Adaptation and mitigation for combating climate change – from single to joint

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Abstract: Adaptation and mitigation are two main approaches to combating climate change. Mitigation is considered as the most important tasks in dealing with climate change in scientific research, financial support and technical practices as global warming intensifies; while currently the warming trend still cannot be reversed, and adaptation task seemed to gain urgency although it is late-starting. The synergies and tradeoffs of these two strategies revealed increasingly importance on reducing adverse climate effects. Research on synergistic relationships has developed from definition and feasible analysis, to the development of quantitative tools and exploration in practice and application, though the latter aspect is still in its initial stage. Outcomes/other: Our review shows that the traits of mitigation and adaptation, the differences and similarities between them, then illustrate the significance and mechanism of their synergies and tradeoffs. And it is explained that methods and applications of single and integrated models, and cost-effectiveness analysis.

Discussion/ Conclusion: We hold the opinion that the future research and applications should be enhanced in terms of four aspects: reinforcement of interrelations and common mechanisms between mitigation and adaptation actions study; building and improving the monitoring and evaluating systems; promoting departmental and regional scale investigations and applications; and establishing policy and security systems.

Introduction

Climate change and variability is not only an environmental issue, but also an internationally relevant topic in policy, economics, and law. It impacts regional and national nontraditional security, in terms of aspects such as ecological, economic, and energy security. In the twenty-first century, adaptation actions have the same importance as mitigation in countering climate change. While these two strategies are researched separately in climate change science and policy, their differing paths of development may cause an imbalance between the two – one’s effect may be weakened by the other (Ge et al. 2009).

In practice, we can cost-efficiently achieve the goal of addressing climate change by effectively integrating emission reductions and accommodation actions: improving adaptive capacity through mitigation actions and achieving the goal of emission reductions by facilitating adaptation. Developing the co-benefits of mitigation and adaptation (M&A) is a win-win strategy, and it will be the major pattern of low-carbon and sustainable development in the future. However, the key challenges that still need to be addressed through research include: identifying how overall efficiency can be promoted, whether there are synergistic effects in the existing policies of M&A, and how to evaluate and promote the co-benefits in climate change.

M&A in combating climate change

Mitigation is devoted to the reduction of the rate of increase, and scale of changes, in greenhouse gases (GHG). Adaptation aims to improve the capacity of defense and resilience, which reduces the passive influence of climate change (Ge et al. 2009).

Mitigation

Mitigation action lowers the GHG concentrations via reducing GHG emissions and adding carbon sinks, to meet the objective of reducing the pace of climate change and frequency of extreme events (Lu 2013).

The fundamental challenge for mitigation policies and techniques is minimizing cost; almost all mitigation research consists of economic and societal impact analyses (Lu 2013). Advanced science and technologies play an increasingly important role in mitigation measures; there are major technologies dedicated to reducing GHG emissions, increasing carbon sinks, and carbon capture and storage. At a regional level, there...
are considerable gaps in the development of mechanisms for emission reductions. The primary mechanisms thus far developed include command-and-control mechanisms, quantity-based mechanisms, and price-based mechanisms. The markets of these principal mechanisms comprise the European Union Emissions Trading Scheme (EU ETS) and the Chicago Climate Exchange (CCX), among others.

Adaptation
Adaptation refers to the regulating strategies employed under actual or expected climatic stimulation (Pan and Zheng 2010); their objective being to mitigate climate change impacts and promote adaptive capacity. Effective implementation of adaptive measures could reduce regional vulnerability and simultaneously create potential growth opportunities. Interest in adaptation developed relatively recently compared to mitigation, and as a result, research into adaptation is still in the early stages and often inadequate, especially in developing countries.

Adaptation can be classified as incremental or developmental. In incremental adaptation, when original facilities and inputs are insufficient to resist a natural disaster, considering the emerging climatic risks, investments are added onto existing communal facilities, and the action is specific for the new additional climatic risk. In developmental adaptation, there is a pressing need to address both conventional and new climate risks in developing countries, because of inadequate capacity and investment. Thus, adaptive issues are also development issues (Pan and Zheng 2010). Compared with mitigation actions, adaptation is much more complex and presents more restrictions and difficulties.

Differences and similarities between M&A
While mitigation addresses the degradation rate of climate change, adaptation deals with weakening the adverse impacts of climate change (Laukkonen et al. 2009). Although they share a common ultimate objective, namely, the sustainable development of human society, there are large differences between M&A in practice, including the scales of the departments and the research involved. We reviewed previous studies and have summarized the differences and similarities of M&A in Table 1.

The common goal of M&A is to reduce the impacts of climate change from a long-term perspective and their major differences are as follows:

1. Differences in activity fields and departments (Table 2). The fields related to mitigation are energy consumption and carbon emissions; while the passive, stress response of adaptation exists in fields and departments directed against climate change risk.

