers to bargain with and negotiating the trading price, could lead polluters to bargain with different dealers and different trading prices. Those could cause different simulating results under the same settings. Thus, the model was modified to simulate each negotiation trading prices 1,000 times and each trade 100 times by the Monte Carlo method [29–31], and then calculated the average of each trading result to reduce the uncertainty and variance.

In the third step, each polluter made a decision between reducing its own emissions and trading with other polluters' offset amounts according to a cost-effectiveness analysis. Finally, the model calculated the emissions reduction and trading results, including its reduction, offset, and trade amounts.

2.2.3 Scenario settings

The current main settings of cap-and-trade program are emission benchmark, reduction target, and trading rules. To evaluate the direction of policy review, this paper utilized ABM to simulate the predicted results of the cap-and-trade program with adjustment of those settings and analyzed whether there are better ways for improvement. First, based on the current cap-and-trade program, the optional maximum emission of the previous 7 years was set as the approved amount. The reduction target could be easily achieved if the approved amount was higher and could be used to evaluate whether it would have any influence on the effect of the cap-and-trade program if the emission baseline was changed to the average emission of the previous 7 years or the minimum emission (the strictest) of the previous 7 years. Second, this model was also used to predict the influence of reduction and trade changes in the controlled regions under the assumed 5, 10, 15, and 20% reduction targets. Finally, we established a trading platform to improve trading system, so as to evaluate the impact effect in various scenarios and the recommended promotion methods. The descriptions for each scenario setting are as follows:

(1) Emission baseline: it was set based on three baselines, which were the maximum annual emission of the previous 7 years (the original cap-and-trade setting), average emission of the previous 7 years, and minimum annual emission of the previous 7 years. Further, it was set to review and analyze how the decision-making model was selected based on the emission and cost of different benchmark years for each pollutant source changes against the overall emission reduction and trading amount.
(2) Reduction target: currently, the first-phase reduction target of cap-and-trade program for air pollutants accounts for 5% of total reduction as the subject matter. To understand whether the reduction target would influence the trading decision, the reduction targets of scenario setting were set as 10, 15, and 20%, respectively. Under different emission baseline scenarios, the mode was used to predict the influence on reductions and trading amount changes in controlled regions.
(3) Whether there was any trading platform under operation: the mode set the prices of the trading market to be completely transparent, which enabled the cost prices of each seller to be transparent and made the sellers seek the trading object with the lowest cost for bargaining based on the best cost.

To compare the average reduction cost of pollutants per unit, reduction target, and trading ratio (proportion of reduction target) in various scenarios, such indexes were analyzed further by air quality improvement goal and activeness of the trading market. From the viewpoint of air quality, the more the reduction amount and the lower the average reduction cost per unit, the better the scenario. Based on the activeness of the trading market, for polluters, the more effective the trading market, the better the scenario.

In terms of cost-effectiveness, polluters are pressed to reduce emissions under the mandatory administrative control and economic policies of the cap-and-trade program. However, when the reduction cost is excessively high, they are allowed to obtain the offset amount through trading to reduce the reduction impact. Therefore, to evaluate the cost-effectiveness of various emission baselines under different reduction targets and on the trading platform, it is necessary to compare the economic cost at the targeted reduction amount set in various scenarios. In consideration of such different targeted amounts and considering that the total reduction cost of the pollutant increased as the reduction target, the comparison of total reduction cost is inappropriate and the reduction cost of pollutants per unit is adopted instead.

