

Study and suggestions on Co-benefits of reduction in greenhouse gas emissions and air pollution control

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Abstract. Studying the co-benefits of greenhouse gases and air pollutants is highly relevant as China tries to cope with the dual challenges of climate change and pollution control. Over the past ten years, plenty of studies at home and abroad have paid attention to these co-benefits, including policy analysis, model application, case discussion, etc., and various co-benefit theories have been introduced to lay a solid scientific foundation for the development of energy and environmental development policies. In this paper, different definitions and types of co-benefits are provided, and co-benefit evaluation methodology is explained. International and domestic progress in studies on the co-benefits of reduction in greenhouse gas emissions and air pollution control are elaborated, and prospects and suggestions on future studies are analyzed.

1 Introduction

Co-benefit, also known as ancillary benefit and secondary benefit, was first proposed by German scientist Herman Haken. It refers to involuntary and added benefits from a policy or after a policy is implemented, other than the direct benefits expected during the inception of design [1]. In the general sense, co-benefits are not neutral; they specifically refer to policy outputs or benefits that are positive. Co-benefits run through all aspects of policy implementation and reflects the thinking of holistic management: In a narrow sense, when a policy is evaluated by the measure of cost-effectiveness, co-benefits provide a method to comprehensively measure the net cost of a policy. In a broader sense, co-benefits can be essentially extended to all aspects of natural, social and economic systems. It echoes the concept of sustainable development. The study on co-benefits is of significance to the implementation of sustainable development strategy in China.

Now, co-benefits are often cited in discussions on emission reduction of greenhouse gases (GHGs) and local air pollutants. The Intergovernmental Panel on Climate Change (IPCC) has a clear definition of co-benefits of GHG reduction [2]: co-benefits are quantitative results of the monetization of added benefits after the implementation of a GHG reduction policy, such as reduced emissions of local air pollutants due to less use of fossil fuels and indirect positive impacts on energy security and employment. GHGs and local air pollutants mainly come from the utilization process of carbon-based fossil energy. This “common source” mainly explains why their co-benefits are widely

discussed. Therefore, no doubt co-benefits of reduced air pollutants can be generated by controlling GHG emissions associated with energy production, conversion, and utilization activities, especially carbon dioxide emissions. Co-benefits can and should be explored in the integrated management of energy, environment and climate change. No consensus has been reached on the definition of co-benefits. Definitions provided by some international agencies are similar on one hand and have different focuses on the other, as shown in Table 1.

For some time to come, China will still experience rapid industrialization and urbanization processes. At the same time, it will find itself under increasing pressure to cope with climate change and air pollutant control. China has taken measures in energy conservation, carbon reduction and pollution control, and a complete control and governance system that defines aggregate and intensity constraint targets and specific measures has been established. Take the energy sector as an example [3]. During the “Thirteenth Five-Year Plan” period, the total energy consumption will be controlled within 5 billion tce, and the energy consumption per unit of GDP will be reduced by more than 15%. Various specific measures will be taken to achieve the aggregate and intensity control targets in the structural reform on the energy supply side and energy consumption revolution. However, this governance system targets at energy conservation and carbon reduction as well as air pollution control separately. The design of policy measures, reflected in whether the setting of targets or the specific action plan, does not allow for the evaluation of the comprehensive impact of GHG and air pollutant emissions or their co-benefits. Considering the significance of co-benefits to development decision-

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making, studies are necessary in that they can explore the incorporation of co-benefits to the policy framework and the integrated management of energy, environment and climate change based on their co-benefits [3].

