Managing Incentives for Greenhouse Gas Emission Reduction

Mengfei Jiang

A thesis submitted in fulfilment of the requirements for the degree of
Doctor of Philosophy in Carbon Finance

THE UNIVERSITY
of EDINBURGH

2019

Declarations

The following thesis sections are based on work from jointly-authored working papers:

Thesis sections	**Jointly-authored working papers**
Chapter 2: Stakeholder views on the carbon market and interactions between low-carbon policies in China: Lessons from the Guangdong ETS	Jiang, M., Liang, X., Reiner, D., Lin, B. and Duan, M. *Stakeholder views on interactions between low-carbon policies and carbon markets in China: Lessons from the Guangdong ETS,* 2018. Energy Policy Research Group Working Group Series 1805, University of Cambridge.
Chapter 3: Empirical study on carbon price determinants and the impact of other low-carbon policies on Chinese pilot ETS	Jiang, M., Liu, G., Zhou, H. and Liang, X. *Empirical study on carbon price determinants and impacts of other low-carbon policies on Chinese pilot ETS.* To be submitted.
Chapter 4: Impact of emission trading market linkage on carbon price	Jiang, M., Liang, X., Lucquiaud, M. *Impact of emission trading market linkage on carbon price: Findings of the GTAP-E model.* To be submitted.

The candidate confirms that she is the principal author of the working papers listed above. For each article, the candidate undertook the literature review, data collection, analyses, drafting of the papers and made a significant contribution to the conceptual framework used.

Mengfei Jiang

January 2019

Acknowledgements

Firstly, I would like to express my sincere gratitude to my supervisor Dr Xi Liang for his continuous support of my PhD study, for his patience, motivation, and immense knowledge. His guidance helped me throughout the research and writing of this thesis. I could not have imagined having a better advisor and mentor for my PhD study.

I would also like to thank: Dr Mathieu Lucquiaud, Dr David Reiner and Professor Boqiang Lin for their insightful comments and encouragement, but also for those hard questions which encouraged me to widen my research from various perspectives.

I would like to take this opportunity to thank Dr Matthew Brander and Professor Dabo Guan - my viva examiners, for their very helpful comments and suggestions.

I would also like to express my gratitude to my friends, colleagues and all the faculty in the Centre for Business and Climate Change and Business School of Edinburgh University for the pleasant working atmosphere and all the discussions.

Finally, I must express my very profound gratitude to my parents for providing me with unfailing support and continuous encouragement throughout my years of study and through the process of researching and writing this thesis. This accomplishment would not have been possible without them. Thank you.

Abstract

The Paris Agreement sets out the goal of limiting the increase in global average temperature to within 2°C. Incentive mechanisms and low-carbon policies, such as emission trading schemes (ETS), feed-in tariffs, carbon taxation, renewable obligation and emission performance standards, are key instruments for achieving greenhouse gas emissions reduction. The cap-and-trade ETS is one of the most popular policy instruments in controlling greenhouse gas emissions. The carbon price quoted from the ETS allowances price is usually considered by investors as the economic value of carbon emissions in formulating a long-term investment decision. However, the allowances price is currently quite low across jurisdictions. Thus, in order to incentivise large-scale and long-term low-carbon investment, a clear and strong carbon pricing signal is essential.

There are divergent but increasingly prevalent views that additional policies may affect carbon prices, as the emission reduction effect of parallel policies would reduce the demand for allowances in the ETS, thus lower carbon prices could hamper the ETS's capacity to promote low-carbon technologies over the medium and long term. This PhD study investigates how parallel energy and climate policies might affect carbon pricing in ETS and illustrates stakeholders' views on this impact. The study defines the 'cross-over effect' of parallel energy and climate policies.

A two-stage survey, including a closed-form questionnaire followed by open interviews, was conducted to elicit views and expectations of stakeholders on one of the carbon markets in China, the Guangdong ETS pilot, with an emphasis on perspectives on how the ETS may interact with other existing or proposed low-carbon and clean energy policies. Our survey results show that academic stakeholders, more than stakeholders from other sectors, viewed the policy interactions as a significant issue for developing a carbon market in China, and there was a positive correlation between recognition of such policy interactions and the time spent on energy saving and emission reduction policies. Relatively few respondents identified correctly the fact that both increasing renewable targets and imposing a carbon tax in addition to an existing ETS would be expected to depress prices in the ETS. Apart from government respondents, all other key stakeholders generally lacked confidence in China's carbon markets, due to their lack of knowledge and information about the market and their concerns regarding uncertainties and failures in government policy and regulation.

Subsequently, an empirical study was conducted to probe the underlying rationality of pricing behaviour and the effect of policy interaction with low-carbon policy in seven ETS pilots in China using ordinary least square and event-based regression. The empirical results show that, first, crude oil and domestic liquid natural gas are positively linked to the allowance price in the Beijing, Shanghai and Guangdong pilots, while coal price lacks explanatory power. Second, extreme weather is positively correlated with Shenzhen carbon prices. Third, in contrast to existing studies, a positive correlation is found between renewable energy supply and carbon prices in the Tianjin carbon market, and low-carbon policy that intends to promote renewable energy would increase carbon prices in the Guangdong pilot. Finally, ETS regulatory events, such as the announcement on surrender date (adjustment) and offset limitation, will increase price variations in the Shenzhen and Tianjin pilots respectively. Overall, the empirical results currently indicate that ETS pilots in China are segmented, but not as rational as previous studies suggest.

Finally, the potential benefits of linking emissions markets across countries and regions are well recognised. In theory, a global market provides more flexibility for parties to achieve reductions in emissions at the lowest marginal cost across all covered sectors. Therefore, quantifying the impact of emission trading market linkage would generate essential references for the forming of a global market. Driven by the above motivation, the GTAP-Energy (GTAP-E) model was employed to assess the impact of carbon market linkage. Our results indicate that, although the abatement costs increase in the Chinese carbon market after the linkage, the strong and robust carbon price could give investors a correct signal on the value of carbon emission. Furthermore, a linkage between the Chinese carbon market and the international markets leads to a significantly smaller GDP reduction in China, 0.04% compared to the non-linkage scenario (0.88%). In addition, allowing multilateral trading of emissions among these countries shifts the burden of the reduction away from oil products in the relatively carbon-efficient economies towards coal in the less carbon-efficient regions. This induces a substantial reduction of the marginal abatement costs in the above economies.

In summary, this PhD research investigates stakeholders' views on the Chinese carbon market as well as interactions between energy and climate change policies; it also discovers the price drivers for carbon prices in China's pilot ETSs and assesses the impact of including Chinese ETSs in a global emission trading system. Moving forward, as the results suggest that the Chinese pilot ETSs may not be rational and most market participants are not fully aware of the function of the carbon market since they merely fulfil the need for government. The next step would be to discover whether there is a media effect driving carbon prices.

Table of contents

List of Tables & Figures

Chapter 1

Introduction

1.1 Introduction

Over the past few decades, a number of extreme climate events, such as Hurricane Katrina in the US in 2003, unusually heavy rain in the UK in 2013 and devastating sandstorms in Northern China, have forced us to face climate change caused by global warming, one of the major threats to human development. If global warming cannot be contained, a lot of islands and cities will be in danger of disappearing from the world map (IPCC, 2014).

Under the 2015 Paris Agreement, almost every country in the world (184 Parties have ratified the Convention) agreed to keep global temperatures well below 2 degrees Celsius above pre-industrial levels and to pursue efforts to limit the temperature increase even further to 1.5 degrees Celsius (°C) (United Nations, 2015). The report by the Intergovernmental Panel on Climate Change (IPCC) assessed that the 1.5°C would be almost certainly reached within 20 years without major cuts in greenhouse gas emissions. The impact and costs of 1.5°C of global warming will be far greater than expected (IPCC, 2018).

Cutting greenhouse gases (GHGs) is widely recognised as the most direct way to curb global warming. According to the 1992 United Nations Framework Convention on Climate Change (UNFCCC), in order to limit the increase of average global temperature below 2℃ by stabilising GHG concentrations in the atmosphere at a certain level (approximately 450 ppm CO_2 equivalent), binding quantitative targets of reducing GHGs were set in the Kyoto Protocol (1998) for 37 industrialised countries and the European Union.

To achieve the emission reduction goal, various market-based instruments have been developed in the last two decades, including emission trading schemes (ETS), renewable obligations, carbon taxation and feed-in tariffs (FITs). Among all the market-based instruments, there is no doubt that the ETS plays an important role in optimising the overall cost for reducing GHGs. Specifically, an ETS with a 'cap-and-trade' principle implies that a certain amount of emissions allowances can be issued during a trading period. The allowances are distributed by market regulators for free or for auction based on historical emission data of listed enterprises. Afterwards, if the emission abatement cost is lower than the market price of the emission allowance in the ETS, enterprises tend to sell the extra allowance by deploying emission abatement measures. Conversely, if the abatement cost is higher, enterprises will purchase allowances in the ETS to avoid additional costs (MacKenzie, 2009).

Since the launch of the EU Emission Trading Scheme (EU ETS) in 2005, the emission trading mechanism has become a popular instrument to facilitate carbon dioxide mitigation globally (The World Bank, 2014). As of 2016, ETSs were operating across four continents in 35 countries, 13 states or provinces, and seven cities, covering 40 per cent of global GDP, and additional systems were under development (The World Bank, 2016). The most prominent emerging market schemes are China's pilot ETSs, which, taken together, makes them the second largest carbon market in the world with more than 1,000 $MtCO_2e$ (The World Bank, 2014).

By putting a price on the carbon emissions pollution associated with business activity, climate impact caused by companies' operations can be taken into account and therefore incentives for reducing emissions can be put into place. Pricing carbon also responds to stakeholder and investor calls for climate action and ETS allowance price is often used as a proxy for the cost of carbon emission pricing. Therefore, a correct emission price signal in the ETS is essential for stimulating long-term, large-scale investment in emission reduction as enterprises will trade off between emission abatement and allowance purchase. However, currently there is a mismatch between the visible carbon price and the actual cost of carbon abatement in ETSs.

In theory, multiple incentives for mitigating GHGs should have the combined force to achieve emission reduction targets. However, experiences in the EU ETS and previous literature show that the traded carbon allowance prices are usually affected by other parallel carbon reduction incentives that could reduce the actual demand for carbon allowances.

Furthermore, although China is currently piloting ETS designs at the provincial level and a trading market at the national level was formed at the end of 2017, China has indicated that it would consider participating in an international carbon market. Given the scale of China's economy and energy system, its energy trends and climate policies will have a significant impact on global climate change mitigation. Additionally, the linkage may reduce the impact from interactions of parallel incentives for carbon reduction.

Therefore, identifying what impact climate policy interactions, as well as a linked global carbon market, have on carbon price is vital for ETS design and reform, especially for the emerging carbon market in China, as the results could provide policymakers with a reference for formulating an ideal carbon market system, avoiding the detours experienced by other ETSs. Thus, this PhD research attempts to employ mixed research methods to solve the underlying problems that will be specified in the next subsection.

1.1.2 Research motivations and research questions

The EU ETS launched in 2005 is the largest emission trading system in the world covering almost half of the EU's carbon emissions, with 11,000 installations. The EU ETS was designed to achieve the EU's commitment under the Kyoto Protocol of reducing GHGs by 20% by 2020 based on 1990 levels (European Commission, 2015). In 2008, the EU introduced a binding renewable energy target stating that 20% of its energy consumption must be from renewable sources by the end of 2020; the original intention of the supplemental policy was to help motivate carbon emission reduction. Theoretically, renewable obligations and the ETS would promote each other directly, adoption of renewable energy would contribute to carbon emission reduction while carbon abatement instruments would stimulate renewable energy (Fischer and Preonas, 2010).

In the first two phases of the EU ETS from 2005 to 2012, EU allowances (EUAs) were allocated rather than auctioned. Due to the over-allocation of EUAs and the economic depression after the financial crisis, most covered entities enjoyed a surplus of allowances and were thus not highly motivated to reduce their emissions (Cadez and Czerny, 2010). In other words, the system was not functional yet (Fan et al., 2013).

Although economic recession (IETA, 2014) and allowance allocation rules (Schleich et al., 2009) were generally recognised as the principal causes, the interactions between the emission trading market and parallel energy and low-carbon policies also contributed to the weakening impact on the ETS, which have not been widely investigated.

In the case of the EU ETS, David Hone (Hone, 2013b), climate change advisor for Shell, concludes that other low-carbon policies (e.g. renewable obligations) have distorted emissions mitigation economics across the EU, and the recession has further exacerbated the situation. Policy interactions are increasingly considered important barriers to introducing a new ETS as it would operate in parallel with pre-existing regulations and interact with each other directly or indirectly, and poorly designed policy mixes might result in undesirable overlaps (Zhang et al., 2014a).

Currently most studies with respect to interactions between climate change policies focus on Europe in scope; few have focused on China to discover the potential risk of carbon market failure caused by co-existing and competitive low-carbon incentives.

As the largest emitter in the world (Liu et al., 2013b), China is applying diverse climate change policies including energy conservation, renewable energy development as well as launching pilot ETSs in seven cities (Zheng, 2013). There are only a few studies on ETSs in China, mainly focusing on describing the market features and characteristics (Cheng and Zhang, 2011, Zhang et al., 2014a), as well as the market design and relevant legal and regulation issues (Zeng, 2010, Wei and Tian, 2013), or modelling the economic performance and impact of emission trading in China (Liu and Dai, 2004) (Zhou et al., 2013). Recognising the significance of the potential impact of parallel policies and the emerging carbon market in China, as well as the limits of existing simulation-based assessment methods of policy interaction, it is important to understand future trends. The trends would be determined by the perception of key stakeholders such as policy makers and market participants.

From a bottom-up perspective, an ETS is a public climate change market-based policy influenced by multiple sector stakeholders; the government is the policy maker that regulates and supervises the implementation of the carbon market, while industry enterprises are the market participants that reduce emissions and maximise the economic benefits at the same time. Moreover, public participation of academia and NGOs should always be included throughout the whole policy-making process including designing, implementing and monitoring (Yang et al., 2010).

Therefore, stakeholder views on carbon markets are critical because policy construction can be influenced directly from, or improved by, government determination, participant confidence and enthusiasm, as well as public cognition and acceptance.

Motivated by the above, the first two research questions centring on the interactions between ETS and other low-carbon policies are as below:

- ***Research question I: what are stakeholders' views on emission reduction, implementation of ETS and interactions between ETSs and other climate change and low-carbon policies in China?***

  This study is interested in stakeholder views on a range of issues related to Chinese energy-saving and emission reduction policies, including evaluation of low-carbon incentives, perspectives on Chinese pilot ETSs and understanding of the interactions between carbon markets and other climate change and low-carbon policies. Specifically, the study is interested in stakeholders' views on the potential conflict between ETSs and other energy and climate change policies, and how they assess the policy interactions' impact on price in China's carbon markets.

- ***Research question II: what are the price drivers and the impact of parallel energy and low-carbon policies on carbon prices in China?***
  Seven pilot ETSs in China have successively been in operation since 2013; this study intends to empirically investigate the underlying rationality of pricing behaviour in those carbon markets and the effect of policy interaction with low-carbon policy in the China's seven ETS pilots.

On the other hand, the potential benefits of linking emission trading markets across countries and regions are well recognised. A global market provides more flexibility for parties to achieve emissions reductions at the lowest marginal cost across all covered sectors. Some hope that this global expansion of carbon markets will revive their fortunes, helping to raise investments in low-carbon and climate change mitigation technologies. Although China is currently piloting ETS designs at the provincial level, a trading market at the national level had just commenced construction at the end of 2017. Additionally, China has indicated that it would consider participating in an international carbon market. Given the scale of China's economy and energy system, its energy trends and climate policies will have a significant impact on global climate change mitigation.

As a single global carbon market is an unlikely outcome in the near future following the Paris Agreement, it is more likely that any international trading system will grow out of a network of bilateral and multilateral agreements authorised and entered into voluntarily by participating parties. Therefore, a third research question is raised as below:

- ***Research question III: what is the impact of linking ETSs across countries and regions on carbon prices?***
  This study evaluates the impact of linking ETSs in China with other ETSs, and the findings are intended to inform the development of a global ETS.

1.1.3 Research findings and contributions

To answer the first research question, a two-stage survey including a closed-form questionnaire followed by open interviews was conducted to elicit views and expectations of stakeholders on carbon markets in China (Guangdong pilot), with an emphasis on stakeholder perspectives of how the ETS may interact with other existing or proposed low-carbon and clean energy policies.

The survey shows that academic stakeholders, rather than stakeholders from other sectors, viewed the policy interactions as a significant obstacle for developing a carbon market in China, and there is a positive correlation between the recognition of such policy interactions and the time spent on energy-saving and emission reduction policies. Whereas both increasing renewable targets and imposing a carbon tax in addition to an existing ETS would be expected to depress prices in the ETS, relatively few respondents identified this correctly. Apart from government respondents, all other key stakeholders generally lacked confidence in China's carbon markets, due to their lack of knowledge and information about the market and their concerns regarding uncertainties and failures in government policy and regulation.

Contributions from the first study within this PhD project are as follows: first, although previous studies suggest parallel low-carbon policies would influence allowance prices in the ETS and send industry wrong signals (Richstein et al., 2015, Syri and Cross, 2013, Fischer and Preonas, 2010, Bohringer and Rosendahl, 2010, Pethig and Wittlich, 2009), there has been little work on potential policy interaction in China and on related stakeholder beliefs. This is the first survey with a focus on the interaction of low-carbon and energy policies in China, thereby filling the literature gap. Second, learning lessons from existing pilot emission trading systems are crucial in designing a cost-effective national ETS in China. This study will open the discussion and provide policymakers with a better understanding of some of the built-in biases and perceptions of key actors. The investigation of stakeholders' views on the Chinese carbon market and their perceptions of policy interaction would benefit the future design, construction, operation and improvement of emission reduction incentives and instruments.

Subsequently, an empirical study was conducted to address the second question by probing the underlying rationality of pricing behaviour and the effect of policy interaction with low-carbon policy in the seven Chinese ETS pilots during 2014-2016 using an ordinary least square (OLS) and event-based regression model. Compared to existing studies focusing on the price drivers of the Chinese ETS pilots (Lin and Jia, 2019, Fan et al., 2013, Zhao et al., 2017), this study will complement the introduction of further renewable energy and extreme weather as explanatory variables, and take a step beyond by demonstrating the effect on allowance prices of policy interactions between renewable energy policy and ETSs.

The empirical results show that, first, crude oil and domestic liquid natural gas are positively linked to the allowance price in the Beijing, Shanghai and Guangdong pilots, while the price of coal lacks explanatory power. Second, extreme weather is positively correlated with Shenzhen carbon prices. Third, in contrast to existing studies (Tu and Mo, 2017, Koch et al., 2014), a positive correlation is demonstrated between renewable energy supply and carbon prices in the Tianjin carbon market, and low-carbon policy for promoting renewables raises carbon prices in the Guangdong pilot Finally, ETS regulatory events, such as the announcement on surrender date (adjustment) and offset limitation influences price changes in the Shenzhen and Tianjin pilots respectively. Overall, the empirical results indicate current ETS pilots in China are segmented and irrational.

The second study contributes the following: first of all, it fills and extends the current empirical analysis of pricing behaviour in Chinese ETSs by further incorporating renewable energy factors and extreme weather as additional explanatory variables. This is the first attempt by empirical analysis in assessing the impact of parallel low-carbon policy on allowance prices in China. Second, China's ambitious emission reduction target (60-65% carbon-intensity reduction from 2005 levels by 2030) could only be achieved under a functional and efficient policy framework; therefore, understanding the interactions between incentives will benefit the development and improvement of climate change policy, maximise the efficiency of the carbon trading market, effectively promote carbon abatement with a clear carbon price signal, and provide insight into the dynamic relationship between renewable promotion policy and carbon price series.

Furthermore, to assess the impact of linking carbon markets around the world, the GTAP-E model is employed to simulate the linkage. Our results indicate that, although the abatement costs increase in the Chinese carbon market after the linkage, a strong and robust carbon price could give investors the right price signal on the value of carbon emissions. Additionally, a link between the Chinese and the international carbon markets leads to a significantly alleviated GDP decline in China, resulting in 0.04% reduction in GDP compared to the non-linkage scenario of 0.88% reduction in GDP. In addition, allowing multilateral trading of emissions among these countries shifts the burden of the reduction away from oil producers in the relatively carbon-efficient economies towards coal in the less carbon-efficient regions. This induces a substantial reduction of the marginal abatement costs in the above economies.

The third study contributes the following: first, using a top-down approach, this research verifies and replenishes the carbon market linkage analysis based on previous studies. With a modified and extended computable general equilibrium model, it verifies the validity of applying a computable general equilibrium (CGE) model in assessing climate change policy. Second, the study generates essential references for confirming the potential benefits and energy consumption tendency brought by forming an international emission trading market. A growing number of countries are integrating cap-and-trade schemes into their national climate policies, but there are currently only a few links between trading schemes. Because of the diversity in numerous features of existing and emerging schemes, it is appropriate to ask a variety of questions, including whether the schemes can be linked and what impact such a linkage would bring to the relevant parties. The results show that linking results in a convergence of allowance prices and linking promises a wider range of abatement costs in the market by expanding the range of available mitigation options. The results could provide valuable references for policymakers in formulating an efficient policy framework of carbon market linkage.