3 Results and discussion

3.1 Analysis and comparison of three baseline settings

3.1.1 Comparison and description of trading situation

The comparison of various pollution reductions for the three benchmark year settings is as shown in Table 1. First, we find that the reduction target in the region as a whole is lower than the allowable offset amount, implying

Table 1 Analysis table of total reduction target of pollutants set by different benchmark emissions (Unit: t)

Item		Baseline based on max amount among previous 7 years[c]	Baseline based on average amount of previous 7 years	Baseline based on min amount among previous 7 years
PM (10,328)[d]	Reduction target	378 (304)[a]	1,292 (1,200)[a]	1,759 (1,627)[a]
	Offset permit	4,082 (3,993)[a]	1,377 (1,276)[a]	530 (372)[a]
	Trading amount	89 (24%)[b]	110 (9%)[b]	158 (9%)[b]
SO_x (26,507)[d]	Reduction target	56 (52)[a]	1,906 (1,660)[a]	6,363 (6,258)[a]
	Offset permit	22,220 (22,214)[a]	9,385 (9,090)[a]	464 (338)[a]
	Trading amount	6 (10%)[b]	295 (15%)[b]	126 (2%)[b]
NO_x (37,102)[d]	Reduction target	1,398 (1,352)[a]	2,306 (2,216)[a]	5,786 (5,725)[a]
	Offset permit	16,257 (16,202)[a]	4,552 (4,444)[a]	97 (24)[a]
	Trading amount	55 (4%)[b]	108 (5%)[b]	73 (1%)[b]
VOCs (12,046)[d]	Reduction target	664 (549)[a]	1,462 (1,107)[a]	2,414 (2,299)[a]
	Offset permit	5,261 (5,123)[a]	1,525 (1,099)[a]	149 (12)[a]
	Trading amount	138 (21%)[b]	426 (29%)[b]	138 (6%)[b]
The number of agents needed to reduce		137	178	194

[a] The number inside the parentheses indicates the simulation amount after trading

[b] The number inside parentheses indicates trading ratio = (trading amount/reduction target)

[c] Baseline setting is original baseline of the emission cap-and-trade program rules

[d] Pollutant annual emission

that the trading market is in a state of oversupply in the analysis result where benchmark year is set as the maximum emission of the previous 7 years (the cap-and-trade setting). Moreover, the overall trading amount is on the lower side and lagging behind the pollutant reduction target. That simulation result corresponds with actual situation of trading market. We can infer that more and more strict measures in the past years, like the requirement of an environmental impact assessment review and the tightening of the emission standards, have encouraged the polluters to improve their own emission controlling technology before the air emissions cap-and-trade program is implemented. Therefore, most polluters have already reduced their emissions by more than reduction goal (95%) which results in higher MAC and a much larger supply of offset permit amounts than the demand.

In the analysis part where benchmark year is set as the minimum emission of the previous 7 years, the available offset amount reduces greatly and the reduction target is considerably greater than the offset amount. As the trading market presents that demand outstrips supply, the offset sources are less, resulting in less trading amounts (all trading ratios are less than 10%). It can be learned that the setting of the minimum emission of the previous 7 years as the emission benchmark is inappropriate for the promotion of trading system, and polluters only respond by self-reduction.

In the scenario that the emission benchmark adopts the average emission of the previous 7 years, the allowable supply and demand of offset in the region as a whole belongs to the scenario of oversupply; however, compared with the scenario adopting the maximum emission of the previous 7 years (hereinafter referred to as the cap-and-trade setting) as the emission benchmark, the gap between supply and demand is smaller, especially the reduction target of PM and VOCs is close to the allowable offset amounts. In addition, the available allowable amount of offset for SO_x has a bigger gap with the reduction target and is the same with the cap-and-trade setting. As polluters have positively reduced the emissions, causing SO_x annual emission to significantly decrease from 2008 to 2014. Therefore, most polluters' the emission benchmark depends on whether the average emission of the previous 7 years or maximum emission of the previous 7 years is higher than the SO_x emission after year 2015. The trading condition of SO_x is different from the cap-and-trade setting; as the reduction target in the power industry becomes larger, the industry trading amount becomes larger. The main reason for the less trading amount of PM and NO_x is that the major industry category of the polluters who own PM and NO_x offset consists of large-scale industries, such as manufacturing of ready-mix concrete, power industry, and petrochemical industry, and their MAC is higher than that of the other industries, while it is opposite for VOCs. Therefore, the trading amount of VOCs is more and the trading ratio is also higher.