2. Discrepancy in practices among regions and countries. There are different attitudes toward combating climate change among regions and countries, mainly between developed and developing countries. Developed countries focus on mitigation actions, while in some countries of the South, there is high vulnerability to climate risks and less scope to reduce emissions; therefore, adaptation actions are particularly urgent in this region (Ayers and Huq, 2009; Wilbanks et al. 2007).

Mitigation actions are mainly undertaken at a country and regional scale (Figure 1). The net benefits of mitigation are larger on global than regional scales (the beneficiaries of mitigation will extend to outer regions, leading to globalization). While the costs and benefits of adaptation actions are both multi-scaled, the net benefits at regional scales are larger than those at a global scale: the smaller the spatial scale, the larger the benefits, and therefore the adaptation action is more attractive (van Vuuren et al. 2011; Wilbanks et al. 2007). Mitigation contributed to global benefits; however, these benefits are postponed. Adaptation has immediate effects, and on a regional scale, adaptation actions have higher incentive and urgency than mitigation.

Table 1. Differences and similarities between mitigation and adaptation (Duguma et al. 2014a; Duguma, Minang, and van Noordwijk 2014b; Swart and Raes 2007).

| Concept          | Mitigation                              | Adaptation                                           |
|------------------|-----------------------------------------|------------------------------------------------------|
| Differences      | Reducing GHG emissions and increasing carbon sinks | From results                                        |
|                   | Causal association                       | District and region                                  |
|                   | Spatial scale                           | Urban planning, water, agriculture, human health, coastal zone |
|                   | Departments                             | Current and short-term                                |
|                   | Time scales                             | Self-interest                                        |
|                   | Beneficiaries                           | Spontaneous                                          |
|                   | Incentive                               | High                                                 |
|                   | Level of urgency                        | Aims to reduce climate change risk and associated losses |
|                   | Objective                               | Climate-related and associated benefits              |
|                   | Benefits                                | New science and technology                           |
|                   | Driven by                               |                                                      |
The financial support for M&A varies widely. Adaptation has been referred to as “the poor relation” of mitigation; financial investment in mitigation is much higher than that in adaptation. Although adaptation is now being taken more seriously, it still suffers from insufficient financial investment and institutional research (Ayers and Huq, 2009). For example, 96% of funds for combating climate change in years 2010 and 2011 were for mitigation measures (Li 2010).

In addition to the distinctions mentioned earlier, scholars have different perspectives of the mutual relationship of M&A. The relation was summarized in three classes by Landauer, Juhola, and Söderholm (2015) as neutral, positive, and negative. Wilbanks et al. (2007) considered that relations of M&A may be complementary, contrary, or mutually reinforcing in different situations. Through case studies, van Vuuren et al. (2011) deduced that there are complementary, not synergetic, relationships between M&A, and adaptation is much more efficient than mitigation from a financial perspective. Tol (2005) described the relationship between M&A as resource competition.

Synergy and trade-offs of M&A

Significance

The scientific terms “synergies” and “trade-offs” are used in many fields including psychology, medicine, and business; our study focuses on their use in the field of climate science.

The third working group of the Intergovernmental Panel on Climate Change (IPCC) first put forward synergies and trade-offs in their Third Assessment Report, and added a chapter to describe and analyze the situation of their coordinated management in M&A (IPCC AR4 2007). It was extended from the abatement effect of GHG following reduction in air pollution and refers to synergies and trade-offs of M&A actions under different climate change scenarios.

Synergies are described as the effect of “1 + 1 > 2,” that is, the aggregation is greater than the sum of each part, meaning that the combined effect of the interacting adaptation and mitigation actions is greater than the sum of their effects if implemented separately. Trade-offs are situations that involve losing one quality or aspect of something in return for gaining another quality or aspect. It represents the net impact of adaptation and mitigation activities (Klein, Huq, and Denton 2007).

Scales and fields for synergies and trade-offs

The research objectives and scales for synergies and trade-offs change from global, national, and regional to urban and communities (Table 3).

In a systematic literature review of the scales and fields of synergies and trade-offs research, Landauer, Juhola, and Söderholm (2015) found that urban is one of the major scales for such research; it is implicated in a large percentage of work at global, national, regional, and other scales, accounting for about one-fifth of the samples in their review.
Table 3. Synergies and trade-offs research at different scales.