1.1.4 Structure of the thesis

This thesis is organised as follows: Chapter 1 states the motivations for the study and the research questions following from the motivations. This chapter also presents a comprehensive review of the literature within the research context. Chapter 2 investigates stakeholder views on interactions between parallel climate and low-carbon policies using a two-stage survey, followed by an empirical study to discover the rationality of pricing behaviour and the effect of policy interaction on the Chinese carbon market in Chapter 3. Chapter 4 assesses the quantitative impact of global carbon market linkage. Conclusions, policy implications and limitations are discussed in the last chapter.

1.2 Literature review

1.2.1 International climate change policy framework

The first step in tackling global warming and climate change is the United Nation Framework Convention on Climate Change (UNFCCC) which was adopted at the Rio Earth Summit in 1992. The Convention came into force in 1994 aiming to prevent dangerous anthropogenic interference with the climate system (United Nations, 1992). At the end of 1997, the Kyoto Protocol was structured on the principles of the Convention, but due to the complex ratification process, the Protocol did not come into force until 2005. Binding emission reduction targets were set for 37 industrialised countries and the European Union, as these developed countries are largely responsible for the current high levels of GHGs in the atmosphere. These targets add up to an average five per cent reduction in emissions based on 1990 levels over the first commitment period 2008 to 2012. After the first five-year period, the second commitment period from 2013 to 2020 was launched in Doha.

Under the Kyoto Protocol, three flexible and cost-efficient means have been offered in addition to those national measures for countries to meet their own targets: International Emissions Trading, Clean Development Mechanism (CDM) and Joint Implementation (JI). CDM allows countries under the Protocol to implement an emission reduction project in developing countries and to earn tradable certified emission reduction credits (CERs) that equate to one tonne of CO_2. JI allows countries under the Protocol to earn tradable emission reduction units (ERUs) by deploying emission reduction projects in other countries under the Protocol. The International Emissions Trading mechanism provides the platform for countries under the Protocol to trade spare emissions permits with other countries. Therefore, a new commodity was created in this platform; as carbon dioxide is the principal GHG, thus carbon is now tracked and traded like any other commodity in the emission trading market, or simply called the carbon market, and carbon pricing has become an important component of climate policies (UNFCCC, 1998).

As another key step for limiting average increases in global temperature, the Paris Agreement was reached in 2015 and came into force at the end of 2016. The Agreement aims to strengthen the global response to climate change by keeping global temperature rises this century to well below two degrees Celsius above pre-industrial levels and to pursue efforts to limit the temperature increase even further to 1.5°C. The Paris Agreement requires all Parties to put forward their best efforts through 'nationally determined contributions' (NDCs) and to strengthen these efforts in the years ahead (United Nations, 2015).

The above is a brief introduction to the development of the international climate change convention framework. Addressing climate change is a difficult and complex task because fossil fuel use runs throughout our economies and societies. No single policy can solve the issue, thus a carefully thought-through policy package including climate change or low-carbon policies and energy policies would be an optimal solution.

There is a distinction between climate change policies and energy policies. Climate change or low-carbon policies have the primary goal of reducing emissions while energy security and affordability are the main objectives of energy policies with emission reductions as one of a number of their benefits. Climate change policies include carbon pricing, regulation of GHGs, subsidies for decarbonisation activities and supporting policies for low-carbon technologies such as carbon capture and storage. Energy policies that reduce emissions include energy performance standard, renewable energy support, energy taxes and subsidies. (Hood, 2013). Table 1-1 outlines a wide range of key policies that reduce GHGs.

The transition to a decarbonised economy will require all investments to be on a low-carbon footing, thus requiring policy instruments which reach throughout the economy, influencing all production and consumption decisions. By putting a price on emissions to reflect the societal costs of climate change, carbon pricing plays a vital role in achieving the targets. The main policy option of carbon pricing is an emission trading system, which limits the emissions that can be emitted during a certain period. This system gives a direct price incentive for producers to shift towards clean investments and operations.

Since the emergence of the EU ETS, the world has witnessed a rapid growth in GHG trading markets. The Swiss ETS was introduced in 2008 and now covers 55 companies from 25 categories of activities. It is expected that the Swiss ETS will join the EU ETS in the near future. Following in the footsteps of Europe, the US, Canada and Japan have also launched market-based GHGs reduction programs in various forms. In the US, the Regional Greenhouse Gas Initiative (RGGI) began operating in 2009 and covers carbon dioxide emissions from power plants in nine northeast and Mid-Atlantic States. In Canada, in 2007 the province of Alberta set up a GHG reduction program under its Specified Gas Emitters Regulation (SGER). However, since the SGER expired in September 2014, the current GHGs reduction program in Alberta is in the process of renewal. The largest cap-and-trade system is that of California, which in 2014 linked up to the smaller cap-and-trade system in the province of Quebec. In addition, Japan has also established various sub-national systems since 2010, including ETSs in Tokyo, Kyoto and Saitama (The World Bank, 2014, The World Bank, 2016).

Table 1-1 Range of energy and climate policies that reduce GHGs

Policy type	*Policy option*
Market-based instruments	Emission trading system Carbon taxation Taxes/charges on inputs or output of process (e.g. fuel and vehicle taxes)
Command-and-control regulations	Performance standards Technology standards Reporting requirements Requirements for operating certification Land use planning, zoning
Technology support policies	Feed-in tariffs Green certificates/renewable portfolio standard Public and private R&D funding Public investment in underpinning infrastructure for new technologies Policies to remove financial barriers to acquiring green technologies
Information and voluntary approaches	Education and training Product certification and labelling Award schemes Rating and labelling programmes

(Source: Hood, 2013)

Three major research trends have broadened the scope of climate policy development as of the last decade. First, the study of the adoption and integration of climate policy development; in these studies, command-and-control regulations and market-based instruments have been compared in terms of efficiency, commitment, credibility, flexibility, implementation and international cooperation (Hepburn, 2006, Tang et al., 2019, Ren et al., 2018, Haoqi et al., 2017, González-Eguino, 2011) .

In recent years, a dominant view has emerged among researchers that market-based instruments have taken centre-stage in the debate on climate change policy (L.Sonneborn, 2004, Chameides and Oppenheimer, 2007, Turner and Daily, 2008, Patrinos and Bradley, 2009, Stavins, 2001, Wang and Chen, 2015). Tietenberg (2006) concluded that mitigation costs can be reduced by 40%–95% by deploying market-based instruments. In addition to the rapid development of ETSs around the world, different types of environmental tax reforms have been introduced in Sweden, Norway and Germany (Patuelli et al., 2005). In addition, a regional effect has been observed in China (Haoqi et al., 2017), as command-and-control environmental regulation plays a positive role in eco-efficiency improvement whilst market-based regulation has no significant impact on the western region of China, in contrast to the eastern region (Ren et al., 2018).

The mainstream market-based instruments for emission reduction are carbon tax and emissions trading. There is a wealth of literature on cost-benefit analysis from the perspective of economic efficiency which started with Weitzman (1974), Weitzman (1978), which state that the choice of ETS or carbon tax measures is dependent on the relative slope of the marginal abatement cost and benefit curve of emission reduction.[1] Many studies (Pizer, 1999, W.H.Parry and III, 1999, Pizer, 2002, Stranlund and Ben-Haim, 2008) have verified and extended Weitzman's studies in both simulation and empirical analysis by taking unstructured uncertainties into account and these have confirmed that the rule still holds. Nevertheless, Shinkum and Sugeta (2016) further investigated Weitzman's rule, and it seems the rule does not always hold when entry costs of firms and asymmetric information exist.

Despite the pros and cons of emission trading systems and carbon taxation, the early literature favoured taxation policies based on a common perception of flat abatement benefits curves (Schlesinger, 2006, Alton et al., 2014, Pezzey and Jotzo, 2012). However, as more factors were brought into consideration, the advantages of emission trading systems became increasingly prominent (Chameides and Oppenheimer, 2007, Yang and Oppenheimer, 2007, Quirion, 2010, Wang et al., 2016, Xu et al., 2016, Barragán-Beaud et al., 2018, Liu et al., 2018). Finally, contrary to conventional wisdom, controlling the cumulative quantity of GHG emissions may be superior on efficiency grounds when marginal abatement costs are uncertain (Keohane,

[1] If the absolute value of the slope of the marginal benefit curve is less than the absolute value of the slope of the marginal abatement cost curve, then price control policies (such as a carbon tax) will be more efficient than quantity control policies (such as cap and trade or ETS). Otherwise, the quantity control policies will be more efficient and the difference in efficiency will increase with the increase in the difference between the two slopes.

2009). Through a case study of the US, Keohane (2009) argued that emission trading offers a great deal of flexibility in allocating the value of emissions, enhancing its political feasibility.

Therefore, reducing emissions for curbing climate change requires policymakers to find cost-efficient means to meet the obligations. The literature shows that marginal abatement cost curves have frequently been used in this context to illustrate optimal selections of climate change policies. Based on previously published research, this PhD study intends to discover interactions between climate change policies caused by distortion of the marginal abatement cost curve. A dedicated literature review on climate change policy interactions is presented in Chapter 2.

The second stream that opens up is the study of the economics of adaptation to climate change, which includes issues such as costs and benefits of adaptation and the identification of synergies between global climate actions and development objectives.

Climate change policy presents many opportunities as well as challenges (Liobikienė and Butkus, 2018). The widespread concerned is that climate change policy imposes a significant cost on the economy (Bretschger, 2017). Individual countries are reluctant to adopt the necessary policy measures because they fear negative consequences for their domestic economy (Dietz et al., 2016, Aglietta and Espagne, 2016, Orlov and Aaheim, 2017, Dafermos et al., 2018). Nevertheless, Bretschger (2017) identified a sharp contrast between short-term and long-term policy effects, suggesting that pollution abatement has a positive growth effect in the long run. With a case integrated assessment model-based study of Sub-Saharan Africa, Leimbach et al. (2018) found that Sub-Saharan Africa could participate in ambitious climate policy at roughly net zero cost while generating revenues from the export of biomass. A UN report also suggested that a ‘green and low-carbon economy would support growth, especially if one measures wealth as stocks of useful assets, inclusive of natural assets, but not narrowly as flows of produced output’ (UNEP, 2011).

As one of the most prominent climate change mitigation actions, it is widely recognised that a properly functioning ETS can provide for price discovery and allow for cost-effective solutions for achieving greenhouse gas reductions (Ellerman and Buchner, 2008, Ellerman et al., 2010, Martin et al., 2015, Bel and Joseph, 2015). The overall goal of an ETS is to minimise the cost of meeting a set emission target or an emission cap (Laing et al., 2013). In 2015, the UK Parliament House of Commons Energy and Climate Change Select Committee (ECC Select Committee) recommended that a future international climate framework to facilitate ETS linkage would be the most cost-effective way to reduce greenhouse gas emissions (Kachi, 2015).

However, the sharp and persistent price decline in the EU ETS has triggered intense debates about the decisive allowance price drivers (European Commission, 2012, Clò et al., 2013, Koch et al., 2014). Such depressed allowance prices are not likely to provide sufficient incentives for low-carbon technological investments which reduce GHGs (Nordhaus, 2011) and may increase the risk of carbon lock-in (Clò et al., 2013).[2]

Although climate change policies have evolved significantly since the early 1990s, a comprehensive assessment of global patterns of national climate change policies over the last 27 years and across 171 countries found out that carbon pricing is still one of the policies that are least addressed and yet to be uncovered (Schmidt and Fleig, 2018). It is necessary to explore the price behaviours of ETSs to justify the effectiveness of market-based carbon pricing instruments. A dedicated literature review on the price drivers of ETSs is presented in Chapter 3.

The third major trend in the literature is about the international context that ETS could provide. Research in this area has been particularly fruitful in the last few years as ETS linkage is considered a viable catalyst for enhancing the role of a cap-and-trade system.

There are two possible approaches to linking ETSs and other carbon pricing systems: a global top-down approach through the UNFCCC framework, or a bottom-up approach through bilateral and multilateral agreements between jurisdictions. 'Top-down' is determined by a centralised multilateral decision-making process under the UNFCCC framework, while 'bottom-up' is a sub-national or individual decentralised decision-making procedure (Zapfel and Vainio, 2002, Tuerk et al., 2009, Green et al., 2014).

Linking two or more ETSs appears to offer a win-win outcome. It signals a common effort to address climate change while allowing for more flexible arrangements to address the political and economic specificities of each jurisdiction (Marschinski et al., 2012, Green et al., 2014, Burtraw et al., 2013). Furthermore, linked markets are likely to be more liquid, since the more active the market participants, the weaker the price setting capability of each one individually

[2] Carbon lock-in refers to 'Industrial economies have been locked into fossil fuel-based energy systems through a process of technological and institutional co-evolution driven by path-dependent increasing returns to scale. It is asserted that this condition, termed carbon lock-in, creates persistent market and policy failures that can inhibit the diffusion of carbon-saving technologies despite their apparent environmental and economic advantages' UNRUH, G. C. 2000. Understanding carbon lock-in. *Energy Policy,* **28**, 817-830..

(Metcalf and Weisbach, 2012). In addition, the potential for carbon leakage emerging may be relieved when competing industries in the linked system face a similar price for compliance (Kachi et al., 2015). Most importantly, merging two or more systems expands the number of mitigation options, thereby facilitating reductions at the least possible cost overall (Flachsland et al., 2009, IETA, 2016, Qi and Weng, 2016). The broader the base for a given carbon price, the more efficiently it operates, and the lower the overall cost of reducing emissions for the economies within its scope (IETA, 2016).

However, the impact of a global trading system may not always be positive for all parties. Babiker et al. (2001) and Flachsland et al. (2009) argue that market distortions or trade effects can affect the competitiveness of the industry and the economic advantages for the participating countries, while Tomás et al. (2010) showed that a loss in industry competitiveness may not result from the enforcement of the emission trading system, but from other restrictions. Meanwhile, the experiences and lessons of international climate negotiations suggest that reaching a global top-down international carbon market is extraordinarily difficult due to the heterogeneity in the design and type of emerging carbon markets (Carbon Trust, 2009, Ranson and Stavins, 2016, Jackson et al., 2018).

Existing papers focus on the evaluation of linking ETSs among a small scope of regions, mainly the EU or US. As the effects of linkage mainly rely on the relative emission mitigation cost across regions (Qi and Weng, 2016), the difference in research region scope would result in different evaluation conclusions. Furthermore, many studies have discussed either the institutional compatibility or the feasibility of ETS linkage (Ellis and Tirpak, 2006, Tuerk et al., 2009, Jotzo and Betz, 2009, Borghesi et al., 2016), but this PhD study puts more focus on the economic impact of ETS linkage. Therefore, a multi-regional computable general equilibrium model will be employed to capture the impact on emission reductions, abatement costs as well as economic growth from ETS linkage among a wider scope of regions. A dedicated literature review on computable general equilibrium modelling for ETS policy assessment is provided in Chapter 4.

1.2.2 Climate change policy development in China

Chinese carbon markets are the main context of this PhD research, therefore it is important to follow the current state and trend of the Chinese carbon market. Since China's market reform in the 1970s, its economic growth has been remarkable in that its GDP has increased more than 80-fold. Given the requirements of hyper growth in economic development, this has led to an enormous increase in energy consumption. In 2010, China's energy consumption exceeded the United State for the first time, and became the world's largest energy consumer with the equivalent of 2.43 billion tonnes of oil consumed (Lee and Zhang, 2012). Meanwhile, huge energy consumption in China, especially fossil fuel consumption, meant that China's contribution to the world's GHGs and global warming was greater than ever. As the world's leading energy consumer, 80% of the world's increase in carbon emissions was from China in 2011 (Liu et al., 2013b). Therefore, highly efficient and large-scale reduction is the most pressing economic priority for the Chinese government.

1.2.2.1 Energy saving and emission reduction in China

In the Copenhagen climate negotiations in 2009, the Chinese government committed to a reduction in national carbon emissions intensity (carbon emissions per unit of GDP) of up to 40%-45% by 2020 based on the 2005 level. Under the 12^{th} Five-Year Plan (12^{th} FYP) from 2011 to 2015, energy intensity (energy consumption per unit of GDP) was reduced by 16% and carbon intensity by 17% below 2010 levels by the end of 2015. In the most recent (13^{th}) FYP, with an average GDP growth expectation of above 6.5%, the carbon intensity reduction target by the end of 2020 has increased to 18%. Table 1-2 shows the changes in energy-saving and emission reduction targets in the 11^{th}, 12^{th} and 13^{th} FYPs; it is obvious that the general trend is a decrease in carbon intensity and energy intensity.

Table 1-2 Energy-saving and emission reduction targets in the 11th, 12th and 13th Five-Year Plans

Targets	*11^{th} FYP (by 2020)*	*2010 (target achieved)*	*12^{th} FYP (by 2015)*	*2015 (target achieved)*	*13^{th} FYP (by 2020)*
Average GDP growth	7.5%	11.2%	7%	7.8%	>6.5%
Carbon intensity: Reduction in carbon emissions per unit of GDP	-	-	17%	20%	18%
Energy intensity percentage	20%	19.1%	16%	18.2%	15%

(Sources: NDRC, 2016a, Hu, 2016)

Meanwhile, a series of upcoming incentive schemes, including ETS pilot programs in seven cities, have been included in the FYP. As a matter of fact, China started to develop a low-carbon economy in the last century following the publication of the first White Paper regarding sustainable development in 1994. Table 1-3 shows the dominant national climate change policies in China (Wu et al., 2012).

Table 1-3 Main national climate change policies in China

Year	*Official documents*	*Key policies*
1998	People's Public of China Energy Saving Law	Energy conservation and efficiency; Develop low-carbon and renewable technologies.
2005	Renewable Energy Law	National renewable energy targets; Mandatory connection and purchase policy; National FITs system; Cost-sharing and funding for renewable energy.
2006	Eleventh Five-Year Plan	Setting GHG emissions reduction target; Improving energy efficiency.
2007	National Action Plan on Climate Change	Slow down GHG emission; Promote renewable energy.
2011	Twelfth Five-Year Plan	Binding GHG emissions reduction target; Pilot ETS project; Promote renewable energy.
2016	Thirteenth Five-Year Plan	Binding GHG emissions reduction target; Building medium to long-term emission reduction programme; Optimising industry and energy mix.

(Source: National Development and Reform Commission [NDRC])

Until recently, 'command-and-control' policy intervention with direct regulatory control played the leading role in curbing climate change while market-based mechanisms had limited application. However, as a widely recognised essential policy tool, market-based mechanisms can help China meet its energy and carbon intensity targets as well as improving energy efficiency (Han et al., 2012).

As one of the most effective financial incentive mechanisms for renewable energy, feed-in tariffs (FITs) ensure renewable energy generators can cover their costs and earn an appropriate profit by setting a price for grid companies to pay for on-grid electricity generated by specific technologies (Schuman and Lin, 2012).

The NDRC (National Development and Reform Commission) introduced FITs for wind power in 2009, which are 0.51, 0.54, 0.58 and 0.61 CNY per KWh for four different regions in China from 2009 to the present, according to different wind resources in each region. Two years later, in 2011, the solar PV FIT was introduced at 1.15 and 1.00 CNY per KWh for solar PV projects approved and completed at different times (Zeng et al., 2013).

According to the report by the Global Energy Network Institute (GENI) and the World Resource Institute on renewable energy in China, hydropower, wind, solar and biomass power will be the main sources of renewable energy in China. China is the world's largest hydropower generator with 229 GW installed capacity, and its target in the 12th FYP was set at 290 GW in 2015. In the 13th FYP, China's goal is increasing total installed hydropower capacity to 380 GW by 2020, of which 40 GW is pumped hydro. Wind power development is also very rapid in China with 75 GW installed capacity in 2012 and 100 GW achieved in 2015. As for solar PV, the target in the 13th FYP is 105 GW by 2020, and the targeted cost reduction is 50% by 2020 compared to 2015 levels. Although biomass contributes the least to Chinese renewable energy, it is expected that 15GW of cumulative biomass and waste electricity generation capacity will be reached by 2020.

1.2.2.2 Emission trading schemes in China

The Chinese government pays great attention to the development of a future carbon market. The Five-Year Plan is the most important national document released by the Chinese Central Government. With increasing energy demand and consumption, as well as growing GHG emissions, the energy policy in the Five-Year Plan changed significantly from expanding energy production to improving energy efficiency; reducing carbon emissions and promoting renewable energy for sustainable development was highlighted in the most recent plan (Yuan and Zuo, 2011).