Table 1 Definitions and illustrations of Co-benefits by international agencies

| Agency | Time | Definition or Illustration |
|---|------|--|
| Intergovernmental Panel on Climate Change (IPCC) | 2001 | According to the Third Assessment Report, co-benefits refer to non-climate change mitigation benefits that are clearly mentioned as additional motives in the design and implementation of greenhouse gas mitigation policies. |
| Organization for Economic Co-operation and Development (OECD) | 2009 | There is a potentially large and diverse range of collateral benefits that can be associated with climate change mitigation policies in addition to the direct avoided climate impact benefits. Depending on the context, mitigation actions targeting clean energy technologies or energy efficiency, for example, are likely to include improvements in local or in indoor air quality which in turn limit risks to human health. These collateral benefits are referred to here as “co-benefits” of climate change mitigation policies [4]. |
| US Environmental Protection Agency (U.S. EPA) | 2004 | The ancillary or additional benefits of policies that are implemented with a primary goal, such as climate change mitigation - acknowledging that most policies designed to reduce greenhouse gas emissions also have other, often at least equally important, benefits (e.g., energy savings, economic benefits, air quality benefits, public health benefits). Also referred to as “multiple benefits” [5]. |
| European Environment Agency (EEA) | 2007 | Mitigation measures can also have other benefits for society, such as health cost savings resulting from reduced air pollution [6]. |
| The Ministry of the Environment | 2008 | Co-benefits in environmental pollution |

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|---|------|--|
| of Japan (MOEJ) | | control can help developing countries reduce greenhouse gas emissions and make progress [7]. |
| Policy Research Center for Environment and Economy, the Ministry of Ecology and Environment of the People’s Republic of China (PRCEE) | 2004 | On the one hand, co-benefits include reduced emissions of other local pollutants, such as SO ₂ , NO _x , CO, VOC, and PM, along with the control of greenhouse gas emissions. On the other hand, co-benefits also include reduction or absorption of CO ₂ and other greenhouse gas emissions in addition to the control of local pollutant emissions and during ecological construction. |

2 Classification of Co-benefits

Most of the studies on co-benefits of GHG and air pollutant control focus on climate policies, which is thus the basis for the classification of co-benefits in this section. As shown in Table 2, co-benefits of climate policies are classified by quantitative/qualitative assessment, and quantitative assessment is classified into physical quantification/economic quantification.

Table 2 Main types of Co-benefits of climate policies

| Quantitative Studies | | Qualitative Studies |
|---|---|---|
| Physical quantification | Economic quantification | |
| Reduced emissions of local air pollutants | Avoidance of control costs due to reduced emissions of local air pollutants | Stimulation of technological innovation, technological substitution, etc. |
| Reduced ecosystem damage (comprehensively characterized by indicators such as acid rain and eutrophication) | Health benefits [monetized by Willingness to Pay (WTP) or human capital approach] | Enhanced energy security (increased energy diversity and reduced energy dependency) |
| Health benefits (characterized by morbidity rate or mortality rate) | Positive effects on employment (measured as changes in GDP) | Positive impact on employment |

Of all the types of co-benefits listed in Table 2, reduced emissions of local air pollutants due to the implementation of climate policies are the most concerned co-benefits [8-10]. The physical quantities of

reduced local air pollutants are of high policy significance in countries or regions where the aggregate air pollution control mode is adopted. Associated health benefits on the basis of reductions can be further evaluated. Statistics show that health benefits are the most important co-benefits that account for more than 80% of all co-benefits of climate policies. The health benefits are quantitatively measured with the Air-health Pathway. Characteristic indicators of health benefits include endpoint physical quantities of health effect evaluation, such as mortality rate, loss of life, and rate of seeing a doctor [11], and quantities of money measured by equivalent valuation methods such as WTP/human capital approach [12-15]. However, the results of health benefit evaluation are not reliable and credible enough, because both the methods and parameters are highly uncertain. For example, the selected evaluation endpoints cannot fully and accurately reflect the health impact of pollutants, and the sample surveys to support environmental valuation is underrepresented [16].

Another way to economically quantify the reduction of air pollutants is to calculate the control cost avoided by the reduction, and this is a common approach in EU studies [17-20]. However, because the evaluation results from this approach rely heavily on the model and scenarios adopted by the researcher, the reduction in air pollution control cost varies greatly among studies. According to Van Vuuren, Cofala, and Eerens, the reduced cost of air pollutant cut as a result of EU's participation in the Kyoto Protocol accounted for about half of the cost of climate policy implementation. Under the same research context, Nathan [19] found that the cost savings accounted for only 0.2% to 3.9%.