| Scales          | Field                  | Research content                                                                                   | Sources                                                                 |
|-----------------|------------------------|---------------------------------------------------------------------------------------------------|------------------------------------------------------------------------|
| Communities     | Communities sustainability | Synergies between adaptation and mitigation in British Columbian communities                        | Shaw et al. (2014)                                                     |
| Local           | Individuals and communities Infrastructure service | Combining climate change adaptation and mitigation measures at the local level                     | Laukkonen et al. (2009)                                               |
| Urban           | Infrastructure service Urban environment         | Climate change mitigation and adaptation in North American cities                                  | Zimmerman and Faris (2011)                                            |
|                 | Urban form              | The synergies strategy and development of adaptation and mitigation in urban region                | Hetz (2015); Juhola et al. (2013); Wang and Zhao (2011)                |
| Regional        | Policy                  | Urban form and climate change: Balancing adaptation and mitigation in the United States and Australia | Hamin and Guran (2009)                                               |
|                 | Agriculture             | Methodology and policy framework for analyzing regional adaptive capacity assessments              | Juhola and Kruse (2015)                                              |
|                 | Electricity transmission | Climate-smart agriculture global research agenda: scientific basis for action                      | Steenwerth et al. (2014)                                             |
|                 | Land-use                | Study on environmental effects of emissions reductions in West-to-East electricity transmission     | Li (2010)                                                            |
|                 |                       | Climate change mitigation and adaptation in the land use sector                                    | Duguma, Minang, and van Noordwijk (2014b)                             |
| National        | Social welfare Analysis methods | Synergy of adaptation and mitigation strategies in the case of Vietnam                           | Dang, Michaelowa, and Tuan (2003); Duguma et al. (2014a)            |
|                 | Policy                  | The value of linking mitigation and adaptation: a case study of Bangladesh                         | Ayers and Huq Nigel (2009)                                           |
| Global          | Individuals and communities Global health          | Combining climate change adaptation and mitigation measures at the local level                   | Hinkel and Klein (2009)                                             |
| Cross-scale     | Global health           | Climate change adaptation and mitigation: cross-sector action to protect global health            | Bowen, Ebi, and Friel (2014)                                         |
|                 | Policy                  | Successful adaptation to climate change across scales                                             | Adger, Arnell, and Tompkins (2005)                                  |
|                 | Policy                  | From federal to city mitigation and adaptation: climate change policy in Mexico City              | Sosa-Rodriguez (2014)                                               |
|                 | Environmental           | Promoting co-benefits in mitigation, local environmental quality and development in Asian cities | de Oliveira et al. (2013)                                           |

**Mechanism of synergies and trade-offs**

In Figure 2, the top right quadrant represents synergy (positive synergies), where the implementation of a mitigation action does not cause vulnerability in the region, or the implementation of adaptation measures reduces GHG emissions at the same time. Essentially, the mitigation (or adaptation) action has positive external effects to adaptation (or mitigation). For example, afforestation activity increases carbon sinks while improving regional adaptive capacity, that is, a synergy effect.

The top left and bottom right quadrants correspond to trade-off effects. The top left quadrant, trade-offs of adaptation, is where adaptive actions bring “negative external effects” to mitigation: inappropriate adaptation to reduce or eliminate regional vulnerability while causing more GHG emissions will weaken the mitigation effect. For example, dam construction, for preventing sea water encroachment, raises the consumption of steel and cement, which are higher carbon emission goods, thereby generating “adaptive emissions.” The bottom right quadrant corresponds to trade-offs of mitigation, where a mitigation action enhances regional vulnerabilities or brings new vulnerabilities when GHG emissions are reduced; the mitigation leads to “negative external effects” to adaptation such as a hydroelectric station that competes with local communities for water consumption (Fu, Zheng, and Wang 2014; IPCC AR4 2007; Zheng, Wang, and Pan 2013).

The bottom left quadrant is the counterexample: “negative synergies.” For example, traffic congestion brings both increased GHG and pollution, and deforestation causes the reduction of regional adaptive capacity along with the loss of further carbon sinks.

There are synergies and trade-offs not only between M&A actions, but also among the different kinds of mitigation or adaptation measures (Felgenhauer and Webster 2013). Discovering and exploiting synergetic relationships can lower costs and help to balance the dual goals of climate change M&A under limited resources, which is an urgent and practical issue for regions with high emissions and high vulnerability (Fu, Zheng, and Wang 2014). Urban design could pay proper attention to climate-safe siting, energy-conserving building characteristics, and low transportation requirements, which would both limit energy use and also reduce exposure to the possible negative consequences of climate change in low-lying coastal areas or areas prone to flooding (Swart and Raes 2007). Also in the land-use and forestry sectors synergies can be found, reforestation to prevent flooding and erosion sequesters carbon (Dang, Michaelowa, and Tuan 2003).

**Research methods for synergies and trade-offs**

The methods to analyze synergies and trade-offs of M&A include integrated assessment models (IAMs), single models, and cost-benefit analysis (CBA). The
methods and models and their applications are reviewed in the following sections.

**IAMs and Their Application**

IAMs are mainstream comprehensive models in climate change research and are powerful tools for multidimensional, dynamic, and complicated systems. IAMs integrate basic causality of different disciplines in evaluating climate change, linking the impacts of climate change on the economy and vice versa.

Dowlatabadi and Morgan (1993; Dowlatabadi 1995) summarized 18 IAMs and recommended focusing on IMAGE, DICE, CETA, and PAGE models. On this basis, Wei, Mi, and Zhang (2013) analyzed and combined 29 typical climate models and subdivided these models into three main categories: optimization models, computable general equilibrium (CGE) models, and simulation models. Moss et al. (2010) proposed that there are three main framework approaches for synergies and trade-offs research: the climate model; the comprehensive evaluation model; and impacts, adaptation, and vulnerability, which includes 12 fields.