In fact, China has already conducted a series of experimental projects to test the feasibility of emission trading systems in China. For instance, in 2002, China's State Council set out the 10th FYP for Preventing and Controlling Acid Rain and SO_2 emissions in the two control zones, which suggested the implementation of a pilot project for an SO_2 emissions trading scheme in the two control zones. There were different types of pilot programmes according to different motivations, such as compensation between new and old emitting sources, or within the same enterprise, and emission trading between enterprises. However, none of these trading cases could successfully develop a well-organised trading market (Chang and Wang, 2010). In March 2011, China officially included in the 12th FYP plans to establish carbon emission trading systems. Seven pilots had been authorised by the NDRC in October of the same year (IETA, 2012) (Table 1-4).

Table 1-4 Overview of ETS pilots in China

	Shenzhen	Shanghai	Beijing	Guangdong	Tianjin	Hubei	Chongqing
General information							
Starting date	18 Jun. 2013	26 Nov. 2013	28 Nov. 2013	19 Dec. 2013	26 Dec. 2013	2 Apr. 2014	19 Jun. 2014
Reduction target[3]	21%	20.5%	20.5%	20.5%	20.5%	19.5%	19.5%
GHG emissions[4] ($MtCO_2e$)	153	297.7	188.1	610.5	215	463.1	243.1
Per capita GDP (2013)	CNY 136,947 (EUR 18,727)	CNY 90,092 (EUR 12,320)	CNY 93, 213 (EUR 12,746)	CNY 58,540 (EUR 8,005)	CNY 99,607 (EUR 13,621)	CNY 42,613 (EUR 5,827)	CNY 42,795 (EUR 5,852)
Per capita GDP growth (2013)	11.5%	6.1%	5.2%	7.8%	7.9%	9.7%	11.3%
ETS size							
Absolute cap ($MtCO_2$)	34.78 (2015)	160 (2015)	50 (2015)	408 (2015)	160 (2015)	281 (2015)	106 (2014)
Estimated coverage	40%	57%	45%	60%	60%	35%	40%
Scope	Industry; Power; Buildings	Industry; Transport; Aviation; Buildings	Industry; Power; Buildings	Industry; Power	Industry; Power; Buildings	Industry; Power	Industry; Power
Firm or facility-level threshold for inclusion in ETS	Enterprise: 5,000 tCO_2e/year; public buildings: 20,000 m^2; government buildings: 10,000 m^2	Power and industry: 20,000 tCO_2/year; non-industry: 10,000tCO_2/year	10,000 tCO_2/year, considering both direct and indirect emissions	20,000 tCO_2/year or 10,000 tce/year energy consumption	20,000 tCO_2/year considering both direct and indirect emissions	10,000 tce/year energy consumption	20,000 tCO_2e/year
Allocation and purchase							

3 Carbon intensity reduction target by 2020 (end of the 12th Five-Year Plan), based on carbon intensity level in 2015.
4 Overall GHG emissions excluding LULUCF in 2012.

Allocation methodology	Benchmarking	Bench-marking and Grand-fathering[5]	Bench-marking and Grand-fathering[6]	Bench-marking and Grand-fathering[7]	Bench-marking and Grand-fathering	Grand-fathering	Grand-fathering
Purchase allowance	Auction (3% of allowances in 2014)	One-off action before compliance deadline	Buy or auction allowances in order to stabilise the market.	Auction (3% in 2013 and 10% in 2015, 2016)	Buy or sell allowances in order to stabilise the market	Auction (small proportion)	Compliance entities must not sell more than 50% of their free allocation
Flexibility							
Banking	Allowed						
Borrowing	Not allowed						
Offsetting[8]	Domestic offsets						
Offset limitation[9]	10%	5%	5%	10%	10%	10%	8%
Compliance							
Compliance period	One year						
MRV	Annual reporting of CO_2; third-party verification is required						
Penalties for non-compliance	CNY 50,000-150,000 (EUR 6,544-19,632)	CNY 10,000-50,000 (EUR 1,308-6,544)	up to 50,000 (EUR 6,544)	CNY 10,000-50,000 (EUR 1,308-6,544)	No financial penalties	CNY 10,000-150,000 (EUR 1,309-19,632)	No financial penalties
Penalties for failing to surrender enough allowances	3 times the average market price	N/A	3-5 times the average market price	Double the allowances deducted from allocation for the following year	Disqualified for preferential financial support and policies for 3 years	1-3 times the average market price	Disqualified for preferential financial support and policies for 3 years

(Source: ICAP, 2018b)

5 Mainly free allocation through grand-fathering based on 2009-2012 emissions or emissions intensity; Bench-marking for specific entities.
6 Mainly free allocation through grand-fathering based on 2009-2012 emissions or emissions intensity; Bench-marking for new entrants and entities with expanded capacity.
7 Mainly free allocation through grand-fathering based on 2009-2012 emissions or emissions intensity; Bench-marking for electricity generators, certain cement and iron and steel industrial processes and new entrants.
8 Domestic project-based carbon offset credits - China Certified Emission Reductions (CCER) are allowed.
9 The use of CCER credits is limited to corresponding proportion of the annual compliance obligation.

The published literature on ETSs in China follows three main research directions: the mechanism and design of ETS, evaluation of ETS effectiveness, and the feasibility of regional pilot ETS linkage.

First, a number of studies recognise that the mechanism design of ETSs largely determines their environmental and economic effectiveness, market efficiency and effect on social welfare. There is no universal model for carbon emission trading (Zhou et al., 2013, Li et al., 2014b); policy designs for sectoral (Zhang et al., 2011, Cong and Wei, 2012, Xu et al., 2015a, Jiang et al., 2015, Cai et al., 2015, Chen et al., 2015, Biedenkopf et al., 2017), regional (Yi et al., 2011, Wei et al., 2012, Qi et al., 2014a, Wu et al., 2014b, Jiang et al., 2014, Liao et al., 2015, Chang et al.), and national ETSs (Raufer and Li, 2009, Li et al., 2011, Hübler et al., 2014, Cheng and Zhang, 2011, Jiang et al., 2017) have been proposed.

With regard to the sectoral-level ETS, most research attaches importance to the energy-intensive industrial sectors, particularly the power sector. Through an agent-based model for the power sector in China, Cong and Wei (2012) indicated that electricity prices would increase because external environmental cost would be internalised during carbon emission trading. They also considered that output-based allocation would be superior to emission-based allocation for carbon market design in China, since output-based allocation is much more conducive to environmental conservation. Xu et al. (2015a) stated that power plants with lower carbon intensities should be allocated more allowances to achieve reduction targets effectively. In addition to the power sector, approaches for constructing ETSs in the transportation sector are discussed by Jiang et al. (2015) and Cai et al. (2015). Biedenkopf et al. (2017) and Chen et al. (2015) took the lead in exploring key elements and implementation paths of the ETS in China's building sector. Zhang et al. (2011) addressed the importance of a reasonable cap on sectoral emissions, transparent MRV and strong incentives for broad participation.

While China is currently piloting ETSs at the regional level, many researchers have focused on the design of ETS for specific regions. Due to regional divergences in economic development, industry structure and resource endowment, regional allowance allocation approaches considering equity, intensity reduction target fulfilment and reduction potential among regions in China are generally proposed (Yi et al.). Wei et al. (2012) found a large gap exists in potential reduction capacity and marginal abatement cost among Eastern, Middle and Western China by generating an abatement capacity index based on weighted equity and efficiency indexes. Chang et al. (2016) verified previous studies by empirical analysis and proposed the Shapley value-based allocation criterion as an equal and effective emissions reduction target allocation, as they found that Eastern and Southern China, and the Middle Yellow River regions are the main emissions allowance buyers, while Western and Northern China, and the Middle Yangtze River regions are the main sellers of emissions permits, due to the diverse abatement costs. Qi et al. (2014a) and Jiang et al. (2014) provided a summary of the distinct features of the Hubei and Shenzhen pilot ETSs in China, and described the policy designs including coverage, cap, allowance allocation and compliance rules. Liao et al. (2015) and Wu et al. (2014b) elucidated the evolution of Shanghai's ETS. The former study suggested the Shanghai's ETS should adopt different modes at different periods and should introduce a tiered price mechanism and subsidy mechanism while the latter proposed improving the current ETS design in terms of allocation principles, information disclosure and risk management.

Compared with the sectoral or regional research, a larger part of the literature is focused on establishing a nationwide ETS in China, from the perspectives of either specific mechanism design or general framework and institutional arrangements. As more sectors and enterprises participating in the ETS could provide greater economic benefits (Li et al., 2011), a nationwide ETS is expected after piloting ETSs. Jiang et al. (2017) identified heavy industry sectors that should be included in a national ETS's coverage, and proposed that the design of a cap on emissions should allow for a proper increment and establish a new entrant reserve to coordinate economic development. The setting of emission caps directly affects the ETS's emission mitigation effect; it is argued that the benefits of absolute and relative caps are mainly determined by uncertainties surrounding China's economic growth and business-as-usual (BAU) emissions (Tian and Whalley, 2009). An intensity-based cap is widely recognised as more suitable for China's ETS at the current stage (Cheng and Zhang, 2011, Hübler et al., 2014).

China is a large country that consists of 23 provinces and four municipalities. Many studies have considered how to reasonably distribute China's national cap to the provinces and municipalities (Wang et al., 2013, Yu et al., 2014, Zhang, 2014). Policy makers are required to allocate allowances based on principles of equity, development and economic and technical efficiency. The auction would gradually replace free allocation with the evolution of the ETS (Cong and Wei, 2012), since a full auction might be difficult to implement currently because of its potential for larger output losses (Hübler et al., 2014).

Only a few studies have attempted to provide a proposed carbon price level for China's national ETS, even though this plays a key role in optimising the effectiveness of the trading system's emission reduction. Li and Lu (2015) employed a combination of dynamic computable general equilibrium (CGE) simulation and econometric analyses, by which 30–50 CNY/t CO_2 was recommended as an ideal price benchmark for China's ETS for the period 2016–2020. Flexible mechanisms, such as carbon offsetting schemes and carbon floor price, serve as market stabilisers to reduce carbon price fluctuations. Wang and Wang (2015) perceived carbon offsetting scheme as a double-edged sword, thereby suggested the regulator should carefully formulate a reasonable offset limit. Apart from these, some studies have proposed adopting diversified market stability mechanisms. Mo et al. (2013) devised an integrated price stabiliser constituting a price smoothing mechanism across compliance years and a ceiling-floor price mechanism throughout the compliance period.

In Raufer and Li (2009) on ETS design, they propose a carbon market design based on a three-component air quality management approach, which is more suitable for China's conditions rather than imitating approaches from the US or Europe. The three-component air quality management approach contains a real-time trading market, a real-time intermittent control system and a software-oriented predictive emission monitoring system.

Second, many researchers have evaluated the effectiveness of emission reduction and economic efficiency of ETSs in China. It is noted that implementing ETSs in China would contribute to carbon abatement cost reduction and low-carbon economic transition (Ping and Zhennan, 2011, Zhou et al., 2013). However, it might lead to differential impacts across provinces (Zhang et al., 2013a, Cui et al., 2014) and cause obvious output and export losses in energy-intensive sectors (Li et al., 2014a).

Whether Chinese ETSs could stimulate low-carbon economic transition is an important measurement for assessing their effectiveness, as the low-carbon economic transition is expected to play a fundamental role in long-term emission reductions. Zhang and Xu (2013) revealed that implementing an ETS might favour low-carbon production over high-carbon production. However, empirical research by Mo et al. (2016) found that the Chinese ETSs cannot support its own investments in low-carbon energy currently, and carbon price uncertainty would restrain investment in low-carbon energy, therefore policy mix and stabilisation mechanisms are needed. Xu et al. (2017) concluded that the production of low-carbon products would increase with a rising carbon price based on analysis of the made-to-order supply chain. On the whole, implementing ETSs in China will affect enterprises' production and emission reduction decisions as well as the related expected profits, and has the potential to promote low-carbon production in China (Du et al., 2013, Du et al., 2015).

Finally, as China is moving from pilot ETSs to a nation-wide ETS, several studies have investigated linking regional pilot ETSs in China. Zhou et al. (2013) claimed that the link between provincial ETSs could significantly cut China's total carbon abatement costs. Liu et al. (2013a) also confirmed the potential benefits of interregional linkage, but they further noted that the linkage might lead to more uneven welfare distribution and social inequity.

Since China currently has connections with the international carbon market only via the Clean Development Mechanism (CDM), some studies have turned their attention to linking China's ETSs with those in other countries. Bernard et al. (2008) proposed a linkage between Russia, China and Annex B countries; it appears that competition between Russia and China on the international market for carbon emissions would significantly lower the permit prices. Nevertheless, the linkage between China and other developing countries in Asia showed that China would play a major role and would be a net buyer in the Asia ETS, with the highest level of per capita emissions and levels of income per capita (Massetti and Tavoni, 2012). Linking China's ETS with the EU ETS demonstrated that the welfare effect of such a linkage would be closely related to transferring allowances, and China would always benefit from it even with a restricted transferring volume (Hübler et al., 2014). Böhringer et al. (2014) further confirmed these results using a marginal abatement cost curve showing that the substantial revenues from permit exports would turn the carbon abatement costs of China into net gains. Generally, researchers believe that China should join a global ETS by 2030 or 2050 the latest, in order to compensate for its welfare losses by selling surplus allowances (Hübler, 2011, Heindl and Voigt, 2012), but the linkage might have an adverse impact on China's energy-intensive industries (Xu et al., 2015b).

Through reviewing the important controversies in the current literature, it appears that only a handful of studies have discussed the issue of carbon pricing under China's ETS; there is an urgent need to investigate the major influencing factors and their function mechanisms on carbon allowance prices. In addition, the overwhelming majority of current studies are based on ex-ante model simulation (Babiker et al., 2001, Hübler, 2011, Xu et al., 2015b, Springer et al., 2019), therefore ex-post empirical studies on current pilot ETSs are of great value to guide the design and operation of China's national ETS.

Chapter 2

Stakeholder views on the carbon market and interactions between low-carbon policies in China: Lessons from the Guangdong ETS

2.1 Introduction

China's economy has been growing at a sustained average annual rate of over 9% for three decades and energy use has therefore increased fivefold since 1980 (to nearly 3 billion tons of oil equivalent in 2011) (IEA, 2017). In 2010, China's energy consumption exceeded that of the United States (Lee and Zhang, 2012). As coal continues to dominate the primary energy structure and occupy a majority of incremental electricity demand in China, rising energy consumption driven by a rapidly growing economy has caused China to become the world's leading emitter of GHGs (Guan et al., 2009). The Paris Agreement agreed in December 2015 sets out a global action plan to put the world on track to avoid dangerous climate change, by limiting global warming to well below 2°C above pre-industrial levels in the long term, and to pursue best efforts to limit increased warming to 1.5°C (United Nations, 2015). China also formally submitted its intended nationally determined contribution (INDC) to the new global climate agreement by lowering carbon dioxide intensity by 60%-65% from 2005 levels and peaking its GHG emissions by around 2030 (NDRC, 2015).

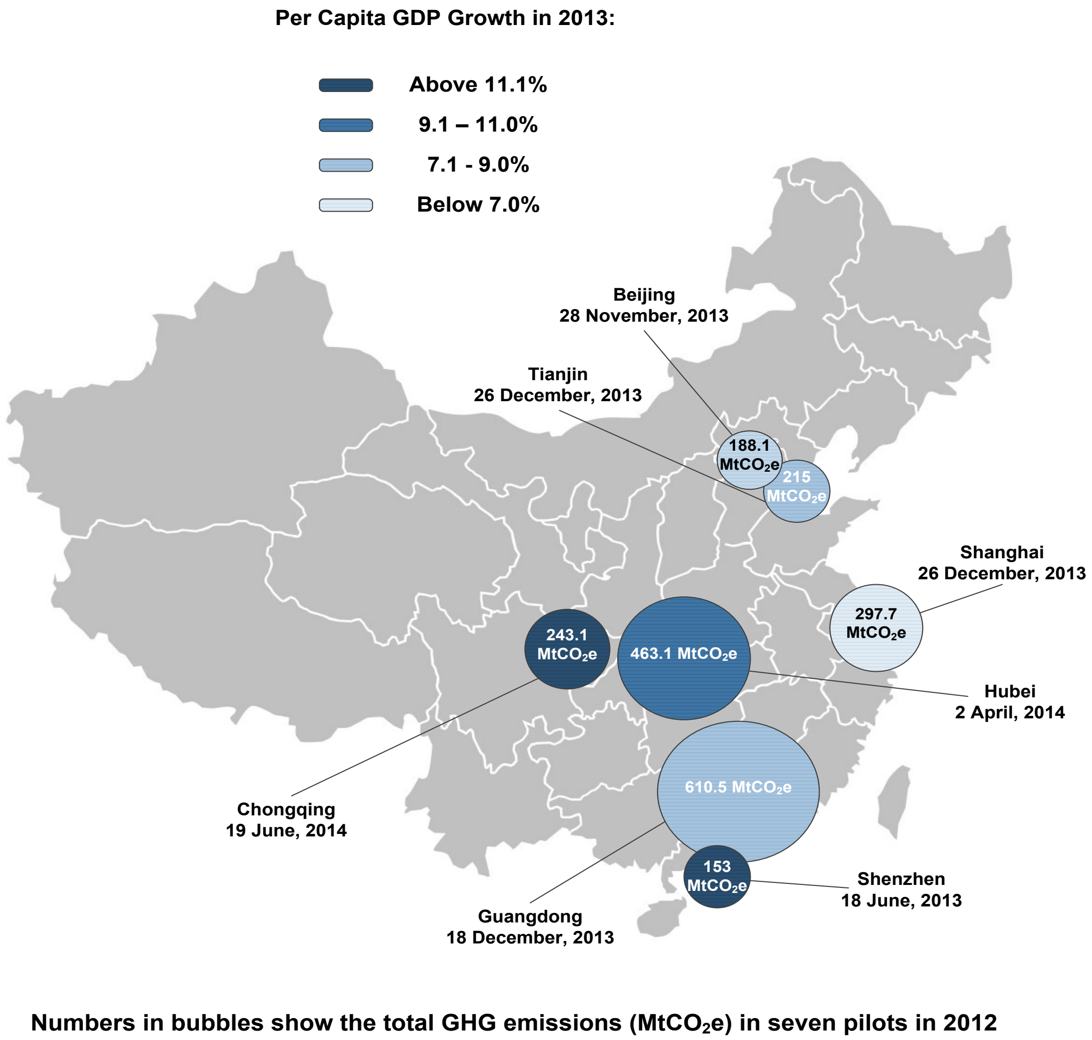
Although China has not adopted mandatory national emission abatement targets under the Kyoto Protocol (UNFCCC, 1998), initial steps towards a national carbon market have been taken through piloting regional carbon emission trading systems, with an eye to establishing a carbon pricing system in the country. In March 2011, China officially included pilot ETSs in the 12^{th} FYP with a view to meeting its 2020 carbon intensity target (Cui et al., 2014). In October 2011, seven pilot cities and provinces (Figure 2-1) were authorised to proceed by the NDRC, the central policy-making body (NDRC, 2011). Since the final pilot ETS commenced trading in Chongqing on 19 June 2014, all seven pilots in China have been in operation. Carbon dioxide emissions are being monitored in China's pilot schemes so far (Chongqing pilot ETS also covers non-CO_2 GHGs including CH_4 and N_2O), and the trading period of the seven pilot ETSs ran from 2013 to 2016, after which a national ETS was launched on 19 December 2017 (NDRC, 2016b, NDRC, 2017b).

Initially, the seven Chinese pilot ETSs were scheduled to end after three compliance years and were to be replaced by the national ETS in 2016. However, as the launch of the national ETS was postponed to the end of 2017 and trading will begin three year later after 2020, the pilots are continuing to operate until then and probably also beyond. The initial phase of the national ETS will give regulators the opportunity to improve the system design as well as allow market participants time to familiarise themselves with the ETS based on experiences in the pilots.

The design and implementation of a carbon market are influenced by different stakeholders: government and industry who are directly involved in the markets; academics and non-governmental organisations (NGOs) who have relevant expertise or experience will also contribute to market design and functioning. Consequently, it is critically important to investigate stakeholder views on the Chinese carbon market because policy construction would benefit from greater participant confidence, which would contribute to wider public acceptance.

Each province or city participating in a pilot ETS has a different economic growth outlook and GHG emissions profile, which implies each pilot ETS will have different effective reduction targets and design characteristics in order to achieve its target. For instance, Beijing, Tianjin, Shanghai and Shenzhen are commercial centres along the coast, with relatively high GDP per capita, and large commercial and residential buildings are covered in these ETSs. Conversely, Hubei and Chongqing are located in central China with a lower GDP per capita but higher GDP growth rates and are less commercialised. Accordingly, these pilot ETSs cover heavy industrial sectors only, and emissions offset credits must originate from within their own provinces, since the abatement cost is expected to be cheaper within these provinces (EYGM, 2014). The diversity of the emissions trading market design roughly corresponds to the regional income level, thus regional emission reduction targets can be achieved without adversely affecting economic growth projections.