Moreover, in the comparison part of the trading amount for the three emission baseline settings, the emission benchmark adopting the average emission of the previous 7 years has the most trading amount; therefore, this emission benchmark setting will be compared with the cap-and-trade setting subsequently in different simulation scenarios. While the scenario adopting the minimum emission of the previous 7 years has very few trading amounts and fails to achieve the trading purpose under the cap-and-trade program, it would not be included in subsequent scenario comparisons.

3.1.2 Influence of reduction target adjustment

According to the simulation results (see Fig. 3 for details), under the cap-and-trade setting, the higher the reduction target is, the larger is the trading amount, representing that the pressure of the reduction target facilitates the polluters to respond to emission trading. In particular, SO_x amount obviously increases. When the reduction target increases to 15%, the total SO_x reduction demand increases to nearly 10 times and the polluters without a reduction pressure originally need to respond to the new reduction target. In addition, when the reduction target increases to 20%, it also results in the same situation where the total reduction of NO_x and the trading amount increases.

In the scenario that the emission benchmark adopts the average amount of the previous 7 years, all of the reduction targets are greater than the cap-and-trade setting. We find that when the reduction target is higher, in terms of trading amount, only NO_x increases, and there is no definite influence on PM and VOCs; in contrast, SO_x becomes less, and the trading amount also reduces with the reduction target, which is different from the simulation results of the cap-and-trade setting.

An analysis of the trading amounts of two emission baselines reveals that the baseline setting of the cap-and-trade program and that of the average emission of the previous 7 years results in different reduction objects and costs, making the two have different trends of trading amount under different reduction target proportions. Under the baseline setting adopting the average emission of the previous 7 years, the reduction target of NO_x and SO_x are mainly for power industry and iron and steel smelting industry, and the reduction costs of mentioned industries are higher. When the reduction amount is increased, the offset resources that can provide lower offset costs become less, making it difficult to find suitable offset sources and causing the trading amount to be less;