IAMs are good at analyzing situations under different assumptions and including the interactive effect of multiple factors, recognizing the potential impacts in complicated scenarios, and supporting decision making on respective multiple layers. Challenges limiting the use of IAMs include the uncertainty of climate change; especially regarding the costs and benefits used in cost–benefit-based climate models (Wei, Mi, and Zhang 2013). IAMs focus less on adaptation choices, and in the major IAMs, adaptation actions are not considered at all (de Bruin, Dellow, and Tol 2009a; de Bruin, Dellow, and Agrawala 2009b; Tol and Fankhauser 1998; van Vuuren et al. 2011; Zemel 2015). IAMs are effective in the fields of coupling earth system (models) and the socioeconomic systems, and turned to be a critical focus area in M&A recently. The more widely used IAMs, IMAGE and AD-DICE, are described as follows.

(1) IMAGE models and sub models are extensively used in climate change research and play an important role in specific regional, technology, and policy studies. The IMAGE comprehensive model (Bouwman, Kram, and Klein 2006) is composed of a series of associated models that in conjunction describe long-term global and dynamic environmental changes, such as air quality, climate, and land use changes. The models evaluate energy and land use development in the twenty-first century under predictions of population and economic growth, and assumptions of consumption patterns (van Vuuren et al. 2011). A limitation of IMAGE is that although the models are robust when describing human activities, they need to cooperate with other models to provide a more macroscopic view (van Vuuren et al. 2011). The sub models of IMAGE that can be used separately mainly include the global energy model TIMER (Mgi, Lucas, and van Vuuren 2008; Isaac and van Vuuren 2009); the FAIR model for currency CBA (Mgi, Lucas, and van Vuuren 2008); the Dynamic and Interactive Vulnerability Assessment model that describes the risk of sea level rise (Hinkel

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Figure 2. Significance and mechanism of synergies and trade-offs.
and Klein 2009); the global hydrology model MacPDM; MARA/ARMA, a malaria distribution model; the GTAP model, which is for agricultural trading and food production; the HYDE3 model for population and land use status; the C-cycle model that simulates the carbon interchange between the terrestrial biosphere and atmosphere; and the GLOBIO3 model, which is an assessment framework for terrestrial biodiversity (Bouwman, Kram, and Klein 2006).

(2) The AD-DICE model adds an adaptation assessment into the traditional comprehensive evaluative Dynamic Integrated model of Climate and Economy (DICE) model (de Bruin, Dellink, and Tol 2007; de Bruin, Dellink, and Tol 2009a). By adding adaptation to the model, it is possible to calculate the reduction by adaptation actions, of the losses from climate change, in which losses include surplus loss, protection costs, and abatement cost. AD-RICE model is the regional version of AD-DICE.

**Single models and their application**

In contrast to IAMs, single models have a targeted approach with high pertinence to specific departments and fields. We take the departments of energy consumption and urban road transportation as examples.

In the field of energy consumption, Chen used the MARKAL and long-range energy alternatives planning system (LEAPs) models to analyze the energy consumption and emissions in Shanghai (Chen et al. 2006; Chen et al. 2007). MARKAL was based on various policy simulations to predict energy consumption and carbon emissions and analyze the synergy effects with reduction of pollutants under China’s energy policies (Chen et al. 2006). While the research subject was seen as a relatively independent “Energy Island” in the model, in reality, Shanghai is closely linked with other cities and provinces, and further studies are needed to reinforce the impact of external energy communications on the results obtained. The LEAPs model discussed the impact of a low-carbon scenario on emissions of carbon and local air pollutants (LAP) (Chen et al. 2007). Only two pollutants, PM10 and SO2, were taken into account in the LEAPs model, whereas the real-world conditions are much more complicated.

In the field of urban road transportation, Thambiran and Diab (2011) used the EEA’s computer program to calculate emissions from road transport (COPERT) IV model to research air pollution and climate change co-benefit opportunities in South Africa. Oanh, Phuong, and Permadi (2012) analyzed the motorcycle fleet in Hanoi to estimate the air pollution emissions and climate mitigation co-benefit of technology implementation, using the international vehicle emissions model to adjust the emissions factor. The model is widely used in developing urban areas that are already contaminated. Xu et al. (2014) used the flexible coefficient method to study the environmental management of urban transportation and to solve the problems of air pollutants and GHG emissions.

**Cost-benefit analysis**

CBA is an important part of the assessment of synergies and trade-offs, aiming to reduce the cost of climate change, based on the monetary unit (van Vuuren et al. 2011).

The FAIR model, derived from the AD-DICE model, uses marginal abatement costs (MAC) curves to distribute regional emission quotas based on the low-cost principle (van Vuuren et al. 2011). MAC is widely used in CBA; Yang, Teng, and Wang (2013) used MAC curves to evaluate the environmental and economic effects of GHG emissions reduction policies in the cement industry.