In addition, a few studies further comprehensively evaluated the impact of air pollutant emissions on global or regional ecosystems. Among typical air pollutants, SO₂ is the main contributor of acid rain that harms the ecological environment in such ways as soil acidification, water loss and soil erosion, and forest reduction; NO_x leads to eutrophication and further unbalanced nitrogen cycle. The RAINS (Regional Air Pollution Information and Simulation) model designed and developed by the International Institute for Applied System Analysis (IIASA) has been the most mature and widely used model system to assess various ecological and environmental effects of different air pollutants to date [21].

Furthermore, co-benefits of climate policies to economy and society are also analyzed in some studies. The economic benefits are often measured by carbon tax [22], and social co-benefits are multifaceted, such as improved solid waste management [23], enhanced energy security [24], less congestion in highways, agricultural growth [25], employment influence and technology facilitation [26]. Economic and social impacts are mainly measured with quantitative methods, due to inconsistent and immature physical or economic quantification approaches.

The physical quantities (reduction in air pollutants, comprehensive impact on the ecological environment) and economic quantities (health benefits, avoidance of control cost) of co-benefits have different advantages in

assisting in policy making: the former can be combined with regional goals of ecological environmental protection conveniently and the direct result of ecological environmental protection is a catalyst to arouse public awareness; the latter is economically oriented for the assessment of policy cost-effectiveness and can be taken into consideration with regional macroeconomic policies [27].

3 Methodology of Co-benefit evaluation

3.1 Greenhouse gas – Air pollution interaction and synergies (GAINS)

GAINS has been used all over the world as a co-benefit quantitative model developed by the IIASA. Its applications include economic statistics, energy and agricultural planning, and emission inventories in typical regions. GAINS can be used to simulate emission scenarios of all major air pollutants resulting from a given economic activity to be applied and estimate the potential and cost of emission reduction, with the interactions of reduced emissions from various pollutants taken into account. The GAINS model tracks pollutants from driving sources (such as energy consumption, industrial activities, and agricultural production) while allowing for the characteristics of emissions from different sources and regions. It then analyzes the potential of emission reduction through a wide range of technical and non-technical measures, estimates the cost of emission reduction, and calculates the impact indicators of GHG emissions, human health, and ecosystems.

3.2 Integration of environmental strategy (IES) of EPA

IES is a framework that analyzes co-benefits by combining necessary models with tools. It is often used to quantify the co-benefits of GHG reduction and air pollution control in the environment (including air quality and GHGs), public health, and economy. An IES project include a series of steps, including building a project team, developing energy/emission scenarios, calculating atmospheric concentrations, quantifying the impact on public health, assessing the economic value of health benefits, ranking various measures and results, and taking measures.

3.3 Energy-environment-economics (3E) model for quantification of Co-benefits

GHG and pollutant control policies are concerned about the comprehensive, balanced, and coordinated development of energy, economics, and environment. Therefore, quantitative studies usually adopt a model system that covers all of these subsystems. This type of model is called the Energy-Economics-Environment (3E) model which is a major method to measure co-benefits. Depending on micro or macro modeling, the 3E model is

divided into bottom-up, top-down, and hybrid types. Since they have different characteristics, they suit different subjects and yield different calculation results when applied in co-benefit studies.

4 Studies on the Co-benefits of reduction in GHG emissions and air pollution control

4.1 Progress in foreign studies

Co-benefit studies started early in foreign countries and dated back to the late 1990s or so. Studies in Europe, the United States, and Japan are relatively comprehensive and extensive. They are mostly characterized by the use of models, and the development of such models is mature. Mature models and reasonable scenario analysis method together push quantitative studies on the topic to a high level. Most of these studies focus on the co-benefits of climate change policies as well as their health and social benefits, and are committed to measuring them through monetization or quantification. These studies are also extensive, conducted at global, national and city levels and covering extremely diverse sectors.