Guangdong Province, often referred to as the Pearl River Delta Economic Zone, has some characteristics of an advanced industrialised economy. Guangdong Province contributed 11.6% of national GDP in 2013, and the Guangdong ETS pilot is the largest of the seven schemes, with an absolute cap of 408 $MtCO_2$ in 2014, initially covering the power and industry sectors, to be followed by the transportation sector. These sectors account for more than half of the province's emissions (ICAP, 2018b). Hence, the experiences of implementing carbon emission trading policies in Guangdong will be important in designing and operating a larger national ETS.



<u>Figure 2-1 Map of seven pilot ETSs in China</u>

(Source: EYGM, 2014)

In addition, although global warming is already an urgent issue, China has other priorities including enhancing energy supply rapidly to meet national needs, improving energy efficiency, and environmental protection. Generally, the Chinese central government prescribes climate change and energy policies, as local governments may have different objectives compared to the central government; these policies set by the central government are often self-enforced by local governments (Teng and Gu, 2008). Figure 2-2 summarises the existing low-carbon policies developed by the central government and the specific implementation plans in Guangdong Province.

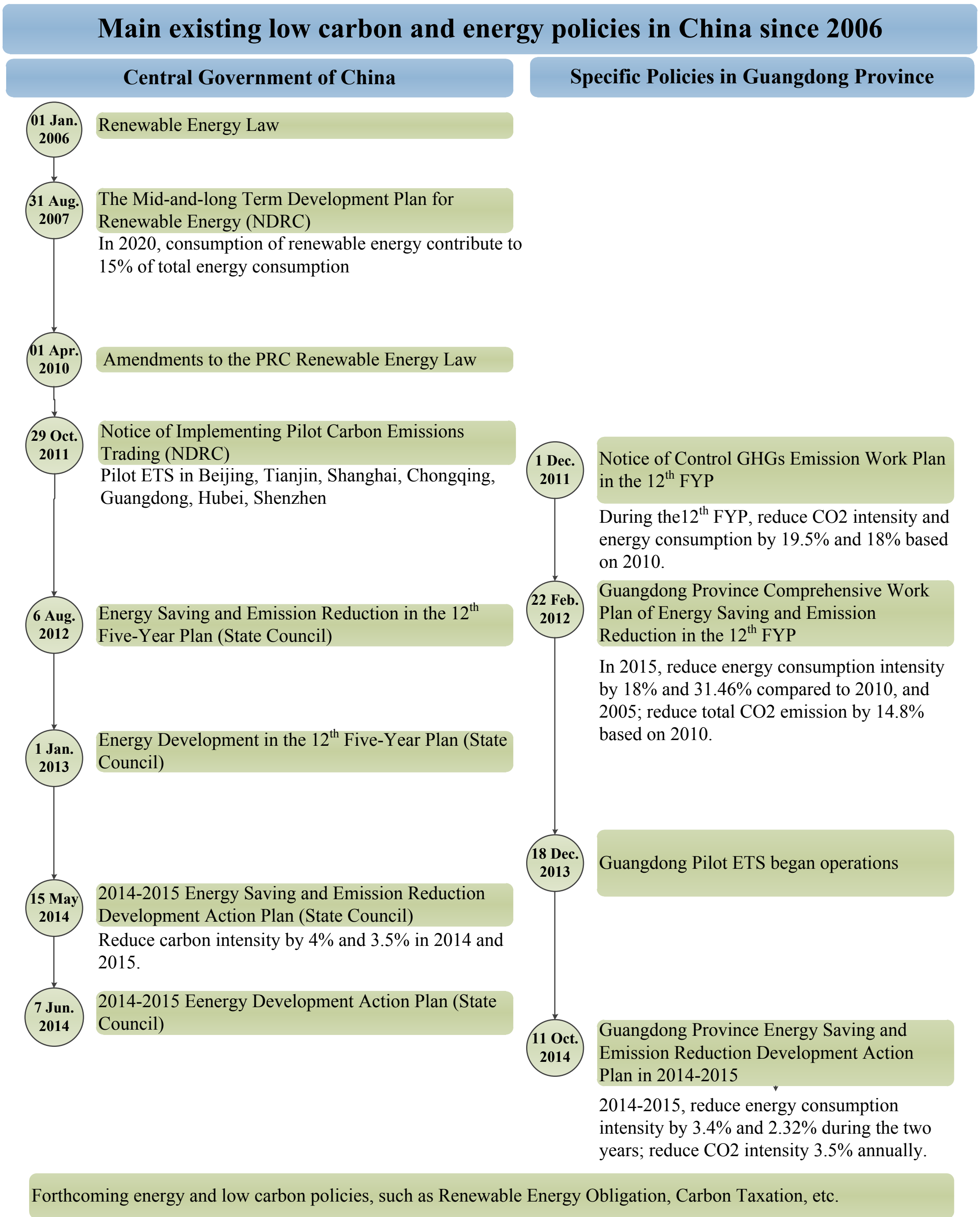


Figure 2-2 Existing main national and Guangdong province climate change policies

(Sources: www.ndrc.gov.cn; www.gov.cn)

In spite of the high political priority given to ETS as a policy instrument, the Chinese energy system is primarily regulated by administrative measures rather than market-based instruments (Lo, 2014). Meanwhile, in recent years a range of policies including carbon taxation, renewable obligations and energy efficiency quota trading mechanisms have been discussed by both government officials and leading academics in China (Chen, 2013, Fang, 2018). All such parallel mechanisms would potentially reduce the implied allowance price in the ETS and give investors a misleading signal about the value of carbon in longer-term investments (Hood, 2013).

Therefore, this study is interested in stakeholder views on the Chinese carbon market and interactions between energy and low-carbon policies in China. Through conducting a survey about the Guangdong pilot ETS, stakeholders' perceptions and expectations of the Chinese carbon market, and their understanding of the interactions between the carbon market and other energy and low-carbon policies, were investigated. The structure of the study is as follows: section 2.2 reviews the literature relevant to this context while section 2.3 describes the survey methodology; section 2.4 presents the results and discussion and the last section provides conclusions and policy recommendations.

2.2 Literature review

Since the launch of the EU ETS in 2005, emissions trading has become a popular instrument to encourage climate mitigation globally (Brousers et al., 2016, Yang et al., 2016, Wang et al., 2015, Kachi, 2015, Cui et al., 2014). The carbon price would be key for an effective and successful carbon market mechanism (Tang et al., 2019); however, the collapse of EU allowances (EUAs) prices in 2008 following the global financial crisis significantly weakened incentives to continue reducing emissions. Although the financial crisis of 2008-2009 and overly generous national allowance allocations (IETA, 2014, Zhang and Wei, 2010, Schleich et al., 2009) were generally recognised as the principal causes for the price drop, further studies have shown that the interactions between the emissions trading market and competing energy and low-carbon policies also contributed to weakening the impact of the ETS.

In theory, energy and low-carbon policies could act in a complementary manner; for instance, renewable energy obligations could contribute to carbon emission reduction targets while carbon abatement instruments should stimulate renewable energy deployment (Fischer and Preonas, 2010). However, a number of studies highlight that in practice there has been duplication and conflict between different policies that are all nominally meant to work together to incentivise emission reductions.

Sorrell (2003) explored the interaction of policy instruments among the EU ETS, the UK Renewables Obligation and the UK Energy Efficiency Commitment, particularly on scope, timing, objectives and operation. His study pointed out that the UK Renewable Obligations would interact with the EU ETS as emission reduction would be double-counted, and no extra reduction would be achieved. Based on Sorrell's work, Sijm (2005) proposed removing these instruments when the EU ETS is fully applied under the perfect market assumption and the single objective to minimise CO_2 abatement cost, as he believed once the EU ETS became operational, the effectiveness of all other policies to reduce CO_2 emissions of the participating sectors would become zero. However, in practice and especially in the short term, many policies with the aim of managing fossil fuel use by participating sectors will still function when the EU ETS becomes operational.

In contrast, Stern (2006) suggested that the carbon pricing mechanism is the first element and cornerstone of a climate and energy policy package; it enables least-cost emissions reduction and stimulates companies to invest in carbon abatement. Either through carbon taxes or tradable emission permits, carbon pricing needs to combine with other policy mechanisms to create suitable investment incentives. Kautto et al. (2012) also found that the cooperation of an ETS with national energy policies can stimulate fuel switching and improve electricity efficiency via higher electricity prices. Combined multiple climate change policies also have synergies on fuel switching as well as biomass utilisation. What's more, they suggested that the short-term inefficiency of combined multiple policies would be replaced by long-term benefits.

Nevertheless, there is an increasing number of studies showing that a renewable obligation would depress emission prices in an ETS and would not contribute to long-term reductions in emissions (Syri and Cross, 2013). Pethig and Wittlich (2009) illustrated that no incremental emission reduction could be achieved by the supplemental renewable energy obligation. Böhringer and Rosendahl (2010) added to the above findings with a theoretical analysis of overlapping regulations. They argued that renewable energy obligations will not only cut down emission prices, they will even increase the emission generated by carbon-intensive power plants. This is due to the carbon-intensive installation benefitting the most from low emission prices. Through a CGE model, Morris et al. (2010) argued that combining a renewable portfolio standard with a cap-and-trade policy to reduce emissions would reduce the cost-effectiveness of the whole system. The renewable portfolio standard would shift investment away from the least-cost emission reduction options and towards these specific renewable technologies, which are not necessarily least-cost or even low-cost.

Most studies investigating the interaction between renewable obligations and ETSs are based on prospective scenarios as both of these two incentive mechanisms are relatively novel. However, recent research by Bergh et al. (2013) confirmed the above results by a quantitative analysis. They demonstrated that the maximum decrease in the emission price caused by renewable energy obligation would be €15/tCO_2, €46/tCO_2, and more than €100/tCO_2 respectively in 2007, 2008 and 2010.

Other than interacting with renewable energy policies, ETSs may also interact with other forms of carbon pricing, such as carbon taxation. Bowen and Rydge (2011) argued that the UK effective carbon price is even higher and more pervasive than the suggested EUA prices. Higher, therefore more consistent and less volatile, carbon prices are needed to transform and meet the ambitious 2050 target. In this case, carbon taxes are preferred more than the cap-and-trade system because the tax rate can be regularly reviewed. However, if different methods of carbon pricing are applied, the subsequent interaction can lead to inefficient allocation of abatement activity across sectors, unnecessary costs and distortion of final prices (Bowen and Rydge, 2011). The expectation of future price, technological progress and other emission control policies could impact the carbon price since they affect the demand or supply of carbon emissions (Lei et al., 2011). Hone (2013b) contends that the EU ETS, in combination with other low-carbon policies (notably binding European commitments on renewables) has 'distorted emissions mitigation economics across the EU, and the recession has further exacerbated the situation'.

Sorrell (2015) concluded that more cost-effective ways in many end-use sectors also improve energy efficiency, exemplified by the marginal abatement cost curves. These cost-effective ways function through organisational initiatives and policy interventions, such as labelling schemes, minimum efficiency standards, and targeted information programmes, and they become key players in demand reduction.

In an integrated policy package, it is possible that the elements inside the package may interact and reinforce or undermine total reductions in emissions. If the policies in a policy package interact well, synergies between energy, climate and trade-offs can be reduced (Stern, 2006). Unfortunately, insufficient policy integration might interfere with policy objectives such as emission permits and energy security, and deviate from climate objectives. There can also be interaction between an ETS and energy policies aimed at reducing emissions, such as energy efficiency and technology deployment policies.

Figure 2-2 demonstrates the shift of the abatement curve driven by parallel low-carbon policies; the marginal abatement cost curve (MACC) is a set of points reflecting the options with marginal costs and emission reductions (Ellerman and Decaux, 1998). With increasing emission reductions, the option with the lower marginal abatement cost sets the price for emission permits. Total emission reductions will be achieved at least-cost until the equilibrium market price has been reached (Kesicki and Ekins, 2012) (Figure 2-2(a)). In principle, if a country adopts a stringent mandatory policy to promote low-carbon technologies through parallel energy and low-carbon policies (such as an ambitious renewable obligation target, a mandatory energy efficiency programme, or a high carbon tax), the MACC would shift to the right (as illustrated in Figure 2-2(b)) and thereby the carbon price visible in the market will fall.

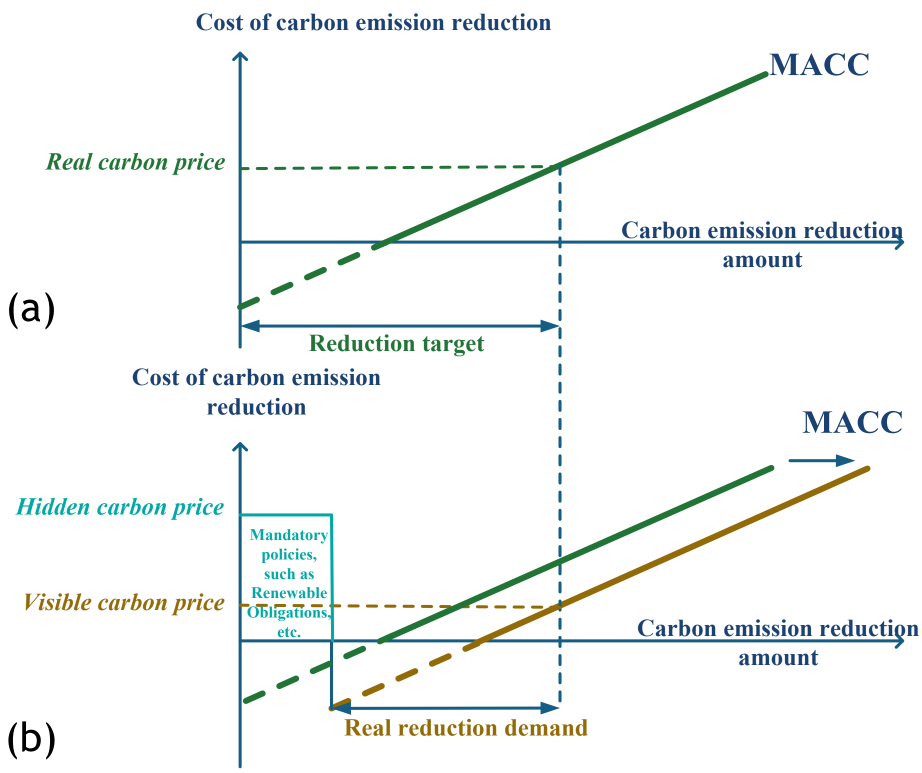


Figure 2-3 Shift of abatement curve driven by parallel low-carbon policies (Source: Hone, 2013b)

Although a number of studies on interactions have focused on Europe, there are few studies of potential interactions between different climate change and renewables policies in China. China is still at an early stage in establishing a functional and effective emission trading system to facilitate GHG emission reductions, so existing studies mainly describe the market features and characteristics (Zhou et al., 2011, Zhang et al., 2014a, Duan et al., 2014), market design and relevant legal and regulatory issues (Fan and Wang, 2014, Wu et al., 2014a, Jiang et al., 2016, Qi et al., 2014a), or model the economic performance and impact of emission trading in China at some point in the future (Zhou et al., 2013, Qi et al., 2014b).

Although previous studies suggest parallel low-carbon policies could influence allowance prices in the ETS and send the wrong signals to industry, there has been little work on the potential interactions between low-carbon policies and the pilot ETSs in China and on related stakeholder views. Identifying stakeholders' awareness of policy interactions is vital for the emerging carbon market in China, as a common understanding between stakeholders would help improve national climate change (and energy) policy planning and avoid some of the problems experienced in other countries and systems.

A number of studies on both stakeholder and public perspectives towards climate change issues have been conducted addressing a range of topics including stakeholder perceptions of carbon capture and storage (Liang and Reiner, 2013, Reiner and Liang, 2012, Li et al., 2012), mandatory reporting of GHG emissions (Lai, 2014) or climate adaptation (O'Keeffe et al., 2016). On the question of policy interactions, Fischer and Preonas (2010) provided a theoretical rationale for why overlapping low-carbon policies will have a depressing effect on emission markets, which have been confirmed in empirical studies (Koch et al., 2014) and economic models (Morris et al., 2010). However, there have been no studies at the intersection of stakeholder studies and policy interaction to determine, for example, whether analysts have effectively conveyed the potential impact of these interactions and whether this has been appreciated by stakeholders. Therefore, I adopted a survey approach to help examine stakeholder awareness of policy interactions.

2.3 Methodology and demographic information

A two-stage survey consisting of a questionnaire and follow-up interviews were employed. In June 2014 100 internet-based questionnaires were sent out to stakeholders involved in the Guangdong pilot ETS, followed by semi-structured telephone interviews in August 2014 with a subset of 10 respondents for a deeper understanding of stakeholder views.

2.3.1 Internet-based questionnaire design

The online survey system Wenjuan was adopted as the survey platform. The internet-based questionnaire was made up of 22 questions, involving a combination of multiple-choice, ranking and open-ended questions to obtain stakeholder views on a range of issues including Chinese emission reduction policies and carbon markets, understanding of the interactions between policies as well as views on potential challenges in the implementation of the Chinese carbon markets. All stakeholders were asked to respond based on their personal opinions, knowledge and experience.

The pool of respondents drew upon those with significant involvement in the Guangdong pilot ETS with respect to market design and policy making, market participation and relevant research. Specifically, we adopted an expert sampling approach, selecting equal numbers of senior stakeholders from each of the key groups: 25 government stakeholders of at least director level within the relevant ministry; 25 industry stakeholders of at least deputy general manager level in listed companies in the energy sector; 25 academic stakeholders, with the grade of lecturer or above, working in energy and environment; and another 25 stakeholders working at managerial level in environmental NGOs. An invitation letter and a participant information letter were emailed to all stakeholders simultaneously describing the purpose of the study, and the principle of anonymity and confidentiality that would be employed.

The questionnaire began with a set of general questions about the role and experience of participants before turning to their evaluation of low-carbon policies and incentives. The next set of questions focused on their perspectives regarding Chinese carbon emission reductions including emissions trading and other emission reduction instruments. Specifically, respondents were asked to estimate and rate the likelihood of China achieving deep cuts in GHGs over the next 10 years, and to select the most cost-effective policy instruments to reduce GHGs in China. We also asked how respondents explained the collapse of the carbon price in the EU ETS as well as their assessment and expectations of the pilot carbon markets in China.

Subsequently, 'what-if' scenario questions were designed to explore stakeholder opinions on the interactions between other low-carbon policies and the Guangdong pilot ETS. They were asked to consider the most likely immediate impact on the carbon price in the Guangdong pilot ETS if either a new short-term renewable energy obligation or a carbon tax were to be enacted. Furthermore, stakeholders were asked for their views on potential conflicts between energy-saving and emission reduction measures on the one hand, and between a national ETS and international systems on the other. The last few questions covered issues associated with building markets, including potential challenges for market regulation and implementation barriers.

2.3.2 Semi-structured telecom interview design

As a follow up to the questionnaire, we conducted semi-structured interviews to obtain more detailed views. To be able to have a more in-depth discussion about the issues involved the main selection criterion was that the respondents indicated that they had spent more than 50% of their working time on energy-saving and emission reduction policies in China in the past year. Interviewees were asked to provide:

- A brief overview and outlook for Chinese pilot carbon markets;
- More detailed reasons behind the options they had chosen in the 'what-if' scenario questions;
- Opinions on the main challenges in the implementation of the Chinese carbon market.

2.3.3 Demographic information of respondents

We received 30 responses out of a total of 91 internet-based questionnaires delivered (nine questionnaires were returned due to invalid email addresses), giving a response rate of 33%. The sectoral distribution of respondents was: industry (27%); finance (20%); consulting (17%); government (10%); academia (13%); and NGOs (10%) (Figure 2-4).

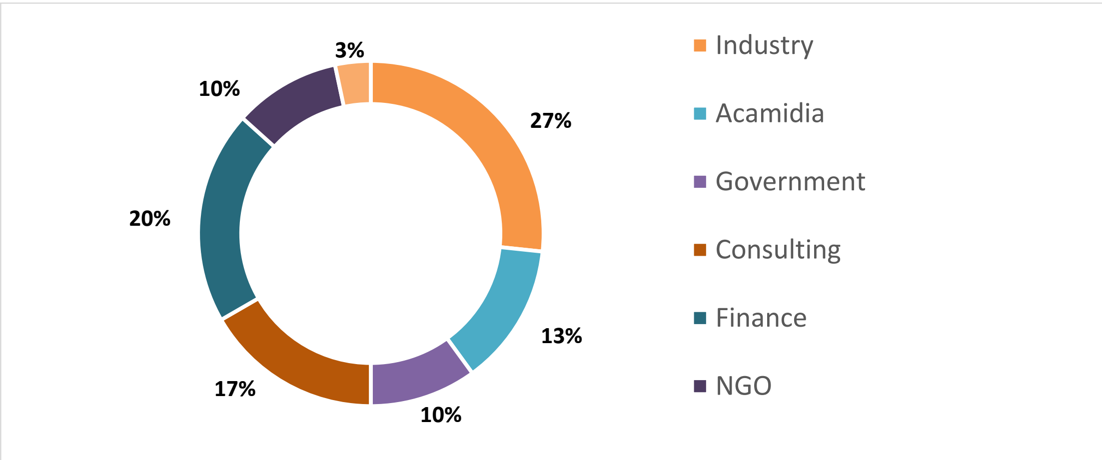


Figure 2-4 Demographic information of respondents

In the previous year, one third (33.3%) of respondents had spent more than 50% of their working time on energy and climate policy although none of them spent 90% or more of their working time on the subject. A further 30% spent 20%-50% of their working time and over one third (36.7%) spent less than 20% of their time on relevant policy issues. The internet, conferences and newspapers were the main channels that a large majority of respondents used to obtain up-to-date information about the Chinese carbon market, followed by TV news and personal networks.