In general, the uncertainty of climate change is a great challenge for IAMs, which causes further uncertainty of the cost and benefit of climate policies. Single models have high pertinence to specific departments and fields but fail to address the synergy of social, economic, and environmental questions whose corresponding research methods are based on the police and scenario analyses. Cooperation of diversified models and methods is essential; single models have limitations for systematic and large-scale research. Some scholars disagree on aspects of CBA: Tol (2005) holds that the CBA of M&A are unpaired on spatial scales (the CBA is on the global and national scale for mitigation, while for adaption it is on the local or regional scale). Brown (2014) holds that CBA has insurmountable ethical issues because basic climate policies are against the principles of distributive and procedural justice and neglect to protect human rights. Therefore, we should also determine emission targets based on ethical analysis in researching and developing climate policy, rather than only focusing on minimizing cost.

**System approach**

System approaches are applied equally in the fields. Duguma et al. explored enabling conditions for synergy between M&A and its synergy potentials, and selected 8 indicators used for analyzing the synergy scores of countries (Duguma et al. 2014a). Larsen K and Gunnarsson-Östling U who examined the processes of citizen participation in constructing scenarios to discuss the interrelationships between
M&A argued the tension arising from climate strategies relying on either adaptation or mitigation strategies or combining both (Larsen and Gunnarsson-Östling 2009).

Exploring synergies between M&A in research and practice

The relationship between kinds of M&A is intricate and has overlapping and interacting effects in implementation and at multiple spatial and temporal scales. The exploitation of co-benefits, whereby adaptive measures are beneficial to emissions reduction and mitigation actions improve regional adaptive capacity, is integral to cost-effective and efficient sustainable development. A key question to address is how to identify the synergic action and the combined relationship between M&A strategies, as there are still many difficulties and issues in the research and application process. The preceding part discussed the significance and methods associated with M&A research. Next, we explore practical applications and provide suggestions for improving systematic scientific research for combating climate change.

Further, the work to exploring and improving the synergies between M&A in practice could be launched in three layers: the theory, application, and guarantee levels in which the theoretical research provides scientific support for application and security construction; and in turn, the latter provides feedback on continual improvement information and technical requirements to theoretical research (Figure 3). The theory and application contents are specified as follows.

Theory research

Strengthen research for mutual relationships and internal mechanisms between M&A measures. To deal with whether there are synergies in special M&A measures and how to improve the overall efficiency in combating climate change, we propose a study that progresses successively from qualitative diagnosis and quantitative assessment to CBA and optimal decision-making. This requires first in building a matrix of integration measures and dividing the relationship into four quadrants based on interaction types: positive synergies (+,+), trade-offs (+,−) (−,+), and negative synergies (−,−), to reflect synergies of the strategies. In quantitative assessment, the single models and IAMs could be used to find further synergies in the relationship between strategies, and the scenario analysis will be a crucial method. The CBA should be conducted to demonstrate economic feasibility, compare costs and benefits, choose reasonable action plans, and confirm the priority of policies.

Suggestions for practice and application

(1) Constructing and improving the monitoring and evaluation systems. Currently, the corresponding monitoring, tracking, feedback, and assessing systems have room for improvement; data accessing, processing, feedback, and regulating and controlling technologies need to be enhanced. Establishing and enhancing the Internet of Things as an information platform, which interactively supports data acquisition and monitoring, processing and integrating, feedback and regulating, predicting and warning functions, will contribute to addressing these problems. Merging data from multiple sources including ground monitoring and investigation, remote sensing and other multi-source data integration and acquisition, as well as mapping out methods for statistical analysis will likewise contribute. In addition to the further development of sensor technologies, other techniques and equipment for data storing and transmitting, analysis of big data, and adoption of cloud services should be used in systems and platforms to improve the capacity for combating climate change.

(2) Combining M&A measures at regional and departmental levels. Synergies and cost–benefit advantages of M&A mainly occur at regional and departmental levels. Adaptive issues and aims have strong pertinence and are relatively homogeneous at this scale. Regional and department scale synergies research needs to be reinforced, as does demonstration and application. Demonstration and pilot projects should be carried forward, summing up successful experiences for the benefit of other regions and departments, and lowering costs for subsequent attempts. It is critical that more attention is paid to local conditions; rather than applying experiences uniformly, regional realities should be
identified and incorporated, and rational targets and measures made according to the practical situation. The difficulty will be how to improve coordination capacities among departments, organizations, and governments in practice.