(1) Studies on cost Co-benefits

Studies on cost co-benefits focus on the co-benefits in reduced emissions of traditional pollutants as a result of GHG reduction measures intended to deliver cost and health benefits through model simulations. Bollen et al. applied the MERGE model in a cost-benefit analysis on GHG reduction policies and pollution control measures [28]. Petter Tollerfsen et al. Applied the Regional Acidification Information and Simulation (RAINS) model to evaluate the climate cost of air pollutants and generate the co-benefits of reducing air pollutant emissions to cope with climate change [29]. Rive applied the CGE model in a study on the reduced cost of pollution control with the intervention of climate policy in Western European countries [30]. Rafaj et al. applied the GAINS and global energy system models to study the impact of global GHG policies on traditional air pollutants and quantify the pollution control cost and the health and the environmental impact [31]. Chae studied the co-benefits of the air quality management plan and the GHG reduction program in Seoul, South Korea, and calculated the cost-effectiveness of each project [32].

(2) Studies on Materialized Co-benefits

There are few studies on materialized co-benefits, and they mainly analyze the co-benefits of policies coping with GHG reduction and air pollutant control. Shrestha et al. studied the co-benefits of policies coping with GHG reduction and air pollutant control in Thailand under the Markal model [33].

4.2 Progress in domestic studies

Co-benefit studies started relatively late in China and did not appear until about 2003. Compared with those of international scholars, the studies in China are still limited by the use of emission reductions as the single

evaluation criterion. Most of them focus on evaluating the co-benefits of emission reduction measures supported by engineering technologies in a city or industry, and few of them adopt energy or economic models to quantify other co-benefits (such as public health benefits and social benefits) and the economic cost of collaborative emission reduction. Given the national situation where the reduction in pollutant emissions attract more attention, domestic scholars focus more on the co-benefits of pollution control policies than on those of GHG control policies.

(1) Qualitative studies

Tao Hu et al. indicated that the co-benefits of environmental improvements and GHG reduction will have an impact on the climate change and environmental policies in China, especially pollution control and ecological construction policies [34]. Liping Li et al. examined a co-benefit plan based on total emission reduction realized by three measures of “engineering emission reduction”, “structural emission reduction”, and “management emission reduction”. The result showed that different emission reduction technologies and measures lead to different co-benefits: positive co-benefits mainly come from “structural emission reduction”, while negative ones mainly come from “engineering emission reduction” [35].

(2) Quantitative studies

Quantitative studies focus on simulating and evaluating the costs, health benefits or materialized co-benefits in different scenarios at the regional or industry level by applying a model. Changhong Chen et al. applied the Markal model to predict energy consumption and air pollutant emissions in the basic scenario and the energy policy scenario [36]. He et al. applied the LEAP model to predict energy consumption in China in different scenarios, estimate pollutants and GHGs, monetize and compare the benefits of CO₂ emission reduction and health benefits [37]. Yuanbo Xie applied the LEAP model to predict the emission reduction effects of major air pollutants and GHGs in Beijing for 2010-2020 in three scenarios [38]. Xianqiang Mao combined the 3E model with a case study of the thermal power industry and proposed a method to evaluate the co-benefits of technological emission reduction measures [39].