2.3.4 Univariate regression analysis

In consideration of the number of variables, a simple form of statistical analysis – univariate analysis (Miller and Salkind, 2002) – was adopted. These analyses could provide with descriptions of single variables we are interested in and help us narrow down research directions. Therefore, we used univariate regression to test whether certain types of stakeholders had certain tendencies towards their choices. For each of the variables analysed, univariate descriptive statistics can provide an overall picture of the data. Specific definition variables and regressions are described under each subsection.

The main purpose of the univariate regression is to examine the potential correlation between the dependent variable and the independent variable. A general hypothesis underlies each regression. For instance, from figure 2-5, a hypothesis can be put forward that government stakeholders tend to be more confident about deep cuts in GHGs compared with other stakeholders. Afterwards, the regression results show our empirical observation about our hypothesis.

We tried numerous methods of categorisation and picked the ones with significant linear regression results in order to reveal potential correlations between the stakeholders' sectors and their attitudes or expectations on certain issues. Therefore, we only reported the significant univariate regression results. Using univariate regression makes our results convincing compared to a purely qualitative discussion of our results, because it shows statistically significant connections.

Critically speaking, it is generally recognised that statistically, the smaller the sample size, the higher the error margin is (Hsieh et al., 1998). As such, to use a sample size less than 30 ($n < 30$) would imply 'a magnification of error'. However, the purpose of using univariate regression analysis here is to provide descriptive statistics rather than inferential statistics, therefore, the approach would be applicable in this case.

2.4 Results and discussion

2.4.1 Perspectives on emissions reduction and the carbon market in China

- ***Predictions about emission reductions in China***

Asked about expectations of whether current climate policies in China could achieve deep cuts in GHG intensity in the next 10 years, most respondents were pessimistic; half (50%) considered it difficult to reach a stringent target, and another 20% of stakeholders were not sure, although over one quarter (26.7%) of stakeholders believed such reductions were likely, and one stakeholder (3.3%) believed it was 'very likely' (Figure 2-5). The results are consistent with a previous survey conducted in 2009, where more than 80% of respondents believed it would be 'difficult' or 'very difficult' to achieve deep cuts in GHG in the next 20 years (Liang et al., 2011).

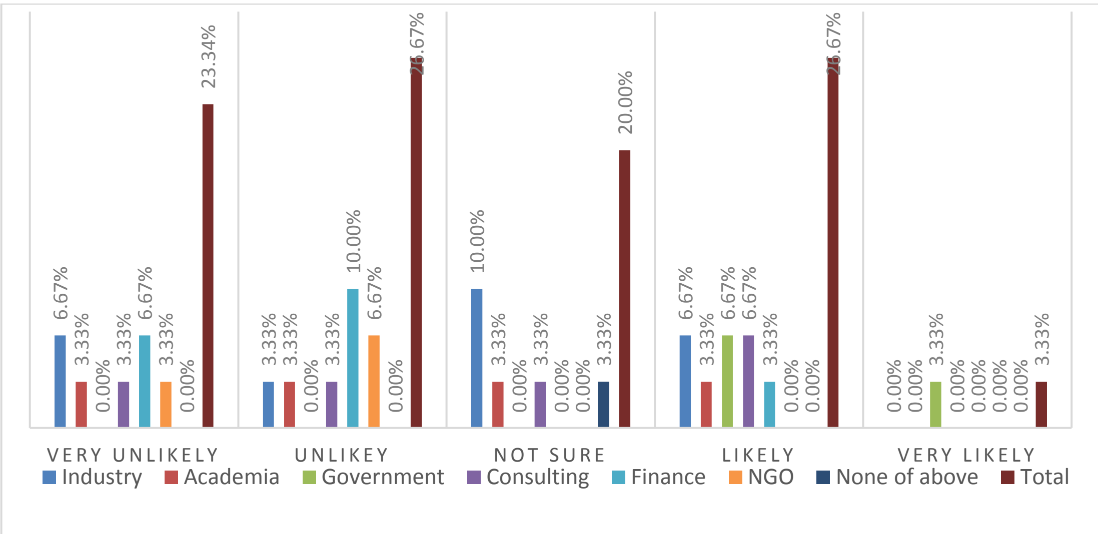


Figure 2-5 Perceived prediction of deep cuts in GHG intensity in China

By using a univariate regression, where *Gov* stands for dummy variables that take the value of 1 if the respondent is from the government sector and 0 otherwise. *Expect* are ordinal variables defining respondents' expectation levels from 1 to 5, while *Expect* = 1 means they consider deep cuts in GHG intensity in the next 10 years to be very unlikely, and *Expect* = 5 means deep cuts are perceived as very likely. To regress *Expect* against *Gov*, we find the statistically significant result that government stakeholders generally believed that deep cuts in GHG intensity are likely to be achieved (Table 2-1). It implies that rather than stakeholders from other sectors, government stakeholders tend to be more hopeful of success in slashing GHG emissions in China in the future.

Table 2-1 Output of univariate regression model *Expect-Gov*

VARIABLE	Model *Expect-Gov*
GOV	1.593**
	[2.428]
Constant	2.407***
	[11.608]
Observations	30
R-squared	0.174
Adj. R-squared	0.144

t-statistics significance
*** p < 0.01, ** p < 0.05, * p < 0.1

To achieve deep emissions reductions, fully 60% of respondents preferred a market-based instrument; an emission trading scheme was viewed as the most cost-effective policy instrument to reduce GHG emissions in China (33.3%), followed by carbon taxation (26.7%), even though historically the Chinese government has used non-market based forms of regulation to achieve its environmental goals (Lo, 2014). Seventeen per cent of respondents preferred renewable energy subsidies/binding obligations or industrial emission performance standards. Feed-in tariffs (FITs) and preferential policies favouring natural gas and nuclear power were considered to be the least cost-effective measures, with only a single stakeholder (3.3%) voting for each one (Figure 3-5).

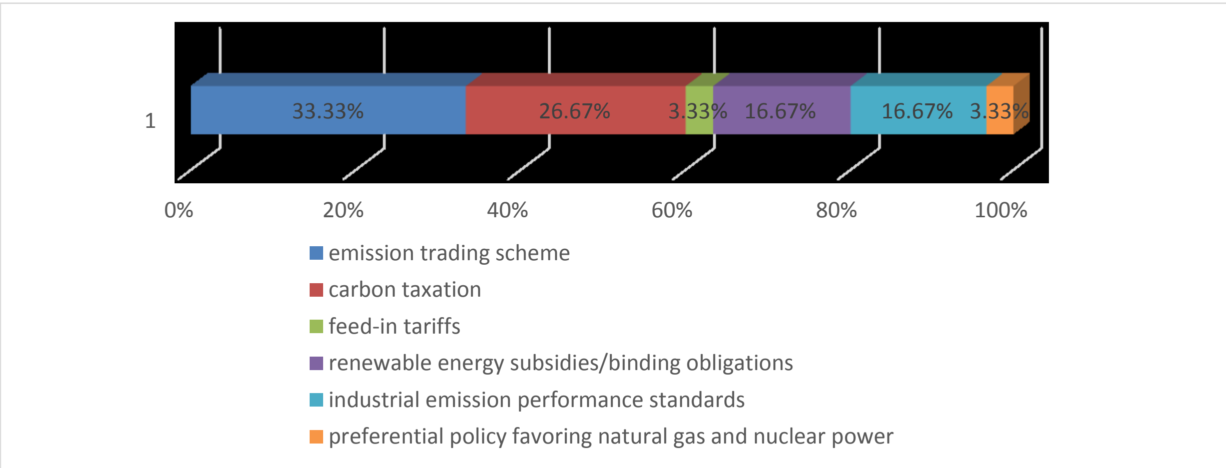


Figure 2-6 The most cost-effective policy instrument to reduce GHG emissions in China

- ***Assessment of progress of Chinese pilot ETS***

Media coverage and many international observers have described the Chinese carbon markets as moving quickly since the pilot ETS policy was launched by the NDRC in 2010 (Zhang et al., 2014a). In contrast, the bell shape of the solid line in Figure 2-7 demonstrates that there are approximately equal proportions of respondents who consider the development speed of ETS in China to be fast or slow: 36.7% of respondents agree that progress has been fast (26.7%) or even too fast (10%); another 40% have the opposite view and take progress to be slow (26.7%) or too slow (13.3%).

After further investigation of respondents' sector segmentation, a trend can be found as academic stakeholders tend to consider the development progress of ETS in China to be slow. A univariate regression of *Assess* on *Acad* confirms this tendency (Table 3-2), where *Acad* are dummy variables that take the value of 1 if the respondent is from the academic sector and 0 otherwise, and *Assess* are ordinal variables defining respondents' assessment levels from 1 to 5. *Assess* = 1 represents progress is too slow and 5 implies too fast.

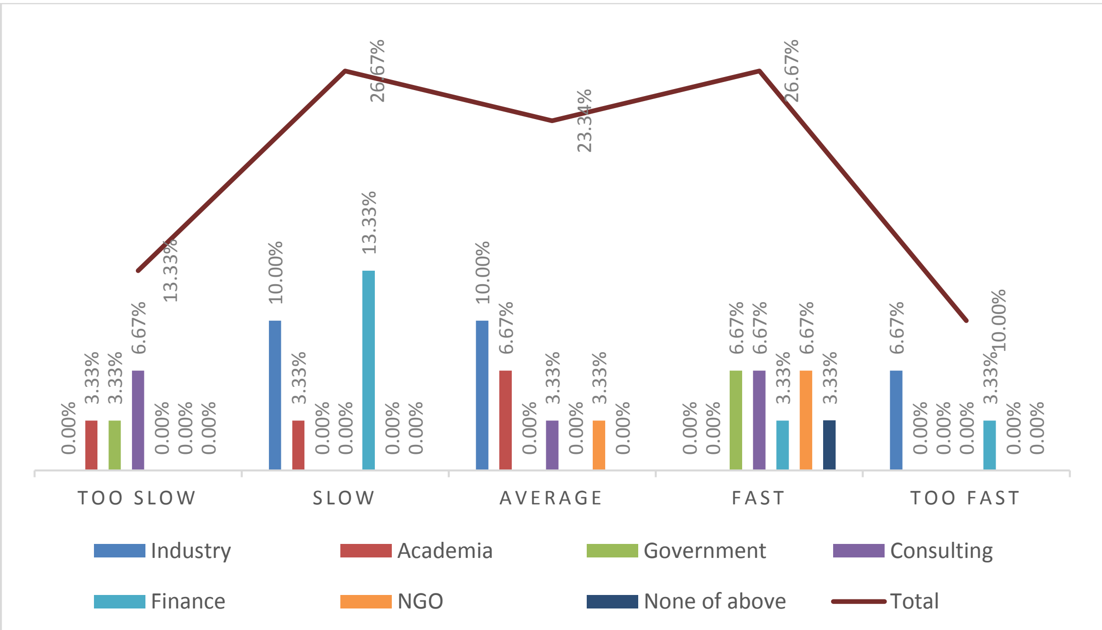


Figure 2-7 Stakeholders' assessment of progress of Chinese pilot ETS

Table 2-2 output of univariate regression model *Assess-Acad*

VARIABLE	Model *ASSESS-Acad*
ACA	-1.040*
	[-1.791]
Constant	3.240***
	[13.664]
Observations	30
R-squared	0.103
Adj. R-squared	0.0707

t-statistics significance
*** p < 0.01, ** p < 0.05, * p < 0.1

Accordingly, there are approximately equal proportions of respondents that are pessimistic (30%) or optimistic (33.3%) about the future of Chinese pilot ETSs, while another 23% describe progress as 'average'. The fact that the largest single response was 'not sure' (36.7%) reveals the large uncertainties over the future of ETS in China. Using different shades to present assessment of progress, where lighter blue denotes slower and darker blue denotes faster, the correlation between stakeholder assessment and perspectives can be visually observed in Figure 2-8; respondents who believed that progress was too slow felt pessimistic or even very pessimistic while respondent assessments of too fast led to relatively optimistic perspectives. In a univariate regression of *Prospect* on *Assess*, where *Prospect* and *Assess* are both ordinal variables where 1 means very pessimistic and too slow respectively while 5 means very optimistic and too fast respectively, the output confirms our observations by indicating a significant positive correlation between these two variables (Table 2-3).

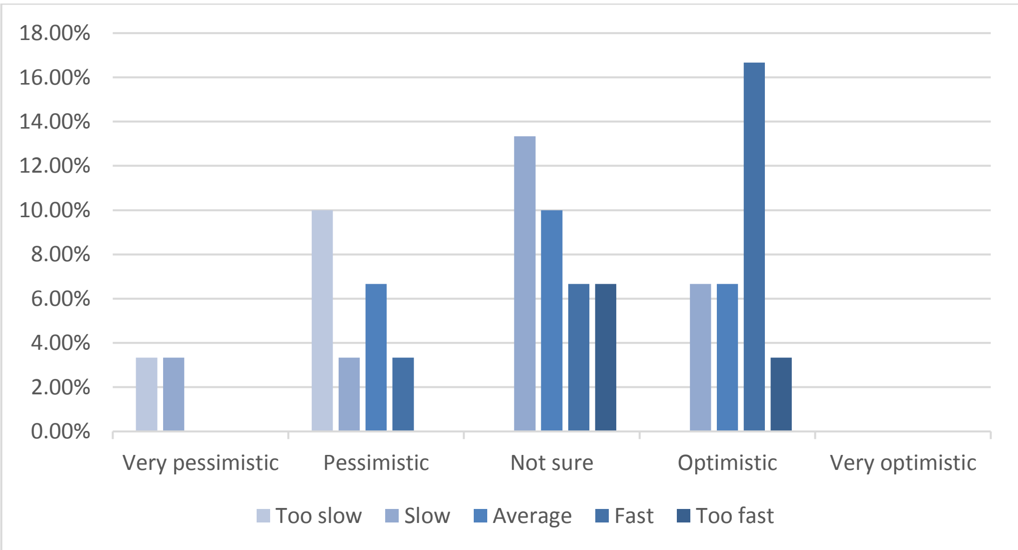


Figure 2-8 Cross-analysis of stakeholder perspectives and assessment on Chinese carbon market

Table 2-3 Output of univariate regression model Prospect-Assess

VARIABLE	Model *Prospect-Assess*
ASSESS	0.298**
	[2.274]
Constant	2.053***
	[4.755]
Observations	30
R-squared	0.156
Adj. R-squared	0.126

t-statistics in brackets
*** p < 0.01, ** p < 0.05, * p < 0.1

- ***Expectation of Guangdong pilot ETS market price***

A quarter of stakeholders were uncertain about the expected range of the average carbon price in Guangdong market. Nearly half (45.8%) expected the carbon price to be between 51-100 CNY/t CO_2 (7-14 EUR/t CO_2), which is higher than the 32 CNY/t CO_2 (4 EUR/t CO_2) found in the October 2013 China Carbon Price Survey. Moreover, one-sixth (16.7%) of respondents proposed an even higher range of 101-200 CNY/t CO_2 (14-27 EUR/t CO_2), while another third (33.3%) expected it to be lower, at 26-50 CNY/t CO_2 (3.5-7 EUR/t CO_2). Only 4.2% believe the price range would be as low as 0-25 CNY/tCO_2 (3.5 EUR/t CO_2) (Figure 2-9).

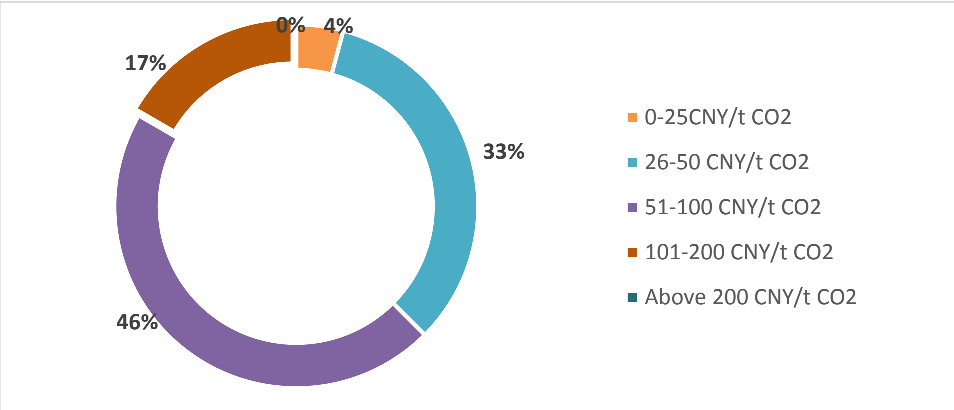


Figure 2-9 Perceived expectation of average carbon price in Guangdong pilot ETS

Conversely, through a univariate regression of *Price*, ordinal variables representing respondents' price expectations (1 = 0-25 CNY/t CO2 while 5 = above 200 CNY/t CO2), on *Acad*, whether the respondent is from academia (*Acad* = 1 means respondents are from academia while *Acad* = 0 indicates non-academic respondents), we find that academic stakeholders significantly expected (at 90% confidence level) the price to be relatively high compared with other stakeholders (Table 2-4).

Table 2-4 Output of univariate regression model *Price-Acad*

VARIABLE	model *Price-Aca*
ACA	1.200*
	[1.936]
Constant	2.000***
	[7.906]
Observations	30
R-squared	0.118
Adj. R-squared	0.0866

t-statistics in brackets
*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

As the world's largest emitter, China has been developing a low-carbon economy since the 1990s. The first White Paper regarding sustainable development was published in 1994, followed by the 'Programme of action for sustainable development in China in the early 21st Century' in 2003. China enacted its first 'Renewable Energy Law' in 2005, soon to be followed by the 'Energy-saving and emission reduction' national programme from 2006 (Wu et al., 2012). It was not until the energy plan proposed in the 11^{th} and 12^{th} FYPs in 2006 and 2011 that specific quantitative emission reduction targets were set, specifically to reduce 40%-45% GHG intensity by 2020 based on 2005 levels (Hu and Monroy, 2012) (Yuan and Zuo, 2011). In the 13^{th} FYP (2015-2020), China set a stronger and more ambitious reduction target of 48% reduction in GHG intensity from 2005 levels by 2020, in line with China's pledge at the COP21 conference in Paris in December 2015, where the Chinese Government promised to peak carbon emissions by 2030 as well as to lower GHG intensity by 60%-65% below 2005 levels (NDRC, 2015).

Recent studies on emission reductions in China may offer some reasons for the somewhat bearish expectations found in the survey. Empirical results show obvious inefficiency in China's regional energy-saving and emission reduction policies (Guo et al., 2017). China's carbon emissions are still driven by significant longstanding inefficiencies in key industrial sectors (Zhang et al., 2016), and the impact of recent low-carbon policies suffers from a lag effect (Zhang et al., 2017). Nonetheless, Yi et al. indicate that the 40%-45% carbon intensity target is very likely to be achieved by 2020 if the Chinese Government makes more effort to adjust the industrial structure and primary energy mix, as well as promoting energy efficiency during the 13th FYP (Yi et al., 2016). Green and Stern (2017) describe important structural changes in the economy that are underway, which will enable Chinese emissions to peak well before 2030.

The results confirm the fact that energy and low-carbon policies in China have gradually been switching from command-and-control to market-based approaches (Wang and Chen, 2015). There is no single policy, whether command-and-control or market-based, which has all the characteristics needed to mitigate emissions and address the full range of energy policy priorities including efficiency, effectiveness, promoting innovation, and security of supply. However, empirical studies have shown that market-based instruments will have a significant impact on efficiency improvement and emission reductions (Zhao et al., 2015), although there may be regional differences in the effectiveness of different instruments (Ren et al., 2018). Despite operating for only a short time and the immature market environment, the pilot ETSs in China appear relatively promising with regard to carbon emissions reduction (Zhang et al., 2017).

Indeed, the preparatory stage for the Chinese pilot carbon markets was relatively short compared with other ETSs developed around the world. Seven pilot ETSs were launched in China within two years, whereas EU ETS took almost five years to get underway (European Commission, 2015). The rapid development of ETSs in China is largely the result of the government's strong political will. Although all pilots have been launched, some of their design details have yet to be finalised, for instance, the monitoring, reporting and verification (MRV) guidelines and regulations until 2015 (ICAP, 2018a). Nonetheless, Chinese stakeholders tend to equate 'speed of development' with the rapid economic transition over the last few decades, which is overwhelmingly perceived as beneficial (Lo, 2014).