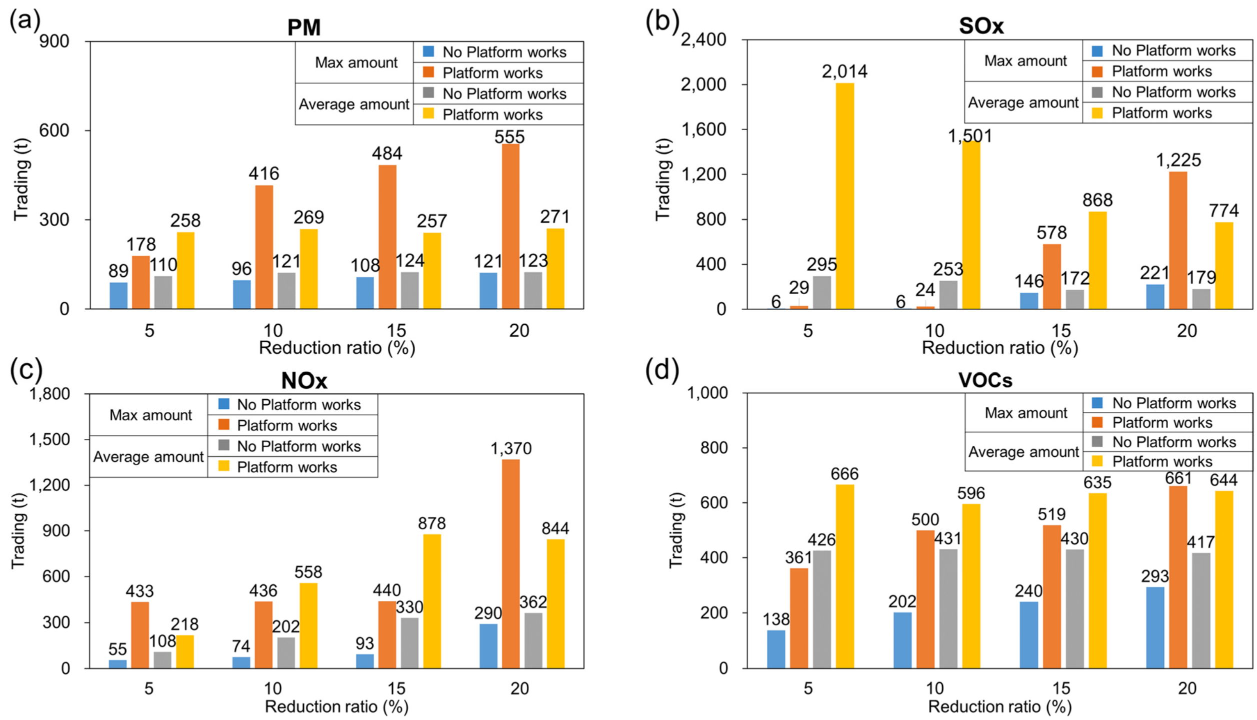

Fig. 3 Comparison diagram of trading amounts of (**a**) particulate matter (PM), (**b**) SO_x, (**c**) NO_x, and (**d**) volatile organic compounds (VOCs) under different reduction ratios. Note: trading ratio = (trading amount/reduction target)

while those of PM and VOCs are similar to those in the case of the cap-and-trade setting, which can be applied to a wide range of industries that can provide lower cost of offset; therefore, a sufficient offset supply can support the increasing demand for higher offset trading amount. However, irrespective of the scenarios set by the emission baseline of the cap-and-trade setting or the average emission of the previous 7 years, whenever the reduction target is increased, the number of polluters required for reduction will also increase, resulting in increased reduction costs for polluters. Therefore, all of the trading amounts under different reduction targets are far lower than the reduction target, representing that each polluter still focuses on the self-reduction decision. Hence, it is difficult to increase trading amount under a more progressive reduction target when the polluters tend to implement emission reduction plan for lower emission for itself instead of purchasing offset from others.

3.1.3 Influence of strategies of trading platform

Under the cap-and-trade setting, it is found that under the trading platform, all trading amounts are more than those without trading platform (see Fig. 3 for detailed comparison results of trading with or without platform); moreover, with an increase in the reduction target, the trading amount also increases. Under the baseline setting adopting the average emission of the previous 7 years, the same trading amounts are more than those without a trading platform. After increasing the reduction proportion, only NO_x increases and there is no definite influence on PM and VOCs; in contrast, SO_x becomes lower, which is similar to the simulation results set without the trading platform.

3.2 Comparison and analysis of simulation scenarios

3.2.1 Air quality protection as the goal

To compare the advantages and disadvantages of scenarios in which average emission of the previous 7 years is adopted as the emission benchmark and the cap-and-trade setting is adopted as the benchmark year, this paper takes the reduction amount in each scenario and the average reduction cost of pollutants (PM, SO_x, NO_x, and VOCs) per unit as the comparison benchmark and examines which of the different reduction proportion targets has more reduction and lower average reduction costs with or without the operation of trading platform. Moreover, it compares them under each reduction target without conducting any trade (no trading system) and the reductions of each polluter with the reduction target directly distributed. Similarly, it compares the average reduction cost per unit for pollutants under each scenario. The list of codes for simulation scenarios is shown

Table 2 List of codes for simulation scenarios

Emission baseline setting	Trading setting	Reduction target (%)	Scenario code	Emission baseline setting	Trading setting	Reduction target (%)	Scenario code
Baseline based on maximum amount in the previous 7 years (original)	No platform work	5	A	Baseline based on average amount in the previous 7 years	No platform work	5	I
		10	B			10	J
		15	C			15	K
		20	D			20	L
	Platform work	5	E		Platform work	5	M
		10	F			10	N
		15	G			15	O
		20	H			20	P
	No trading[a]	5	A1		No trading[a]	5	I1
		10	B1			10	J1
		15	C1			15	K1
		20	D1			20	L1

[a] No trading means that polluters do not offset the s by trading and reduce emissions under the target setting

in Table 2. The analysis of the average cost per reduction amount and reduction amounts for each pollutant in each simulation scenario are shown in Fig. 4a-d.