5 Prospects and suggestions on future Co-benefit studies

5.1 Expand the coverage of Co-benefit analysis to meet the needs of ecological civilization construction and sustainable development

Because energy consumption is naturally associated with GHG and air pollutant emissions, most of co-benefit studies focus on their relationships. However, controlling GHG and air pollutant emissions is simply part of ecological environmental protection. Ecological civilization construction and social sustainable development call for wider implications of co-benefit studies. Specifically, the coverage of co-benefits should

evolve from reduced pollutant emissions at the primary level to reduced emissions and adaptation at the high level. At the primary level, the focus should be extended from air pollution to water, soil and other pollution. For example, some industries, such as the chemical industry and the papermaking industry, are faced with noticeable problems of high energy consumption, air pollution and water pollution discharge. At the intermediate level, the focus should be extended from pollution issues to resource issues, and the synergy of energy with water resources and land resources can be explored. To examine resource constraints, the focus should be laid on promoting coordinated spatial distribution of various energy sources and resources. At the high level, the focus should be extended from emission reduction to adaptation. Attaching equal importance to emission reduction and adaptation is the key to coping with climate change, protecting the ecological environment, and achieving energy/water security. Because adaptation activities are concentrated in farmland, water, forests and other natural ecosystems, in-depth studies on resource issues at the intermediate level is essential to the building of adaptability and fundamental to adaptation studies.

5.2 Improve Co-benefit research methodology to fully and effectively assist policy making

Currently, co-benefit studies in China are not able to effectively support policy making partly because the relevant methodology is not sound enough, and especially there is large modeling gap to fill with foreign countries. Domestic studies mostly borrow mature models and embedded parameters from other countries. However, these model systems and supporting data do not match the status quo in China because they are generally based in Europe and the United States. Therefore, in terms of model development, we should, first of all, establish model frameworks and database platforms based on the current technology applications and economic operations in China. The next step is to further explore improvements in the model architecture, including building a hybrid model that reflects interactions between energy, economy, and environment sectors as well as rich technical details; more integrated model systems that allow for intricate coupling relationships between industries, such as upstream and downstream production and technology matching may be developed; the ability of the models to interpret policies can be enhanced through technical means such as the Monte Carlo uncertainty analysis, the game theory, and the technology diffusion theory. In addition, more and innovative economic quantitative studies on economic, quantitative, and environmental co-benefits are expected in order to provide more convincing cost-benefit analysis.

5.3 Improve institutional top-level design to effectively incorporate Co-benefit research results into decision-making

Co-benefit studies touch energy, economics, environment, and many other fields. In order to effectively incorporate research results into decision-making, a top-level design of administrative institutions that facilitates the output of research results is needed, and the most important part of the design is strengthened coordination across departments. Intergovernmental coordination mechanism should be designed from three aspects of guideline, policy implementation and expert consultation. In terms of guideline, laws and regulations can be enacted to regulate and guide the behavior of the government and other social subjects. There are foreign references in this regard. For example, *Bill for Energy and Water Research Integration Act of 2009* was adopted in the United States, requiring that water resources be integrated in energy research, development and demonstration projects. In terms of policy making, inter-ministerial committee, special task force and other organizations may be created to determine detailed policy planning and implementation stages under the guideline and to coordinate cooperation across government departments, between central and local governments, and between governments and scientific research institutions/enterprises. Given the actual situation in China, the National Energy Commission may list co-benefit matters in its priorities. In terms of expert consultation, a separate expert committee (or expert group) may be created or the existing Expert Committee on Climate Change may be relied upon to offer advice and recommendations on co-benefit matters.

6 Conclusion

China is now under the dual pressure of GHG reduction and environmental pollution control. Enriching co-benefit theories and practice is highly relevant and is consistent with the long-term environmental sustainable development strategy in China. Based on the research analysis and summary mentioned above, future co-benefit studies need to be expanded and improved. It is necessary to strengthen quantitative co-benefit studies. Firstly, the application and development of models should be strengthened, and the advantages of multiple models should be combined to break through the limitations of a single model. Secondly, more academic attention should be paid to the monetization of co-benefits in order to clarify environmental benefits, public health benefits, and social benefits and offer reference and comparability. Thirdly, innovative spirit is appreciated, and novel quantitative methods are encouraged in co-benefit evaluation. Last but not least, co-benefit studies on different regions and sectors should be consistently enhanced to keep enriching the depth and breadth of co-benefit theory and make it a mature theoretical system that can provide better scientific reference and basis for policy making at local and national levels.

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