In terms of stakeholders' expectations of the future carbon price, at the time of the survey (mid-2014), the Guangdong carbon market price was around 60 CNY/tCO_2 (8 EUR/t CO_2) with very low turnover (Figure 2-10). After decreasing over the latter half of 2014, the price in the Guangdong ETS dropped to around 15 CNY/t CO_2 (2 EUR/t CO_2), which is consistent with the expectations of only a small fraction (4.2%) of respondents.

Figure 2-10 Price and volume in Guangdong pilot ETS

(Source: ChinaCarbon.net.cn)

During follow-up interviews, stakeholders expressed mixed views on the impact of carbon pricing through ETSs in China. Government officials were far more confident than industrial and academic stakeholders. One government official considered the carbon market pilot in the province would be robust in response to the economic cycle, and he believed the intensity allowance cap scheme would adjust automatically. An official from Guangdong (the largest pilot scheme with an absolute cap) suggested the carbon price in Guangdong could be supported through a floor price in the auctioning scheme, as a carbon floor price would create more certainty about the minimum price, providing a clearer signal for investors.

Three stakeholders from carbon-intensive industries expressed concern during follow-up interviews about the impact of the economic cycle on carbon allowance prices, but in general, they preferred retaining allowances for future compliance periods. Through cross-tabulation of stakeholder expectations on carbon price in the Guangdong ETS with respondents' sectors, we see that industrial stakeholders are more likely to expect the price to stay the same or to fall.

Meanwhile, one academic stakeholder involved in setting up the rules for one of the pilot carbon markets believed there was significant over-allocation of allowances in most pilot markets in China, and that there would be a negative impact during the compliance stage.

Another academic was concerned that the quality of the initial reporting of emissions could damage the reputation of emissions trading more generally in China, and that this effect had not been widely appreciated (i.e. there was significant over-reporting of emissions at the initial stages).

2.4.2 Perceptions of interactions between incentives

Even though earlier literature indicates that Chinese stakeholders preferred market-based instruments such as emissions trading over-regulation (Lo, 2014, Liang et al., 2011), and in spite of the current moves towards a national emissions trading scheme building on the seven pilots, a carbon tax is still being actively considered as a major policy option by the Ministry of Finance in China. There have also been longstanding discussions on how best to encourage renewable energy in China and having a binding national renewable target is one of the options that have been discussed. Consequently, in the case of the Guangdong ETS Pilot, we have sought to explore opinions regarding the interactions between the ETS and parallel carbon and energy policies.

- ***Perceptions of price collapse in the EU ETS***

Before moving to the Chinese situation in detail, we asked how stakeholders viewed the price collapse in the EU ETS. Poor awareness of how overlapping low-carbon policies would influence the carbon price is reflected in the survey; the global economic downturn was blamed by the majority (60%), followed by excess emission allowance allocations (40%) and failure to reach binding international targets in international negotiations (30%). Only a relatively small number blamed alternative emission reduction mechanisms or increased volumes of Certified Emission Reductions (CERs) from the CDM.

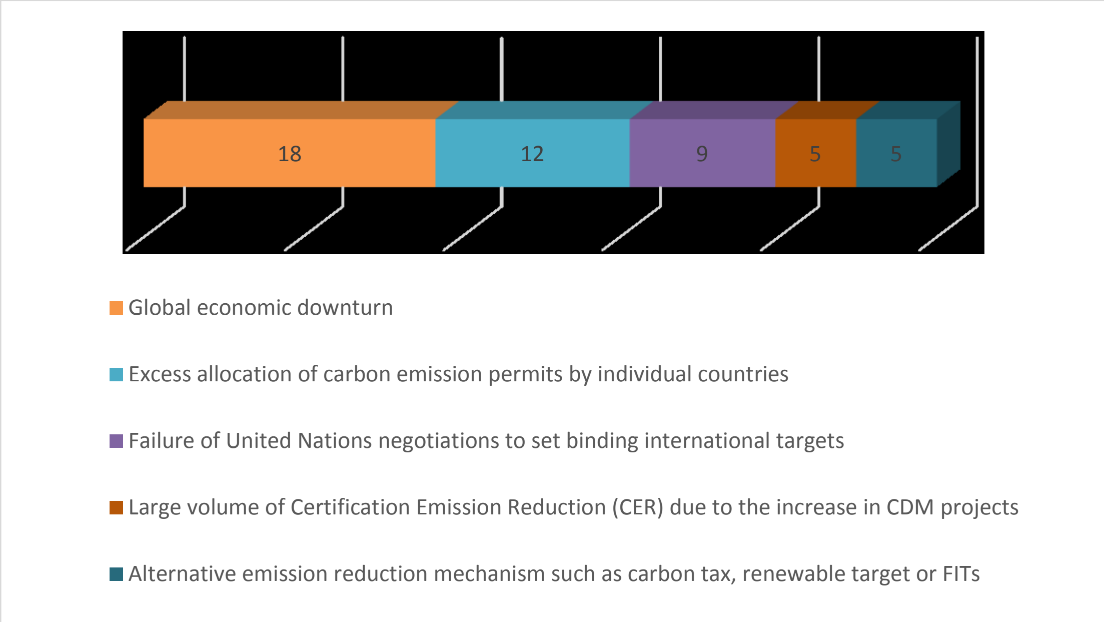


Figure 2-11 Main reasons for the collapse of the carbon price in the EU ETS

- ***Attitudes toward possible conflicts between multiple incentives***

Accordingly, we designed two 'what-if' scenario questions and two statement acceptance questions to explore reactions to hypothetical major policy announcements that we would expect to adversely affect the carbon price by reducing demand for allowances.

Firstly, stakeholders were asked to consider what would the most likely impact be on carbon price in the pilot carbon market if a higher than expected short-term renewable energy target were enacted in the pilot cities (e.g. renewable energy target increases from 10% to 15%). Nearly half (48.3%) of respondents expected the carbon price in these pilot carbon markets to decrease by a small amount, and a further 3.5% expected a large decrease in the carbon price. However, almost a quarter (24.1%) of respondents believed there would be a small increase in the carbon price, and 3.5% thought it would be a large increase. Over one fifth (20.7%) anticipated that the price would remain the same and a renewable energy target would not have any impact on the carbon price in the pilot carbon market (blue bar in Figure 2-12).

In contrast, when stakeholders were asked if an unexpected national carbon tax were suddenly announced for immediate implementation across all major industry sectors, surprisingly, a large majority (59.3%) of respondents believed the carbon price in the ETS would increase and almost one fifth of the total sample (18.5%) thought it would be a large increase. Only 25.9% of stakeholders believed that the carbon price would decrease if a carbon tax were introduced (orange bar in Figure 2-12). Three respondents ignored the question.

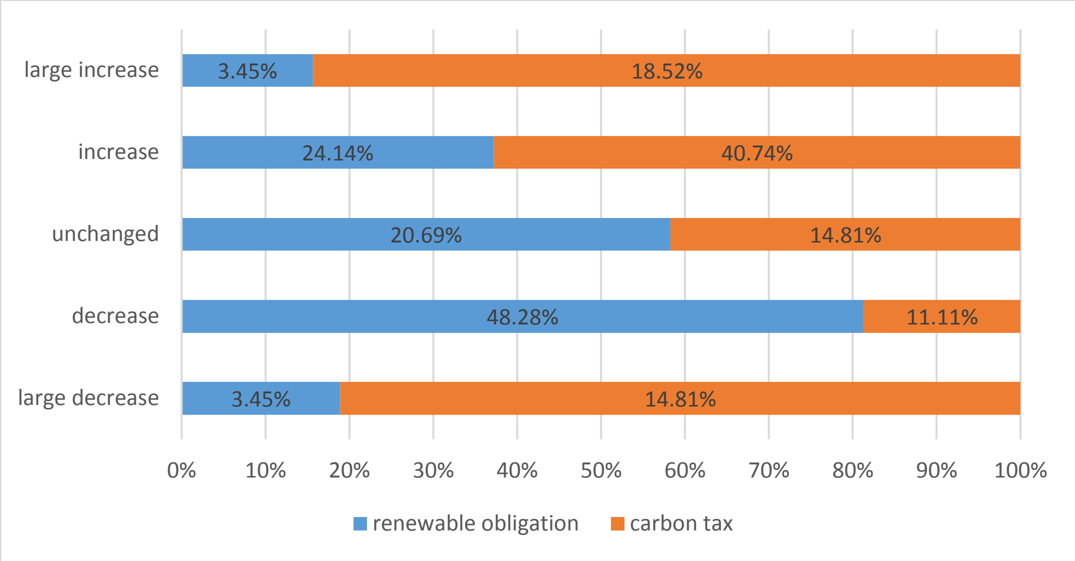


Figure 2-12 Stakeholder-expected market responses to ambitious renewable obligation and carbon tax policies

We then tested further whether stakeholders would recognise possible conflicts that might emerge when there are multiple incentives. Specifically, we asked about the extent to which they agreed that 'incentives, such as 'cap and trade' systems, carbon taxation, renewable energy obligations, and emission performance standards etc., may conflict, and generate different costs and benefits in different situations.' Forty-three per cent of respondents agreed with the statement, while 23.3% disagreed (Figure 2-13).

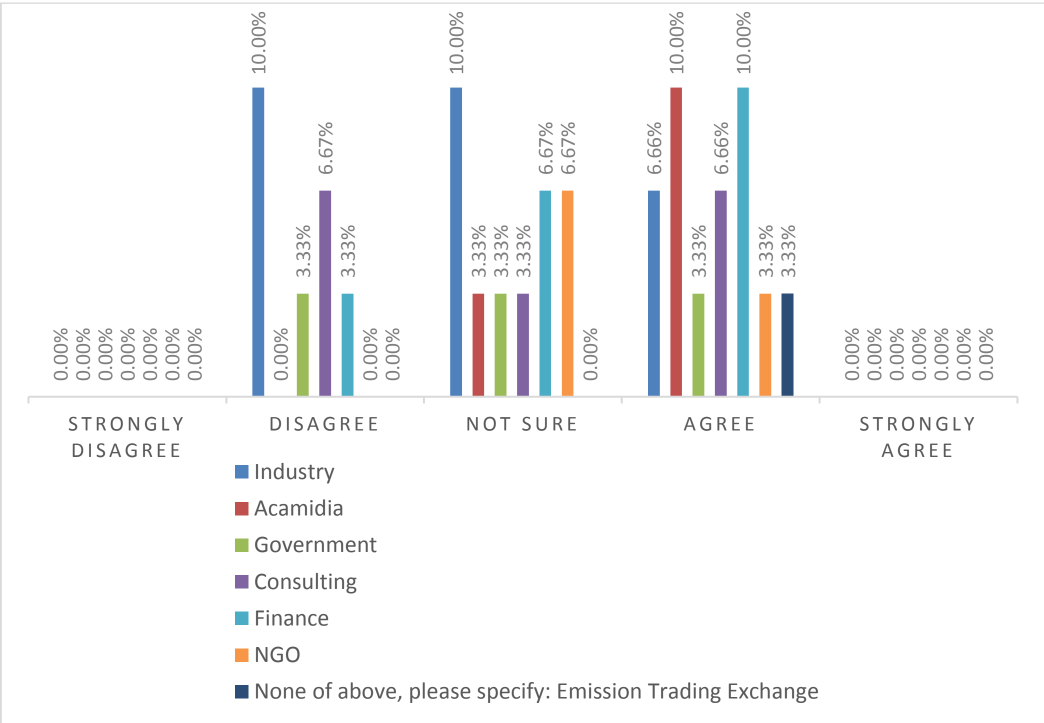


Figure 2-13 Respondent attitudes to statement of policy interactions

As Figure 2-13 reveals, there is a slight tendency for stakeholders to recognise the possible conflicts between carbon markets and overlapping climate change policies; and it is especially noticeable among academic stakeholders. Take *Attit* as ordinal variables representing the extent of agreement or disagreement with the statement, where 1 = strongly disagree and 5 = strongly agree, a statistically significant result is observed from a univariate regression of *Attit* on *Acad* (Table 2-5). The idea is generally more widely accepted among academics than by stakeholders in other sectors.

Table 2-5 Output of univariate regression model *Attit-Acad*

VARIABLE	model *Attit-Aca*
ACA	0.720*
	[1.906]
Constant	3.080***
	[19.977]
Observations	30
R-squared	0.115
Adj. R-squared	0.0833

t-statistics in brackets
*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

- ***Attitudes to linkage between the Chinese and international carbon markets***

There have been many studies on the potential to link national and subnational emission trading schemes, as in the case of Quebec and California, and as was explored for Australia and the European Union (Ranson and Stavins, 2016, Mehling and Haites, 2011). With regard to the statement ‘integrating the Chinese carbon trading market into the international trading system could help reduce the adverse impact on carbon price from the interactions of other national carbon reduction incentive mechanisms’, 36.7% of stakeholders agreed, whereas only 13.3% did not. Nevertheless, for both statements (statement of policy interactions and carbon market linkage), a relatively large proportion (33.3% and 50% respectively) could not decide and no stakeholder expressed a strongly-held attitude (i.e. strongly agreed or strongly disagreed).

To sum up, it is striking that the majority of stakeholders believed that the impact of introducing a renewable target would be to depress carbon prices, while a new carbon tax was seen as lifting the carbon allowance price. The reactions to introducing a tougher renewable energy target and an unexpected national carbon tax provide contrasting results. In theory at least, all else being equal, introducing either measure in addition to the carbon market would reduce the allowance price in the ETS scheme.

The majority of stakeholders in follow-up interviews appreciated that introducing low-carbon policies in parallel (such as a carbon tax or renewable obligations) would affect the carbon allowance price in the ETS but their attitudes differed with regard to the likely magnitude and direction. Two industry and two academic stakeholders during follow-up questioning suggested that renewable energy targets might increase carbon reductions and in turn increase the carbon allowance price, but that carbon taxation policies could provide a 'carbon price floor' to support the allowance prices. Another academic stakeholder believed raising the renewable energy target by 5% could reduce total carbon emissions, while a carbon tax could shift the ETS abatement cost curve to the right, and both measures could significantly reduce the demand and price of carbon allowances in the Chinese ETS.

In the follow-up interviews, two government stakeholders and one stakeholder from the financial sector still did not believe the impact of other mechanisms on carbon price in ETSs would be substantial. The two government officials, though recognising the potential impact of parallel low-carbon incentives on carbon allowance pricing, believed that it is important to introduce more market-based instruments for emission reductions and environmental protection in China, such as energy efficiency quota trading and water rights trading.

Furthermore, it is interesting too that there is a relationship between their attitudes regarding the statement and how much time they claimed have been spent on energy-saving and emission reduction policies in the past year. Using different shades to represent time spent on climate change-related policies, the positive correlation between time spent and respondents' attitudes to the statement is apparent in Figure 2-14. Again, according to the regression of *Attit* on Time, which is a set of ordinal variables representing time spent working on climate change-related policies, the result further supported our finding.

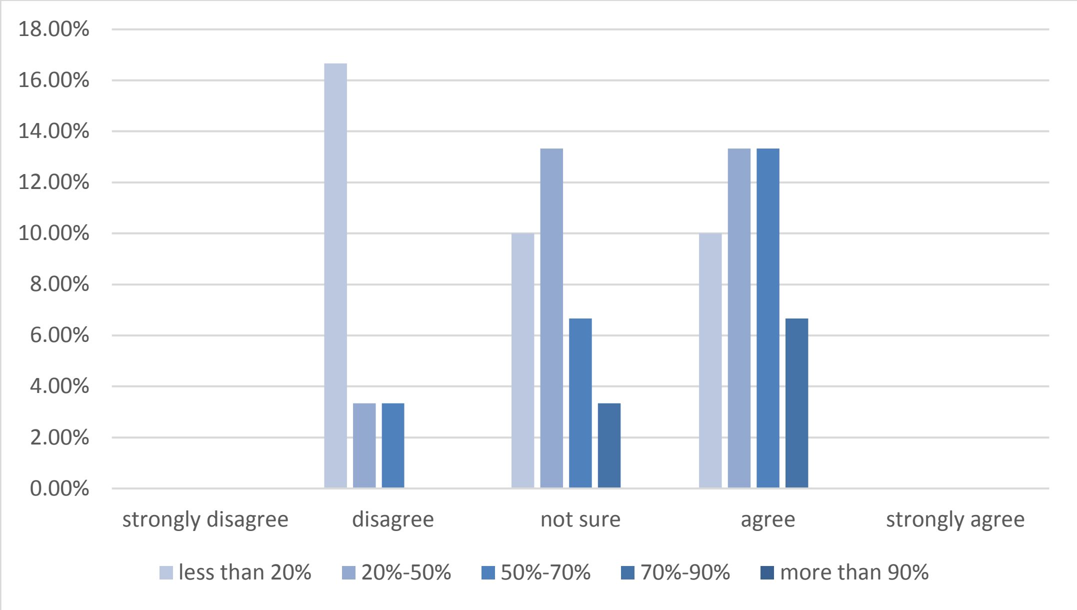


Figure 2-14 Cross-analysis of stakeholders' attitude towards possible conflicts between multiple incentives and time spent on energy-saving and emission reduction policies.

Table 2-6 output of univariate regression model *Attit-Time*

VARIABLE	model *Attit-Time*
TIME	0.288**
	[2.061]
Constant	2.605***
	[8.124]
Observations	30
R-squared	0.132
Adj. R-squared	0.101

T-statistics in brackets
*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

The follow-up interviews also demonstrated divergent views on the compatibility of multiple low-carbon incentive policies. Two government stakeholders considered multiple policy instruments to be better than a single mechanism. However, all academics surveyed were concerned that multiple mechanisms could distort the price signal for environmental goods and provide incorrect signals. Although 33.3% selected the carbon market as their preferred mechanism in an earlier question, no stakeholder in the follow-up interviews believed that the ETS by itself could completely replace other parallel low-carbon incentives in China.

The situation in Europe is very similar. Most stakeholders perceive the trading scheme as the main instrument to cut down GHGs, but there is a growing view that the ETS is not the only instrument required and will need to be combined with other instruments (Fujiwara, 2016). Many stakeholders expressed concern at the negative impact that policies had on carbon prices, especially stakeholders from the power and energy trading sectors (Gaast et al., 2016), and most welcomed the Market Stability Reserve (MSR) as a means of addressing the surplus of allowances. Others still believe, though, that policies supporting renewables have only limited negative effects on the EU ETS (Marcantonini et al., 2017).

In follow-up interviews, one government official and two academic stakeholders emphasised the importance of linking the Chinese carbon market with international carbon markets, arguing that such links could help improve the design and operation of the domestic carbon market in the long-term. Another government official was unsure about the need for international linkages but believed that such linkage could boost the liquidity of the pilot schemes. Industry stakeholders were also unsure about linkage but two were very interested in the impact linkage would have on allowance prices in the long-term. One academic strongly opposed linkage on the grounds that international linkages might reduce the freedom of Chinese climate policy and constrain the Chinese position in future international climate policy negotiations.

2.4.3 Challenges for Chinese carbon markets

- ***The MRV system in Chinese carbon markets***

We asked stakeholders to rank potential problems with the monitoring, reporting and verification (MRV) system that they believed could negatively affect the carbon market. Technical issues raised the greatest concern. Incorrect and incomplete historical databases were viewed as the top challenge, followed by incorrect carbon auditing methodologies. The lack of third-party verification and auditing organisations ranked third. A lack of skilled workers for carbon auditing and corruption during the auditing process was at the bottom of the list (Table 2-7).

Table 2-7 Ranking of potential challenges with regard to MRV system

	1	2	3	4	5	Average ranking
Incorrect and incomplete historical database	62%	15%	12%	4%	8%	1.81
Incorrect carbon auditing methodology	19%	38%	19%	12%	12%	2.58
Lack of third-party verification and auditing organisations	19%	22%	22%	30%	7%	2.85
Lack of skilled workers in carbon auditing	4%	15%	23%	19%	38%	3.73
Corruption during auditing process	0%	8%	23%	35%	35%	3.96

- ***Implementation of Chinese carbon trading market***

In terms of potential implementation, the top-ranked challenge was the pervasive lack of accurate and relevant information and knowledge on the subject, as most respondents agreed that ‘enterprises were still confused about carbon emission trading and worried it might increase costs’. Concerns about a potential negative impact on GDP growth (i.e. that the ‘cap’ implied reduced energy consumption) came second. Stakeholders ranked the challenge of limited financial instruments and the absence of derivatives in carbon credit in third place, followed by the impact of other energy and low-carbon policies (e.g. emission performance standards and renewable energy obligations may reduce demand for emission reductions in carbon markets). Finally, limited financial instruments and institutions were viewed as the least significant challenge of the five listed.