(3) Establishing policy and security systems. We can implement and improve policy and security systems from three aspects: (1) Developing the research system for environmental management policy, including specific operations such as making policy and regulations that beneficially control synergies; developing national or regional action plans for combating climate change; implementing dynamic monitoring and assessment; improving matching strategies as feedback mechanisms; and facilitating adaptation capacity and adaptive management. (2) Enhancing the complementary qualities of M&A actions with policies, programming, and measures. The actions and policies of M&A are traditionally developed and executed separately in different fields, and as such, there is repetition and overlap, and the responsibilities are unclear across different policies. Focusing on the newly enacted policy and regulations to ensure that they are complementary will help to provide a more coordinated approach to combating climate change. (3) Security is key to ensuring the effective implementation of climate measures. Important steps to take include: establishing scientific evaluation systems through legislation, administration, and techniques; improving the commitment of elementary policies and regulations; stimulating initiative in subjects of environmental management in the government, enterprise, and the public; establishing the sector’s cooperation and negotiation, as well as its expert systems; researching implementation and monitoring mechanisms; and perfecting the decision-making and supervisory mechanisms for the environment in general.

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Author contributions
Chunli Zhao and Yan Yan conceived and designed the research; Chunli Zhao, Chenxing Wang, and Yang Song drafted the manuscript; Chenxing Wang and Mingfang Tang prepared figures; Yan Yan, Gang Wu, and Ding Ding discussed the results and revised the manuscript. All authors read and approved the final manuscript.

References
Adger, W. N., N. W. Arnell, and E. L. Tompkins. 2005. “Successful Adaptation to Climate Change across Scales. Global Environ.” Change 15 (2): 77–86. doi:10.1016/j.gloenvcha.2004.12.005.
Ayers, J. M., and S. Huq. 2009. “The Value of Linking Mitigation and Adaptation: A Case Study of Bangladesh.” Environmental Management 43 (5): 753–764. doi:10.1007/s00267-008-9223-2.
Bouwman, A. F., T. Kram, and G. K. Klein. 2006. Integrated Modelling of Global Environmental Change, an Overview of Image 2.4, Netherlands Environmental Assessment Agency. The Netherlands: MNP, Bilthoven.
Bowen, K. J., K. Ebi, and S. Friel. 2014. “Climate Change Adaptation and Mitigation: Next Steps for Cross-Sectoral Action to Protect Global Health.” Mitig. Adapt. Strat. Gl. 19 (7): 1033–1040. doi:10.1007/j.scicotp.2006.11.030.
Brown, D. 2014. “Ethical Problems with Cost-Benefit Analysis of Climate Policy.” Yuejiang Academic Journal 01: 19–24.
Chen, C., B. Chen, B. Wang, C. Huang, J. Zhao, Y. Dai, and H. Kan. 2007. “Low-Carbon Energy Policy and Ambient Air Pollution in Shanghai, China: A Health-Based Economic Assessment.” The Science of the Total Environment 373 (1): 13–21. doi:10.1016/j.scitotenv.2006.11.030.
Chen, C., B. Wang, Q. Fu, C. Green, and D. G. Streets. 2006. “Reductions in Emissions of Local Air Pollutants and Co-Benefits of Chinese Energy Policy: A Shanghai Case Study.” Energy Policy 34 (6): 754–762. doi:10.1016/j.enpol.2004.07.007.
Dang, H. H., A. Michaelowa, and D. D. Tuan. 2003. “Synergy of Adaptation and Mitigation Strategies in the Context of Sustainable Development: The Case of Vietnam.” Climate Policy 3 (sup1): S81–S96. doi:10.1016/j.clipol.2003.10.006.
de Bruin, K., R. Dellink, and S. Agrawala 2009b. Economic Aspects of Adaptation to Climate Change: Integrated Assessment Modelling of Adaptation Costs and Benefits, OECD Environment Working Papers. No. 6, OECD Publishing. doi:10.1787/225282538105.
de Bruin, K. C., R. B. Dellink, and R. S. I. Tol 2007. AD-DICE: An Implementation of Adaptation in the DICE Mode. Fondazione Eni Enrico Mattei Working paper. 51. doi:10.1007/s10584-008-9535-5.
de Bruin, K. C., R. B. Dellink, and R. S. I. Tol 2009a. “AD-DICE: An Implementation of Adaptation in the DICE Model.” Climate Change 95 (1–2): 63–81. doi:10.1007/s10584-008-9535-5.
Dowlatabadi, H. 1995. “Integrated Assessment Models of Climate Change: An Incomplete Overview.” Energy Policy 23 (4–5): 289–296. doi:10.1016/0301-4215(95)90155-Z.
Dowlatabadi, H., and M. G. Morgan. 1993. “Integrated Assessment of Climate Change.” Science-New York Then Washington 259: 1813. doi:10.1126/science.259.5103.1813.
Duguma, L. A., P. A. Minang, and M. van Noordwijk. 2014b. “Climate Change Mitigation and Adaptation in the Land Use Sector: From Complementarity to
Synergy.” Environmental Management 54 (3): 420–432. doi:10.1007/s00267-014-0331-x.

Duguma, L. A., S. W. Wambugu, P. A. Minang, and M. van Noordwijk. 2014a. “A Systematic Analysis of Enabling Conditions for Synergy between Climate Change Mitigation and Adaptation Measures in Developing Countries.” Environment Sciences Policy 42: 138–148. doi:10.1016/j.envsci.2014.06.003.