In the scenarios that include the trading system, the scenario in which the emission benchmark adopts the average emission of the previous 7 years, the reduction target is set as 20% and no trading platform, PM (total reduction is 2.35 kt), SO_x (total reduction is 3.28 kt), NO_x (total reduction is 5.77 kt), and VOCs (total reduction amount is 2.20 kt) has more reductions. However, compared with the scenarios that exclude the trading system, reductions of polluters with the reduction target distributed are more than those of the previous setting.

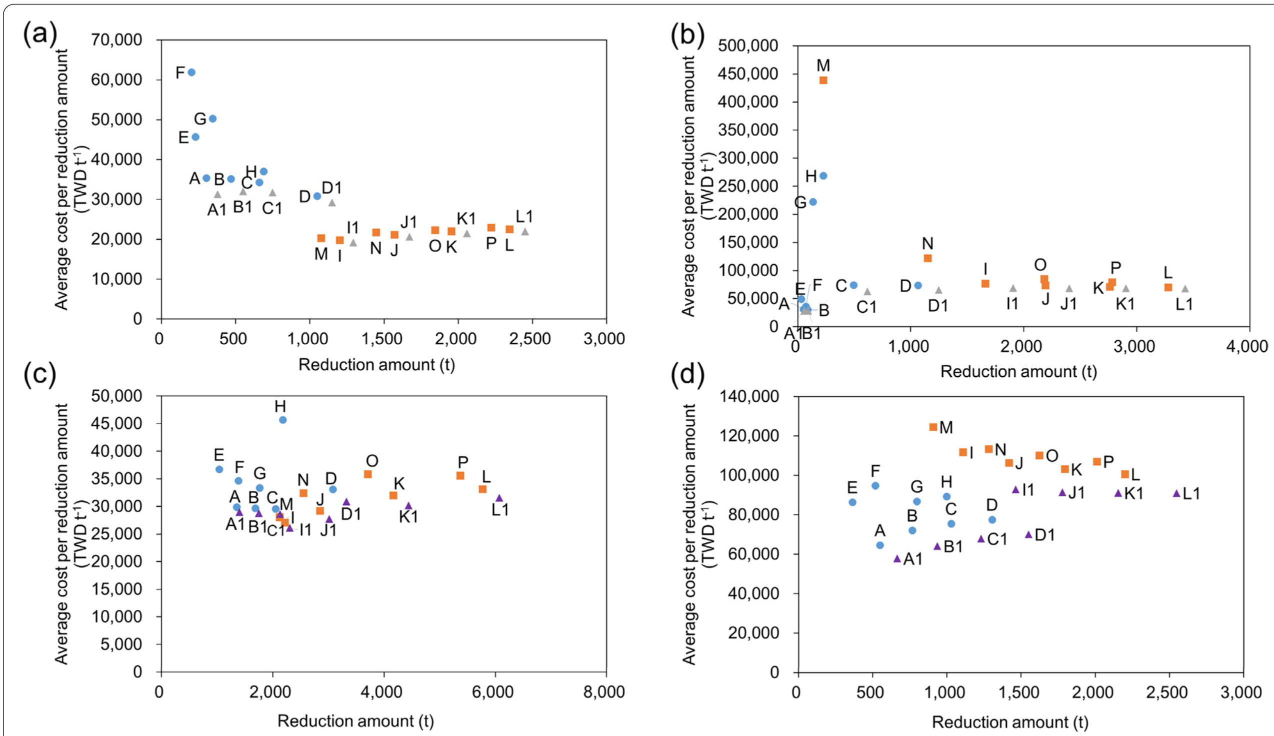

Fig. 4 Comparison diagram of the average cost per reduction amount and reduction amounts for (**a**) particulate matter (PM), (**b**) SO_x, (**c**) NO_x, and (**d**) volatile organic compounds (VOCs) in each simulation scenario. Note: 1 USD ≒ 32 TWD