Table 2-8 Ranking potential challenges with regard to implementation

	1	2	3	4	5	Average ranking
Enterprises still confused about carbon emission trading, and worried it may increase costs	44%	44%	7%	4%	0%	1.7
The ‘cap’ implies decreased energy consumption, may negatively influence GDP growth	42%	19%	23%	0%	15%	2.27
Limited financial instruments; Lack of carbon credit derivatives	8%	15%	31%	23%	23%	3.38
Limited relevant financial institutions	0%	12%	35%	27%	27%	3.69
Other energy and low-carbon policies such as Emission Performance Standard and Renewable Energy Obligation may decrease demand for emission reduction in carbon trading market	8%	8%	4%	46%	35%	3.92

Stakeholders also suggested other challenges for the Chinese carbon market including: (a) the absence of strong regulatory support from the central government; (b) the need to develop novel carbon emission reduction technologies; (c) increased production costs for businesses; (d) the difficulty of setting a 'cap' in any emission trading system; and (e) the need for a comprehensive Chinese carbon market, which they felt would inevitably prove costly.

During follow-up interviews, both government and industry stakeholders considered the major challenge for the Chinese ETS to be how it might evolve towards a comprehensive national scheme. Government officials considered the lack of trading activities to be a short-term constraint on the carbon market. Two academic stakeholders were concerned about the quality of data based on initial auditing, and cited the limitations of budget, time and capacity to address these problems, noting there was sometimes less than CNY 100,000 (approximately EUR 13,500) available for an initial survey and audit at a large conglomerate or energy company. One academic claimed the poor quality of initial data could pose serious challenges and lead to a crisis of confidence affecting future development. An industry stakeholder suggested that a professional standards institute should be established to better regulate the quality of MRV.

2.5 Conclusions

This is the first survey with a focus on the interaction of low-carbon and energy policies in China, which we hope can open the discussion and provide policymakers with a better understanding of some of the built-in biases and perceptions of key actors.

Given expectations of continued high levels of economic and energy demand growth in China, half of the stakeholders surveyed considered a deep cut in emissions in the next decade to be unlikely. Government stakeholders generally were more hopeful of success in cutting GHG emissions in China and were far more confident than industrial and academic stakeholders in the potential benefits from carbon pricing in China.

Academic stakeholders tended to consider the progress of ETS development in China to be slow, and generally felt pessimistic about the potential of Chinese carbon markets to reduce emissions due to over-allocation of permits and imperfect auditing regulations, even though their expectations on the future market price in the Guangdong pilot were relatively high compared with other stakeholders.

Similarly, industrial stakeholders also expressed concern over the impact of the economic cycle on carbon allowance prices. Although there was a wide range of views on the future carbon price, overall more respondents expected the price to drop, led by industrial sector stakeholders. Possible reasons for the bearish attitudes include concerns over an incomplete MRV system, lack of awareness among many enterprises of the benefits of carbon markets, and the perception that participation in the market merely fulfils the need for government social responsibility or corporate strategy (Yang et al., 2016). By contrast, academic stakeholders were more optimistic in their expectations.

There is a relatively limited understanding of how other mechanisms might affect the price of carbon allowances, even though more than one-third of respondents considered the interaction to be a significant challenge. In theory, both a new additional carbon tax and a more stringent renewable target would shift the abatement curve to the right thereby reducing the allowance price. In our survey, however, many stakeholders believed that renewable targets would lower the carbon price, but a majority expected a carbon tax to boost the carbon price seen in the market. Most academic respondents recognised that interactions between the carbon market and other energy and low-carbon policies may decrease 'demand' in emission trading markets. It is noteworthy that the degree of understanding of interactions between instruments was positively associated with the self-reported amount of time spent working on energy-saving and emission reduction policies.

Energy and low-carbon policies in China have been shifting from command-and-control policies to more market-based approaches. Past studies have indicated that a large majority of Chinese stakeholders would prefer market-based instruments to control GHGs (Liu et al., 2013b, Lo, 2014). This enthusiasm for markets is consistent with our results, as an emission trading mechanism was deemed the most cost-effective instrument to achieve deep cuts in emissions in China. Therefore, disagreements over the perceived interaction between overlapping energy and low-carbon policies may undermine the ETS carbon price, despite committing to launching a unified national carbon market by 2017, while support for an ETS was unequivocally and repeatedly confirmed at the highest political level.

Objectively, the preparatory stage for the Chinese pilot carbon markets has been relatively short compared with the systems in Korea, Quebec, and California (The World Bank, 2014), but very few stakeholders considered the pace to be ‘too fast’. The development of a national ETS has taken place in parallel with the pilot schemes and momentum has been growing in China towards a national ETS with the government originally committing to a multi-sector ETS being up and running in 2017. While discussion of whether a Chinese national ETS should ultimately employ a top-down or bottom-up approach[10] is still ongoing, and the road map has not yet been formally announced beyond the initial announcement in December 2017, the NDRC has at least initially adopted a top-down approach towards developing a national system. Moreover, the effort to get a national system up and running so quickly may explain some of the problems and delays encountered by the national ETS driven primarily by the lack of baseline data and the need for an operational data collection system (Feng, 2017).

Our findings suggest there are still some important unresolved issues confronting the new national system. It would have been more desirable if in the process of implementing the national ETS, the Chinese authorities were able to learn lessons from the pilot systems. The lack of transparency in disclosing market information, a lack of knowledge among market participants, and an immature MRV system pose uncertainties for carbon price setting. Fuss et al. (Fuss et al., 2008) claimed that climate change policy uncertainties would induce industries to wait and see whether strong interests in effective and efficient investment response to its policy signals will be brought out by the government. This implies the degree of market information obtained would influence industries’ investment decisions on carbon-saving technologies. In addition, the diversity of stakeholders’ predictions of the carbon price reflects a lack of consensus.

[10] Top-down approach is through the UNFCCC framework; bottom-up approach is through bilateral and multilateral agreements between jurisdictions.

Chapter 3

An empirical study of carbon price determinants and the impact of other low-carbon policies on Chinese pilot ETSs

3.1 Introduction

Climate change is an issue of wide concern in the world and requires both developed and developing countries to make efforts for adaptation and mitigation. Carbon pricing, including carbon taxation, ETSs and other measures, essentially aims to put a price on carbon emissions and is perceived as an effective way to stimulate a low-carbon transition and to combat climate change. During the past few decades, the growing number of carbon pricing schemes and the coverage of GHG emissions have increased fourfold (The World Bank, 2014). Especially following the implementation of the EU ETS in 2005, more ETSs were proposed and launched, such as the Regional Greenhouse Gas Initiative (USA), New Zealand Emissions Trading Schemes, Tokyo Metropolitan Trading Schemes, and the South Korean ETS.

China is the largest GHG emitter in the world; the coal-based power sector in China alone produces more than 7% of global carbon emission and approximately one-third of China's domestic emissions (Pollitt et al., 2017). Thus, China has set domestically binding FYPs, which act as a pathway to achieve its official Nationally Determined Contributions (NDCs) target under the Paris Agreement framework, submitted in 2015.

China launched its own ETSs in late 2011, with seven pilots on track in 2014 and Fujian as the eighth ETS pilot in 2016, complementing the national target of a reduction of 60%-65% in carbon emission intensity by 2020 based on the 2005 level. Figure 3-1 shows the timeline of ETS policy development in China; establishing an ETS was officially included in the 12th FYP announced in March 2011, followed by an announcement by the NDRC in the following October to launch seven ETS pilots, to accumulate relevant experience before forming a national carbon market. These seven regions were chosen based on their different economic characteristics. For example, Beijing and Shanghai are business hubs, Guangdong province is more based on manufacturing sectors, Hubei province relies more heavily on energy-intensive industries (e.g. iron and steel), Tianjin and Chongqing both to some extent focus on industrial and service sectors (Zhang, 2015b). The short-term goal and the starting point of piloting ETS is to accumulate experience for the transition to an integrated national carbon market, which was launched in late 2017.

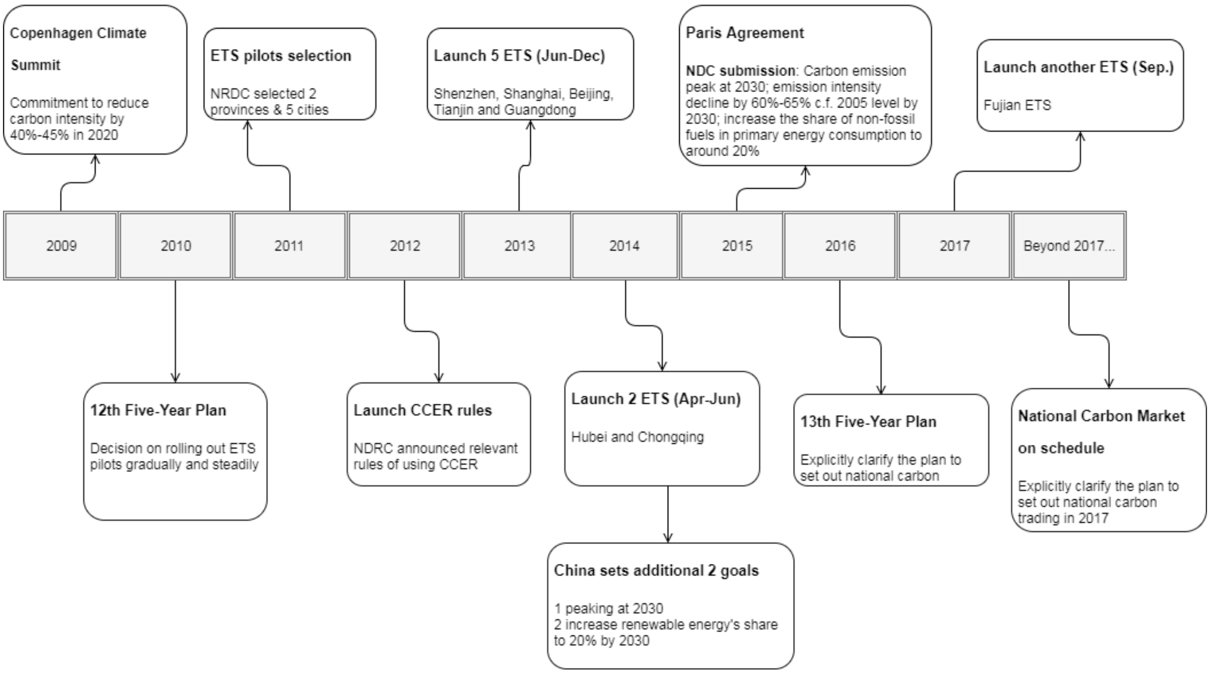


Figure 3-1 Timeline of ETS development in China

In addition to the ETS pilots for stimulating GHGs reduction, there are other incentives to support renewables in China including feed-in tariffs (FITs) and renewable energy quota systems and direct subsidies such as the building-integrated photovoltaics (BIPV) subsidy programme and the Golden Sun Programme in 2009. The FIT is a government scheme designed to encourage uptake of a range of small-scale renewable and low-carbon electricity generation technologies (Ye et al., 2017). For example, the latest FIT policy for distributed generation photovoltaic (DGPV) issued by NDRC (2017a) stipulates that self-consumed generation will be reimbursed at the local retail electricity rate, in addition to the 0.37 RMB/kWh subsidy. Additionally, generation in excess of domestic demand will be taken by the power grid and purchased by local power enterprises at the electricity price for coal-fired generation without sulphur (Zhang et al., 2015). The renewable energy quota system means the electricity retailers need to purchase a certain quantity of renewable energy either on a voluntary basis, which could take the form of tradable renewable energy certificate schemes, or on a mandatory basis with non-compliance punishment (Xiong et al., 2014).

Benefiting from the renewable energy policy framework, the installed capacity of renewable energy in China has increased dramatically since 2006. For example, the capacity of hydropower in China has been growing at an average annual rate of 11% (CNREC, 2013). China now has the largest wind power market in both manufacturing and capacity installation (Zhang et al., 2013b).

Based on previous studies on the EU ETS, this combined low-carbon regime carries a risk of: carbon mispricing arising from ETS system design features and from policy interactions with other low-carbon policies. First, institutional decisions for ETS operation are usually not accurate due to the complexity of ETS design and the imbalanced developing abatement technologies across sectors (Advani et al., 2013). For example, overall cap stringency, carbon offset projects, or incomplete MRV will impose certain mispricing risks in ETSs. As shown in Figure 2-2, after a price collapse in April 2006 following the announcement of the verified emissions in the year 2005, the allowance price dropped toward zero due to the prohibition on banking allowances during December 2007. As a result, it failed to convey valuable information to regulated entities and further depressed market confidence, raising policy concerns.

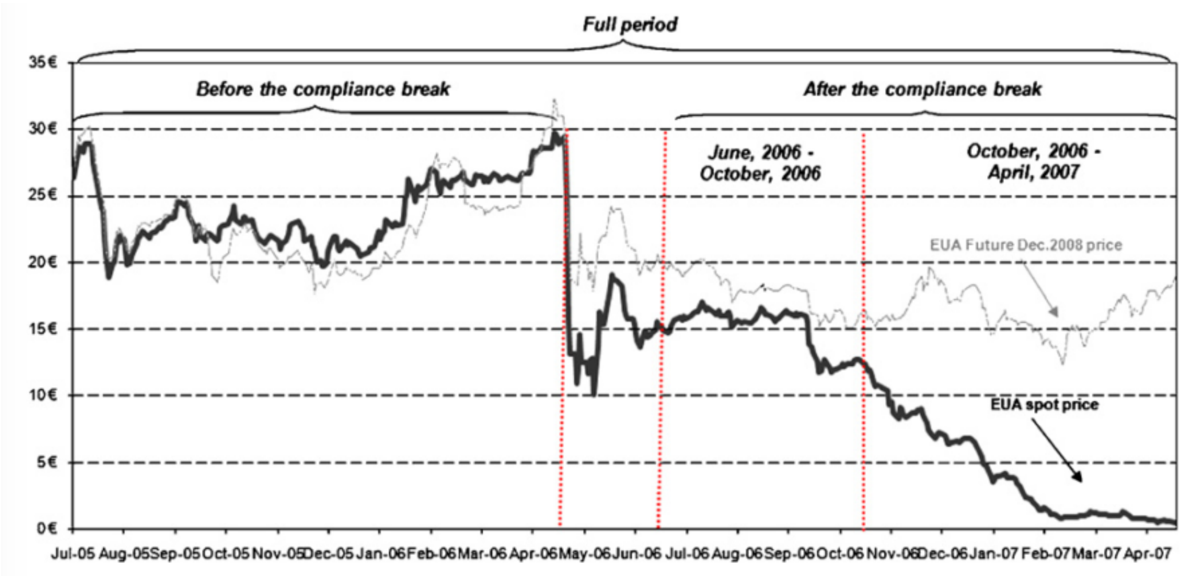


Figure 3-2 EUA price collapses 2006 - 2007

Second, the effect of policy interaction on emission reductions has been widely discussed. One of the key threats identified by scholars is the overlapping effect that weakens incentives for adopting low-carbon technologies thus increasing total emissions (Böhringer and Rosendahl, 2010, European Commission, 2017). Unlike in the EU ETS, the current literature on carbon pricing in China and interaction between parallel low-carbon policies is scarce, even though China has just launched the world's largest ETS. Instead, most of them focus on the assessment of carbon market performance or the policy debate on the carbon tax and ETS policy (Liu et al., 2015, Zhang, 2015b, Zhao et al., 2016). Hence, there is a gap in the literature in empirical research on allowance pricing behaviour and the quantitative effect of policy interactions in Chinese ETS pilots. Thus, to understand the potential risk of carbon mispricing for Chinese ETS, an investigation on price deterministic drivers and policy interaction is crucial.

The contribution of this study is threefold. First, it extends the current empirical analysis of pricing behaviour in the Chinese ETSs by further incorporating renewable energy factors and extreme weather as additional explanatory variables. Second, it conducts the first quantitative analysis in assessing the impact of parallel low-carbon policy on allowance prices in China. Lastly, this study provides an insight into the dynamic relation between macro-level financial risks and carbon price series.

The remainder of this chapter is presented as follows: Section 3.2 discusses prior research and literature on pricing behaviours and policy interaction in carbon markets; Section 3.3 demonstrates the dataset and methodology used in the analysis; Section 3.4 presents the empirical results and interpretation; and Section 3.5 concludes the research findings along with limitations and implications for policy frameworks and future studies.

3.2 Literature review

Overall, carbon prices are mainly driven by the balance between the supply and demand of allowance units (Mansanet-Bataller et al., 2007, Alberola et al., 2008, Tan and Wang, 2017). The demand for allowances is expected to be related to energy prices, extreme weather conditions, macro-economic factors, renewable energy production and issued CERs (Chevallier, 2011). The supply of allowances is primarily determined by policy decisions or regulatory events, such as the level of the emissions cap, the announcement of or information disclosure on a surrender date or the rules of using carbon offsets (Hintermann et al., 2016).

- ***Energy market***

Fossil fuel prices, including crude oil, coal, and natural gas, are empirically proven to be significant factors in determining EUA prices in the EU ETS. Mansanet-Bataller et al. (2007) and Alberola et al. (2008) produced pioneering literature to reveal that energy markets act as decisive factors in explaining allowance price fluctuation. Based on Phase I spot and futures data, the former study established that carbon prices in the EU ETS are linked to fossil fuel use (e.g. oil, gas, coal). By using an extended dataset, the latter study emphasised that the nature of this relationship between energy and carbon prices varies depending on the period under consideration. Bunn and Fezzi (2007) further quantified the mutual interactions of electricity, gas and carbon prices in the UK.

Natural gas is more integrated and believed to have a significantly positive effect on allowance prices (Aatola et al., 2013, Kim and Lee, 2015). When the gas price goes up, carbon emissions go up because entities are reluctant to continually use this relatively clean fuel, thereby carbon price increases. Coal prices are found to be negatively related to allowance prices while gas prices are positively related (Benz and Trück, 2009, Creti et al., 2012, Aatola et al., 2013, Kim and Lee, 2015). The rationale behind this is that coal is comparatively more carbon-intensive than gas. Thus, the increasing price of coal results in less related output and therefore, lower carbon emissions, with a decrease in the carbon price. However, Rickels et al. (2014) found an unexpected positive relationship between coal and allowance prices in phase II of the EU ETS while Koch et al. (2014) could not find coal prices to be a statistically significant factor in explaining EUA prices (Koch et al., 2014).

As for the Brent oil price, previous studies yielded conflicting results due to differences in sample periods, data series and econometric methods. For example, some papers identified the Brent oil price as a significant positive driver of the carbon price as it affects the price of natural gas (Alberola et al., 2008, Reboredo and Ugando, 2015). However, Hammoudeh et al. (2015) argued that the crude oil market and allowance market are negatively correlated while others found that these two markets are not correlated (Alberola et al., 2008, Berdin and Muckley, 2011). Yu et al. (2015) further conducted a multi-scale analysis and indicated that the linear relationship between crude oil price and allowance price is stronger over a larger time scale.

Given that the power sector is the most affected sector under the EU ETS, the fluctuating electricity price is found to be a key indicator of allowance prices (Bunn and Fezzi, 2007, Keppler and Mansanet-Bataller, 2010, Kim and Lee, 2015). However, in the context of China, it has been well recognised that the current power market is a state-managed system rather than market-based, despite the ongoing reform of the electricity supply sector (Pollitt et al., 2017). Thus, the electricity price in China cannot serve as a benchmark for the carbon price as it does in the EU ETS (Chen et al., 2016). Alternatively, another electricity-related variable that may be examined is the renewable energy production level, because GHG emissions would be lower when there are enlarged shares of renewable resources such as hydro, wind and solar power in electricity generation. Koch et al. (2014) found the growth of wind and solar electricity production is a second important determinant of EUA price drops (the first is economic conditions) as the policy interaction effects between ETS and renewable outputs are empirically moderate. In contrast, many scholars found a significant negative correlation between allowance price and the supply level of renewable energy (Aatola et al., 2013, Hintermann et al., 2016). Rickels et al. (2014) further suggested that the short-term variation in wind power supply has no observable effect on allowance prices.

- ***Extreme weather***

Apart from energy market factors, extreme weather and seasonal changes are expected to have an impact on the price path of carbon insofar as they influence energy demand (Mansanet-Bataller et al., 2007, Zeitlberger and Brauneis, 2014). For example, cold winters could increase the level of heating while hot days will yield extra demand for air conditioning, which will increase fuel use for electricity generation, and consequently the level of carbon emissions. Alberola et al. (2008) indicated that unanticipated cold temperatures would have a greater impact on allowance price than regular temperature changes. Chevallier (2012) further highlighted these nonlinear relationships by proving a statistically significant effect can only be found when the weather deviates above or below a certain threshold. The main insight behind this point is that only unanticipated temperature events can have an effect on carbon prices, as market participants can properly anticipate temperatures that conform to seasonal averages.

- ***Macroeconomic indicator***

Chevallier (2009) was the first to find a transmission effect from the stock market to the carbon market, based on previous studies on futures price of agricultural and energy market. Oberndorfer (2009) suggested that stock returns of those affected companies under the ETS scheme positively contribute to carbon prices. This argument is further supported by Lutz et al. (2013) assertion that a stock indicator may serve as a macroeconomic proxy and is positively correlated to the allowance price. The rationale behind the relationship is that the allowance price is expected to fall when the economy slows down because the reduced business activities or lower production levels would reduce allowance demand.