Felgenhauer, T., and M. Webster. 2013. “Multiple Adaptation Types with Mitigation: A Framework for Policy Analysis.” Global Environmental Change 23 (6): 1556–1565. doi:10.1016/j.gloenvcha.2013.09.018.

Fu, C., Y. Zheng, and W. Wang. 2014. “Research Perspectives on Synergic Relationships in Addressing Climate Change Measures.” Resources Science 36 (7): 1535–1542.

Ge, Q., J. Qu, J. Zeng, and X. Fang. 2009. “Review on International Strategies and Trends for Adaptation to Climate Change.” Advancement Climate Change Research 5: 369–375.

Hamin, E. M., and N. Gurrnan. 2009. “Urban Form and Climate Change: Balancing Adaptation and Mitigation in the US and Australia.” Habitat International 33 (3): 238–245. doi:10.1016/j.habitat.2008.10.005.

Hetz, K. 2015. “Contesting Adaptation Synergies: Political Realities in Reconciling Climate Change Adaptation with Urban Development in Johannesburg.” Southern Africa Regional Environment Change 1–12. doi:10.1007/s10113-015-0840-z.

Hinkel, J., and R. J. T. Klein. 2009. “Integrating Knowledge to Assess Coastal Vulnerability to Sea-Level Rise: The Development of the DIVA Tool. Global Environ.” Change 19 (3): 384–395. doi:10.1016/j.gloenvcha.2009.03.002.

IPCC AR4. 2007. Inter-Relationships between Adaptation and Mitigation. Chapter 18.

Isaac, M., and D. P. van Vuuren. 2009. “Modeling Global Residential Sector Energy Demand for Heating and Air Conditioning in the Context of Climate Change.” Energy Policy 37 (2): 507–521. doi:10.1016/j.enpol.2008.09.051.

Jap, D. O., C. N. H. Doll, T. A. Kurniawan, Y. Geng, M. Kapshe, and D. Huisingsh. 2013. “Promoting Win–Win Situations in Climate Change Mitigation, Local Environmental Quality and Development in Asian Cities through Co-Benefits.” Journal Clean Products 58: 1–6. doi:10.10113/s10113-015-0840-z.

Juhola, S., P. Driscoll, J. M. De Suarez, and P. Suarez. 2013. “Social Strategy Games in Communicating Trade-Offs between Mitigation and Adaptation in Cities.” Urban Climate 4: 102–116. doi:10.1016/j.uclim.2013.04.003.

Juhola, S., and S. Kruse. 2015. “A Framework for Analysing Regional Adaptive Capacity Assessments: Challenges for Methodology and Policy Making.” Mitigation and Adaptation Strategies for Global Change 20 (1): 99–120. doi:10.1007/s11027-013-9481-z.

Klein, R. J. T., S. Huq, and F. Denton. 2007. “Inter-Relationships between Adaptation and Mitigation. Climate Change.” In Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, edited by M. Parry, O.F. Canziani, JP, Palutikof, PJ van der Linden and CE Hansson. 745–777.

Cambridge, UK: Cambridge University Press.

Landauer, M., S. Juhola, and M. Söderholm. 2015. “Inter-Relationships between Adaptation and Mitigation: A Systematic Literature Review.” Climate Change. 131 (4): 505–517. doi:10.1007/s10584-015-1395-1.

Larsen, K., and U. Gunnarsson-Östling. 2009. “Climate Change Scenarios and Citizen Participation: Mitigation and Adaptation Perspectives in Constructing Sustainable Futures.” Habitat International 33 (3): 260–266. doi:10.1016/j.habitatint.2008.10.007.

Laukkonen, J., P. K. Blanco, J. Lenhart, M. Keiner, B. Cavric, and C. Kinuthia-Njenga. 2009. “Combining Climate Change Adaptation and Mitigation Measures at the Local Level.” Habitat International 33 (3): 287–292. doi:10.1016/j.habitat.2008.10.003.

Li, Y. 2010. “Study on Environmental Effects of Emission Reduction in West-to-East Electricity Transmission.” China Population, Resources and Environment, 20 (9): 36–41.

Lu, L. 2013. “Policies and Technologies for the Mitigation of Climate Change.” Chinese Journal of Agricultural Resources and Regional Planning 1 (34): 71–75.

Mgi, D. E., P. L. Lucas, and D. P. van Vuuren. 2008. “Regional Abatement Action and Costs under Allocation Schemes for Emission Allowances for Achieving Low CO2-equivalent Concentrations.” Climate Change 90 (3): 243–268. doi:10.1007/s10584-008-9466-1.

Moss, R. H., J. A. Edmonds, K. A. Hibbard, M. R. Manning, S. K. Rose, D. P. van Vuuren, and G. A. Meehl. 2010. “The Next Generation of Scenarios for Climate Change Research and Assessment.” Nature 463 (7282): 747–756. doi:10.1038/nature08823.