3.2.2 Promotion of cap-and-trade as the goal (the higher the proportion of trading amount)

If the government adopts the cap-and-trade program to manage air quality, the trading market must work effectively. The trading activeness will take the proportion of trading amount to total reduction target as the analysis index to represent how polluters will respond by the emission trading under the emission goals setting and further represent the activeness of the trading market. Therefore, the comparison of scenarios will be based on the trading ratio (trading amount/reduction target) and the average reduction cost per unit for pollutants. The analysis of the average cost per reduction amount and trading ratio for each pollutant in each simulation scenario are shown in in Fig. 5a-d.

In a scenario in which the maximum emission of the previous 7 years is set as the emission benchmark, the reduction target is set as 20%. Under the trading platform operation, the trading ratio and average reduction cost per unit are best than other scenarios for PM (the trading ratio and average reduction cost per unit are approximately 48% and TWD 37,000, respectively). However, in a scenario in which the maximum emission of the previous 7 years is set as the emission benchmark, the reduction target is set as 5%. Under the trading platform operation, the trading ratio and average reduction cost per unit are best than other scenarios for SO_x (the trading ratio and average reduction cost per unit are approximately 52% and TWD 49,000, respectively), NO_x (the trading ratio and average reduction cost per unit are approximately 31% and TWD 37,000, respectively), and VOCs (the trading ratio and average reduction cost per unit are approximately 54% and TWD 86,000, respectively). We infer that the trading market has the potential to trade more, because polluters can find the right information for them to trade.

4 Discussion

4.1 Evaluation of trading market

In conclusion, analyzing the above simulation results, under the same scenario of trading platform operation, the two baseline settings are likely to bring trade. The trading platform can facilitate the transparency of the trading cost of the market and allow buyers to clearly understand the base price of the cost for selling to determine their own best seller. It can be seen that through the simulation using this model, the establishment of the trading platform is a support to the trading system. Alternatively, in the scenario of the trading platform under operation, by setting simulations at different baselines and from the perspective of results of different reduction target scenarios, only the trading amount set by the