National Development and Reform Commission of the People’s Republic of China. 2014. National Climate Change Program (2014–2020) Beijing.

Oanah, N. T. K., M. T. T. Phuong, and D. A. Permadi. 2012. “Analysis of Motorcycle Fleet in Hanoi for Estimation of Air Pollution Emission and Climate Mitigation Co-Benefit of Technology Implementation, Atmos.” Environment 59: 438–448. doi:10.1016/j.atmosenv.2012.04.057.

Pan, J., and Y. Zheng. 2010. “Analytical Framework and Policy Implications on Adapting to Climate Change. China Population.” Resources and Environment 20: 1–5. doi:10.3969/j.issn.1002-2104.2010.10.001.

Shaw, A., S. Burch, F. Kristensen, J. Robinson, and A. Dale. 2014. “Accelerating the Sustainability Transition: Exploring Synergies between Adaptation and Mitigation in British Columbian Communities.” Global Environment Change 25: 41–51. doi:10.1016/j.gloenvcha.2014.01.002.

Sosa-Rodriguez, F. S. 2014. “From Federal to City Mitigation and Adaptation: Climate Change Policy in Mexico City.” Mitigation and Adaptation Strategies for Global Change 19 (7): 969–996. doi:10.1007/s11027-013-9455-1.

Steenwerth, K. L., A. K. Hodson, A. J. Bloom, M. R. Carter, A. Cattaneo, and C. J. Chartres, et al. 2014. “Climate-smart Agriculture Global Research Agenda: Scientific Basis for Action.” Agriculture & Food Security 3 (1): 11. doi:10.1186/2048-7010-3-11.

Swart, R., and F. Raes. 2007. “Making Integration of Adaptation and Mitigation Work: Mainstreaming into Sustainable Development Policies.” Climate Policy 7 (4): 288–303. doi:10.1080/14693062.2007.9685657.

Thambiran, T., and R. D. Diab. 2011. “Air Pollution and Climate Change Co-Benefit Opportunities in the Road Transportation Sector in Durban, South Africa.” Atmospheric Environment 45 (16): 2683–2689. doi:10.1016/j.atmosenv.2011.02.059.
Tol, R. S. J. 2005. “Adaptation and Mitigation: Trade-Offs in Substance and Methods.” *Environ. Sciences Policy* 8 (6): 572–578. doi:10.1016/j.envsci.2005.06.011.

Tol, R. S. J., and S. Fankhauser. 1998. “On the Representation of Impact in Integrated Assessment Models of Climate Change.” *Environment Model Assessment* 3 (1–2): 63–74. doi:10.1023/A:1019050503531.

van Vuuren, D. P., M. Isaac, Z. W. Kundzewicz, N. Arnell, T. Barker, P. Criqui, and A. Kitous. 2011. “The Use of Scenarios as the Basis for Combined Assessment of Climate Change Mitigation and Adaptation.” *Global Environmental Change* 21 (2): 575–591. doi:10.1016/j.gloenvcha.2010.11.003.

Wang, W., and D. Zhao. 2011. “Study on the Collaborative Development of Mitigation and Adaptation: Taking Guangdong as an Example.” *China Population, Resources and Environment* 6 (21): 89–94. doi:10.3969/j.issn.1002-2104.2011.06.016.

Wei, Y. M., Z. F. Mi, and H. Zhang. 2013. “Progress of Integrated Assessment Models for Climate Policy.” *Systems Engineering - Theory & Practice* 8: 1906–1915.

Wilbanks, T. J., P. Leiby, R. Perlack, J. T. Ensminger, and S. B. Wright. 2007. “Toward an Integrated Analysis of Mitigation and Adaptation: Some Preliminary Findings.” *Mitigation and Adaptation Strategies for Global Change* 12 (5): 713–725. doi:10.1007/s11027-007-9095-4.

Xu, G., M. Wen, X. Feng, and P. Guo. 2014. “Co-Benefits of Road Transport Policy in Reducing Air Pollutants and Greenhouse Gas Emissions in China.” *Social Science of Beijing* 7: 82–90. doi:10.13262/j.bjsshkxy.bjshkx.140712.

Yang, X., F. Teng, and G. Wang. 2013. “Incorporating Environmental Co-Benefits into Climate Policies: A Regional Study of the Cement Industry in China.” *Applications Energy* 112: 1446–1453. doi:10.1016/j.apenergy.2013.03.040.

Zemel, A. 2015. “Adaptation, Mitigation and Risk: An Analytic Approach.” *Journal of Economic Dynamics and Control* 51: 133–147. doi:10.1016/j.jedc.2014.10.001.

Zheng, Y., W. Wang, and J. Pan. 2013. “Low Carbon Resilient City: Concept, Approach and Policy Options.” *Urban Studies* 3: 10–14.

Zimmerman, R., and C. Faris. 2011. “Climate Change Mitigation and Adaptation in North American Cities.” *Current Opinion Environment Sustainable* 3 (3): 181–187. doi:10.1016/j.cosust.2010.12.004.