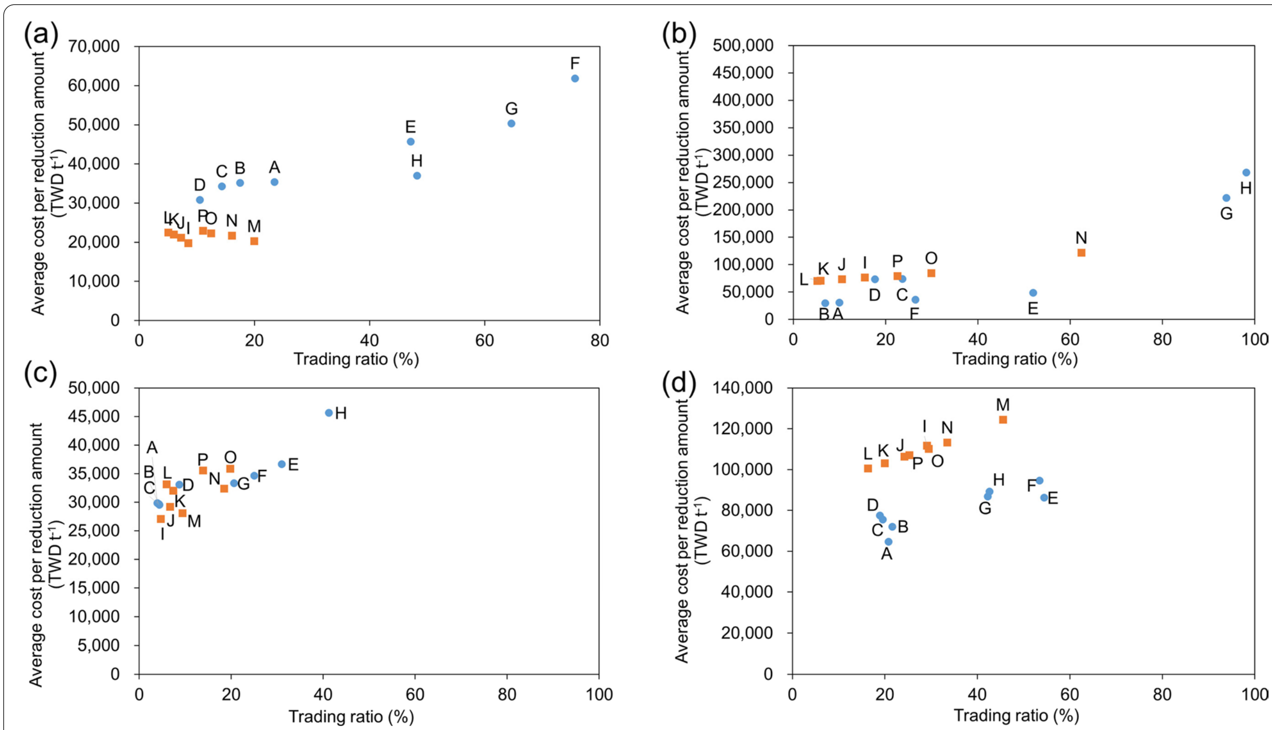

Fig. 5 Comparison diagram of the average cost per reduction amount and trading ratio for (**a**) particulate matter (PM), (**b**) SO_x, (**c**) NO_x, and (**d**) volatile organic compounds (VOCs) in each simulation scenario

emission baseline of the original cap-and-trade setting will grow with an increase in the reduction target. Further, there is no such trend when the baseline is set as the average emission of the previous 7 years. As the reduction targets of emission benchmark calculated using the average emission of the previous 7 years are higher than the cap-and-trade setting, the available offset amount lessens relatively when the reduction targets are increasing, i.e., the sellers that can be taken as the offset sources lessen, making the tendency of trading amount reduce; hence, it is different from the trend of trading results under the cap-and-trade settings.

4.2 Policy evaluation

If the policy makers consider the air quality protection as the premise with necessary trading systems as support, the scenario in which the emission benchmark adopts the average emission of the previous 7 years (except VOCs), the reduction target is set as 20% and no trading platform setting has the most reductions. Moreover, the average cost of pollutant reductions per unit is not obviously higher. If the scenario that excludes the trading system (reduce emissions with the reduction target directly distributed) is also considered, i.e., the reduction of pollutants in the scenario in which the emission benchmark adopts the average emission of the previous 7 years, the reduction target is set as 20% and no trading platform has the most reductions. In addition, in the comparison of scenarios with trading system and without trading system, the scenario without trading system is performing better than that with trading system, no matter the reduction amount or reduction cost per unit. This indicates that when promoting the trading system of cap-and-trade program, the economic feasibility of promotion of trading system will be assessed in detail; otherwise, the method of reducing emissions with the reduction target directly distributed will have a relatively simple measure of administrative control with no need to design any trading system separately. However, it will still consider other supporting measures where polluters fail to reduce emissions.

Furthermore, under the premise that the policy considers the activeness of trading market, the trading ratios that are higher than the baseline are based on the maximum emission of the previous 7 years rather than being based on the average emission of the previous 7 years. This is because trading is likely to occur in the case of a lower reduction target and will provide more polluters for offset. Alternatively, under the existence of trading platform, the trading ratios are higher than those without a trading platform, showing an obvious support from the platform to the activeness of trading.

5 Conclusions

This paper proposes a model based on the ABM theory and cost-effectiveness analysis under the air emission cap, including the methods of the baseline setting, the proportion of reduction target, and whether to set a trading platform. This is performed to demonstrate that the proposed model can analyze and predict the trading conditions that may occur with the joint implementation of other systems, including the trading market setting and different control system settings, and further investigate the feasibility of suggested implementation strategies.

From the comparison of simulation schemes, if the policy makers consider air quality control as the premise, i.e., the more the reductions and the lower the average reduction cost per unit, the better the scenario. We suggest that the reductions of each polluter with the reduction target are directly distributed without conducting any trade, which better satisfies the requirements. The total reduction amount with the emission benchmark adopting the average emission of the previous 7 years is higher, and the average reduction cost per unit for polluters shows no obvious increase with the trading system. Under the premise that the policy prefers the emission trading scheme, the more active the trading market is, the better scenario will be. It is suggested that the original setting of the cap-and-trade program should take the maximum emission of the previous 7 years as the emission benchmark; consequently, the trading ratios are higher and the average reduction cost per unit is lower with better performance in a scenario that includes the trading platform system.

According to the analysis of this paper, for the purpose of improving the air quality in the region, i.e., to reduce emissions, the government is suggested to promote the specified reduction approach for easier operation, lower administrative cost, and promote more reductions. However, for new investment projects (pollution sources) to enter the region, it will not be easy to obtain the offset amount; hence, supported measures must be separately developed. Further, from the perspective of the impact on polluters' emission reductions, supporting the trading system is required to promote the reductions and there will be development (increment) space. The maximum amount of the previous 7 years as the emission benchmark can be implemented, supported by the trading platform mechanism, for a smaller impact on reduction target, which will be taken as the reference for the promotion of the cap-and-trade program under this paper.

In this study, we find that the reduction target in the region as a whole is lower than the allowable offset amount under the setting of the cap-and-trade program, implying that the trading market is in a state of oversupply. Moreover, based on the simulation results of trading amount, the overall trading amount is on the lower side and lags behind the pollutant reduction target. Polluters choose to reduce their emissions in response to the program and seldom obtain the offset amount through trading. With the small released amount of offset, the trading market does not work effectively. These results are similar to the real implementation status of the air emission cap-and-trade program in Taiwan [4]. The rules of cap-and-trade program have not been revised thus far in Taiwan, so there are no robust data that can be used to verify this study's simulation results.

The first stage of the air emissions cap-and-trade program was executed from June 30, 2015, to June 29, 2018, but TEPA has not announced the second stage of the program context. According to the report issued by the TEPA [32], the offset amount (total is about 15.6 kt held by 83 industries) was enough to offset, but the trading system does not meet the expectation because the owners do not release their offset. Therefore, TEPA has thought of building trading platform system to support the cap-and-trade program or evaluate whether the cap-and-trade program should continue. This paper not only discusses the impact and efficiency of the cap-and-trade program but also give some suggestions for improving the program. However, this paper considers major settings (emission benchmark, reduction target, and trading platform) of the cap-and-trade program, however, there are other settings that can be also investigated. For example, the way of emission allowance allocation is based on historic emission baseline; there are other variance allowance allocation rules, that is, grandfather allocation, output-based allocation, auction allocation. Besides, the model does not consider controlled polluters' activities, such as productivity can change in the existing industries or new polluters can join the cap-and-trade program. Nonetheless, we will continue studying these problems to revise the model that can potentially contribute to evaluation of air quality management. Recently, many researchers have applied ABM methods to study issues of carbon trading [22, 33, 34], and Taiwan has begun planning carbon trading system. Furthermore, we can develop a model for analyzing the impacts of other environmental policies, particularly energy policy and greenhouse gas management policy.

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Authors' contributions
Hsing-fu Huang investigated, provided methodology, processed model analysis, and wrote & edited the manuscript. Hwong-wen Ma conducted writing, reviewed and approved its completion. All authors approved the final manuscript.

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Declarations

Competing interests
The authors declare they have no competing interests.

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