- ***Policy interaction***

It is believed that renewable energy policies will affect aggregate demand of fossil fuels thus having an indirect influence on the demand for emissions allowance. Böhringer and Rosendahl (2010) provided a theoretical model suggesting that mandatorily increased renewable energy will reduce the demand for emission allowances in the trading market, and therefore the undervalued price of emission allowances will fail to trigger low-carbon and clean technologies. Following this, Abrell et al. (2011) extended the theoretical model by further analysing the effect on suppressing allowance demand due to the introduction of financial subsidies for renewable energy. In addition to this, many scholars have examined the actual effect on emission reduction levels brought about by policy interaction (Tu and Mo, 2017) (Fujiwara, 2016) (Kim and Lee, 2015) (Zhang et al., 2013b). This phenomenon has been explained by Hone (2013a), who argues that the mandatory policies such as ambitious renewables target or high carbon taxation would distort the marginal abatement cost curve thereby lowering the visible prices in the emission trading market.

However, Shahnazari et al. (2017) generated an integrated real options and portfolio optimisation model of electricity generation investment behaviour under political uncertainty where carbon pricing interacts with renewable portfolio standard (RPS) instruments. They suggested that overlapping a politically contested carbon pricing policy with a renewable portfolio standard may result in a lower risk in renewable energy investment environment, as the overlap allows investors to hedge their portfolio against political uncertainty through renewable energy additions. Consequently, GHG abatement objectives may be achieved at lower cost than would be the case without the policy interaction. Furthermore, Weigt et al. (2013) found a promising interaction between renewable energy promotion and climate policy by showing that renewable energy led to a reduction of emissions in Germany and it contributes more to abatement activities if it is covered by an ETS scheme. Considering the long-term effect, ETS policy and renewable promoting policy might be implemented jointly to ensure the generation of renewable energy (Moselle, 2011).

Among the rest of the extensive literature on policy interactions within climate and energy policies, most of it follows an ex-ante simulation approach and focuses on the interaction between carbon prices and renewable energy policies. They can be divided into two groups: the first is studies using theoretical models to understand the dynamics of policy interactions (Sorrell, 2003) (Pethig and Wittlich, 2009, Böhringer and Rosendahl, 2010); the second group of studies use computable general equilibrium models to study the dynamics of policy interactions in heterogeneous sectors (Boeters and Koornneef, 2011) (Flues et al., 2014) (Kim and Lee, 2015).

Results from this ex-ante literature strongly depend on model assumptions and the data used, and the results from ex-ante simulation and ex-post empirical analyses can be different. For instance, Koch et al. (2014) found that ex-post sensitivity of EUA price changes to wind/solar growth is much smaller than predicted ex-ante by simulation-based studies. The important implication of this finding is that policy interaction effects between ETS and renewable energy standards are potentially exaggerated in simulation-based analyses. There is now a large empirical literature on ETS; however, only a handful of studies have a specific focus on ex-post empirical analyses of interactions of ETS with other energy and climate policies.

Furthermore, as market participants may react sensitively to news of regulatory changes, regulatory announcements may have effects on carbon prices (Daskalakis et al., 2009, Mansanet-Bataller and Pardo, 2009, Conrad et al., 2012). Most studies assessed the impact of ETS policy (e.g. the complementary use of carbon offsets, adjustments on the total cap) that can influence the supply of allowances using dummy variables or an event-study model. Alberola et al. (2008) found the price collapse of the EU ETS during 2006 was associated with the verified emissions announcement in 2015. The prohibition of banking from EU ETS phase I to phase II is proven to have had a significant negative impact on the carbon price, as unused permits were worthless after the year in which they were issued, and there was a considerable allowance surplus at the end of Phase I (Chevallier, 2010). Daskalakis et al. (2009) further suggested that inter-phase banking can smooth out fluctuations. Based on previous papers, Fan et al. (2017) conducted complementary research by employing an event-study model and clustering ETS regulatory policy announcements into six categories, and they indicated that while aggregate impacts of the total events studied are low, impacts of events having underlying negative impacts are higher than those having underlying positive impact. Nearly half of the regulatory policy announcements have significant impacts on EUA returns and are coherent to their theoretical impacts.

The literature on quantitative analysis of carbon pricing in Chinese ETS is currently limited; Zhang (2015a) stated carbon prices tend to be associated with energy prices rather than regulatory events on the supply side. Based on previous work, Chen et al. (2016) conducted VAR models with daily data series and surmised that oil price has a negative influence on carbon price. Moreover, they found an unexpected negative relation with stock prices. They further explained that the stock price in China is dominated by interest rate policy rather than real economic conditions, especially during 2013-2015. However, drawing conclusions based on daily data in the Chinese ETSs needs to be done cautiously. Given that there are a large number of non-trading days in carbon markets during the trading period, daily data tend to be less informative, an issue which Chen et al. (2016) failed to consider.

Wang and Lu (2015) proposed that price determinants for the seven pilots present regional variations due to differences in the degree of development of carbon-intensive and service industries. Macroeconomic factors, energy prices and temperatures have a significant impact on emission allowance prices in China, and price fluctuations are mainly driven by the demand side. This assumption is supported by Fan and Todorova (2017), using volume-weighted weekly carbon prices and other explanatory variables at a weekly frequency. Additionally, they found that carbon markets in China are positively correlated to macroeconomic indicators, such as the stock indices of Shenzhen and Shanghai, and the crude oil price was statistically significant in determining market prices in the Hubei and Shenzhen pilots.

3.3 Methodology

3.3.1 Dataset

3.3.1.1 Carbon prices

Given that the Chinese ETS pilots have not yet launched a futures market, only spot prices are considered here. Emission trading, data including daily price and trading volume, were obtained from the official website (www.chinacarbon.net.cn). The sample period for all ETS pilots was from 19^{th} June 2014 to 21^{st} June 2017. Table 3-1 presents an overview of carbon prices data at a daily frequency.

As trading was relatively inactive (see % days with trading activities in Table 3-1), too many zero returns would weaken the reliability of the regression models, therefore, we followed the example of Fan and Todorova (2017) and transformed daily data to weekly data, which does not omit as many noteworthy fluctuations as monthly data would, and also helps to avoid noisy daily data entries. Moreover, volume-weighted weekly prices are used in the regression model to improve accuracy, since the intra-week trading volume is highly varied.

Table 3-1 Overview of carbon prices raw data

ETS Pilots	*Sample period*	*Total number of daily observations*	*Number of days with trading activities*	*% days with trading activities*
Shenzhen	19/06/2014 – 21/06/2017	785	509	64%
Shanghai	19/06/2014 – 21/06/2017	785	391	49%
Beijing	19/06/2014 – 21/06/2017	785	473	60%
Guangdong	19/06/2014 – 21/06/2017	785	526	67%
Tianjin	19/06/2014 – 21/06/2017	785	330	42%
Hubei	19/06/2014 – 21/06/2017	785	691	88%
Chongqing	19/06/2014 – 21/06/2017	785	115	14%

3.3.1.2 Explanatory variables

Note that all explanatory variables are expressed in the currency of CNY if associated with price. All monthly data were merged into the weekly dataset using Stata. Detailed information on all explanatory variables is summarised in Table 3-2.

- ***Energy market factors***

Conventional energy sources, such as crude oil and natural gas, are perceived to be the price determinants in carbon markets. With respect to crude oil ("*oil_ara*'), the Arabian Dubai Fateh Crude Oil Spot Index was used in the model, and served as the main pricing benchmark for Asian crude oil (Giaever-Enger and Booth, 2008). Gas ('*gas*') is an increasingly important factor in the Chinese energy mix, represented by China Market Price of Commodities Liquid Natural Gas. The price of coal ('*coal*') is the average weekly spot price of China Qinhuangdao 5500 kcal/kg.

The monthly renewable energy data ('*re_prdct*') is represented by the aggregate national electricity production level of different renewable energy sources, including hydropower, nuclear and wind power (onshore and offshore wind). Meanwhile, because daily and weekly series of renewable energy data are not accessible, monthly data series were chosen instead.

- ***Macroeconomic indicators***

To investigate the explanatory power of macro-level indicators, we first employed the CSI 300 stock (‘*s_300*’) index to capture possible economic fluctuations. Given that the Shenzhen Stock Exchange is mainly composed of private companies while Shanghai hosts the biggest state-owned companies from financial services and energy sectors, the broad-based stock index CSI 300 is perceived as a representative indicator for the economy, which is a capitalisation-weighted index tracking the financial performance of 300 actively traded stocks from Shenzhen and Shanghai exchanges.

- ***Extreme Temperature***

Daily temperatures were collected for each pilot first, then the deviation of temperatures, expressed in the form of absolute value, were measured by the differences from their weekly average temperatures and 10-year rolling average temperatures for every week, which alleviates noise from seasonal changes. As the differences were transformed to absolute values, these can be interpreted as the extreme level of temperature on a weekly basis for each pilot.

- ***Low-carbon policy events***

Policy released as an announcement, notice and legal document by either central or local government is defined as ‘regulatory event’ in this study. Two main targeted categories are policies concerning renewable energy development and usage, and ETS policies. Initially 54 events about renewable energy at the national level and 166 events about ETS at the local level were collected as the data pool. Next, the events related to renewable energy on the national level were kept without further adjustment, because they are consistent in their nature of promoting renewable energy installation and usage, and thus are expected to have the same effect on carbon markets. The renewable energy events mainly include tariff settlement, announcements of financial subsidy, and guidelines for increasing the use and output of renewable energy, for example, the announcement of issuing the 13^{th} FYP for wind power generation.

- ***ETS regulatory events***

ETS policy events need to be further classified as follows: surrender dates, i.e. the dates on which covered entities must surrender enough allowances to cover its emissions, otherwise heavy penalties are imposed; CCERs (Chinese Certified Emission Reductions) offset limit announcements, i.e. the events related to the rules of using or verifying carbon offsets. The policy event data are listed in Appendix C.

Table 3-2 Dataset summary

Series	*Specification*	*Frequency*	*Unit*	*Database*
Gas	Market price of commodities liquid natural Gas (LNG) in China	Weekly	CNY/Tonne	Bloomberg
Crude Oil	Arabian Dubai Fateh Crude Oil spot index	Weekly	CNY/Barrel	
Coal	China Qinhuangdao Port Thermal Coal 5500 kcal/kg	Weekly	CNY/metric tonne	
Macroeconomic indicator	Shenzhen Shanghai CSI300	Weekly	CNY	
Extreme weather	Actual temperature-10-year rolling average	Weekly	Celsius Degrees	
Renewable energy	China Energy Production Electricity Hydro Electric Power	Monthly	Billion KWh	
	China Energy Production Electricity Nuclear Electric Power	Monthly	Billion KWh	
	China Energy Production Electricity Wind Electric Power	Monthly	Billion KWh	

3.3.2 Empirical method

3.3.2.1 Ordinary Least Squares

OLS regression was employed in this study. All ETS pilots are expressed in the general regression form as follows:

$$\Delta y_t = \alpha + \beta(\Delta)X_t + u_t \qquad (3\text{-}1)$$

Where Δy_t refers to weekly returns of carbon prices, X_t is the vector of explanatory variables. β stands for the estimated coefficient for each explanatory variable and u_t refers to the residual term of the model.

The use of non-stationary variables can lead to spurious results in regressions (Brooks, 2008). Therefore, the Augmented Dickey-Fuller (ADF) unit root test needs to be conducted. After taking ADF tests, all variables other than weekly returns and extreme weather were found to be non-stationary, therefore those non-stationary data entries were converted to stationary by taking the firstdifferenced form. In order to alleviate possible heteroscedasticity and autocorrelation issues in the error term, all estimation models adopted Newey-West HAC standard errors with maximum 10 lags. Our basic carbon allowance pricing model is as follows:

$$Carbon\ price_t = \alpha_0 + \beta_1 Gas + \beta_2 Coal_t + \beta_3 Crude\ Oil_t + \beta_4 CSI_{300_t} + \beta_5 Rnewable\ Energy_t + \beta_6 Extreme\ Weather_t + \varepsilon_t \quad (3\text{-}2)$$

All raw data and cross-correlation of all the variables are presented in Appendix B. The correlation table suggests that each carbon market is segmented and driven by different price determinants.

3.3.2.2 Event-based study

It is widely recognised that fundamental-based econometric models do not have sufficient explanatory power regarding observed carbon price variations, as the adjusted R^2 or R are generally low (Alberola et al., 2008, Koch et al., 2014, Hintermann et al., 2016). To deal with this issue, many studies assess the impact of given policy events using dummy variables to represent certain event dates. Through this method, the influence of some 'distorted' factors can be examined, and additional explanatory variables through time will be spotted. Following previous works, three dummy variables representing the policy events of renewable energy development and usage, limiting the use of CCERs, and surrender date notification were added. Thus, for each pilot, we considered renewable energy policy events on the national level, denoted as 'Renewable Energy,' and ETS policy events including announcements dates of CCERs and surrender date. The regression model for each pilot is shown as below:

$$\Delta y_t = \alpha_0 + \beta_i(\Delta)X_t + u_t + \gamma_1 D_{Renewable\ Energy} + \gamma_2 D_{CCER} + \gamma_3 D_{Surrender\ Date} \quad (3\text{-}3)$$

Where Δy_t refers to weekly returns of carbon prices, X_t is the vector of explanatory variables as in Equation 4-2. β and γ stand for the estimated coefficient for each explanatory variable, D refers to the type of policy events inserted as dummy variables, and u_t refers to the residual term of the model.

Thus, the more detailed regression model is presented below:

$$Carbon\ price_t = \alpha_0 + \beta_1 Gas_t + \beta_2 Coal_t + \beta_3 Crude\ Oil_t + \beta_4 CSI_{300_t} + \beta_5 Renewable\ Energy_t + \beta_6 Extreme\ Weather_t + \gamma_1 D_{Renewable\ Energy} + \gamma_2 D_{CCER} + \gamma_3\ D_{Surrender\ Date} + \varepsilon_t \quad (3\text{-}4)$$

3.4 Results and findings

3.4.1 Empirical results

The brief summary of regression results for each pilot is presented in Appendix B. Overall, it seems that no statistically significant price determinant can be found in the Chongqing market, which is reasonable given its extremely inactive trading. However, several valuable price drivers were identified across all other markets. In the Beijing market, carbon prices appear to be positively associated with the Arabian crude oil price, which is significant at the 5% level, while other factors are not significant. A similar effect can also be found in the Shanghai market, in which the Arabian crude oil price positively affects the carbon price with a 5% significance level. As for the Guangdong market, the Chinese market price of LNG is significant at the 1% level and positively correlated with carbon prices, while other factors are not significant. However, in the Shenzhen market none of the aforementioned energy factors is found to influence carbon prices, except extreme weather (at the 10% significance level). Finally, carbon prices in the Tianjin market show a weak positive correlation with the renewable energy production level, while all other factors found to be insignificant.

The Beijing and Shanghai markets seem to have no reaction to policy events with a noteworthy significance level. Renewable energy policy announcements are found to be significant in Guangdong and Hubei markets at the significance levels of 5% and 10% respectively. Moreover, regulatory announcements that are associated with a surrender date are negatively linked with carbon allowance prices in the Shenzhen market at the 5% significance level. Finally, a dummy variable for CCER announcements only had a statistically significant effect in the Tianjin market, at the 10% significance level. The relations between macroeconomic indicators and carbon prices seem to be weak.

Table 3-3 Summary of impacts on carbon prices from explanatory factors

Factors	*Previous literature on the EU ETS*	*Previous literature on China's carbon market*	***Results in this study***
Theory-based price driven factors			
Gas prices	Positive	Insignificant	**Positive (Guangdong)**
Crude oil prices	Positive/Negative/Insignificant	Positive/Negative	**Positive (Beijing, Shanghai)**
Coal prices	Positive/Negative/Insignificant	Insignificant	**Insignificant**
Macroeconomic indicator	Positive	Positive/Negative	**Insignificant**
Extreme weather	Positive/Insignificant	-	**Positive (Shenzhen)**
Renewable energy production	Negative/Insignificant	-	**Positive (Tianjin)**
Events factors			
Renewable energy policy announcements	Negative	-	**Positive (Guangdong, Hubei)**
CCERs offset limitation announcements	-	-	**Positive (Tianjin)**
Surrender dates	-	-	**Negative (Shenzhen)**

3.4.2 Discussion

- ***Explanatory power of energy market and macroeconomic factors***

Coal price is a not significant price driver in any of the pilot carbon markets. The rationale behind this is as follows: first, coal is a globally traded commodity with a stable price over a fairly long period, except during 2016 when its price rose because of the Chinese Government's attempt to decarbonise its economic structure and thus reduce the amount of coal mining; second, even though the use of coal is expected to be reduced gradually, coal still dominates the current energy consumption mix in China partly due to the insufficient natural gas resource and rich coal reserves (See Figure 3-3) (Xie et al., 2010, BP, 2017). As energy demand in an emerging economy imposes a relatively inelastic demand on coal use, coal consumption in China does not depend on coal prices, and thus coal prices do not have a significant impact on emission prices in carbon markets in China.

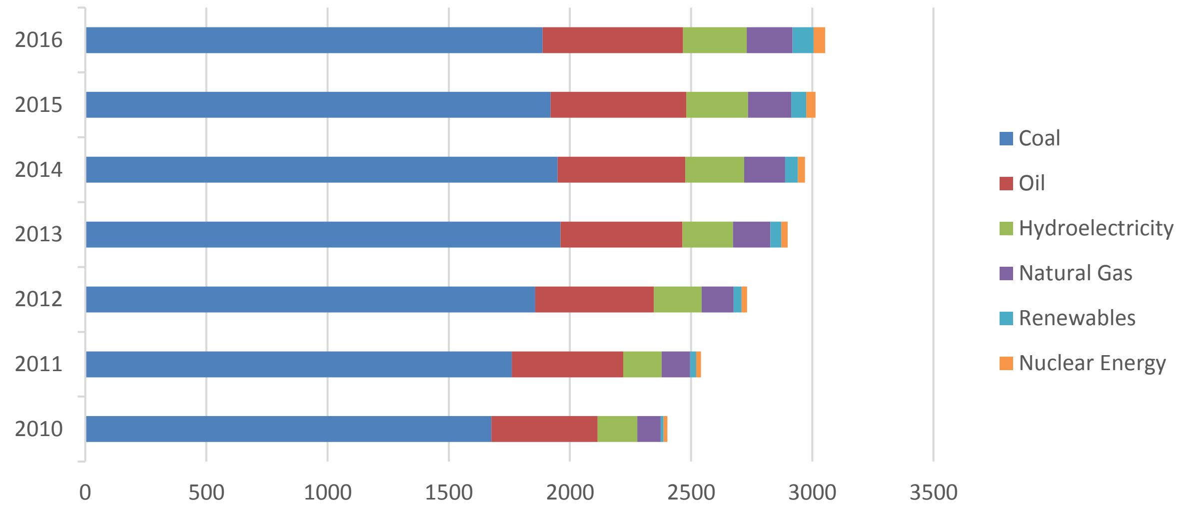


Figure 3-3 China primary energy consumption by fuel type 2010-2016

Even though coal price is not significant, a positively significant dynamic relationship exists between other energy prices (i.e. Arabian crude oil and natural gas) and carbon prices in the Beijing, Shanghai and Guangdong markets. This supports the mainstream studies such as Chevallier (2011) and Conrad et al. (2012), in that an increase in the international oil price sends a signal of an increase in energy demand, which is translated as an increase in the carbon emissions level. Moreover, the rising natural gas price in China reinforces dependence on coal consumption. Thus, the level of carbon emissions will also increase.

- ***Dynamic relations with renewable energy supply and extreme weather***

Table 3-3 summarises the empirical results of this study by comparing them with previous research. As the very first study to probe the dynamic relation between the renewable energy supply level and carbon allowance price, a positive correlation is found in the Tianjin market. In contrast, mainstream studies on the EU ETS report negative correlations or no significant relationship, because a reduced demand for emissions allowance results from the substitution effect between carbon-intensive power generation and renewable energy plants. However, in this case, the coefficient of renewable energy production level is positive and statistically significant at the 10% level. In fact, this result may be consistent with the context in China.

First, this could be interpreted as the signalling effect from the increasing level of renewable energy supply on the emerging demand for overall electricity generation, which indicates an increasing demand for carbon allowances. Second, unlike Europe which has rich reserves of natural gas in the North Sea, China has large coal reserves and insufficient gas resources. Under such an energy reserve mix, exporting more intermittent renewable energy to the power grid means more hot back-up power from coal-fired power plants with high flexibility resilience to rapid load change (Agora Energiewende, 2017, The World Bank, 2014). Thus, some market participants will expect a potentially higher demand for carbon allowances and drive up the price.

Regarding the relation between extreme weather and carbon prices, the result demonstrates a statistically significant relationship within the Shenzhen market. Aligned with the findings of Zeitlberger and Brauneis (2014), the result in the Shenzhen market indicates that additional carbon emissions, resulting from increasing energy demand due to the unexpected heating and cooling activities beyond seasonal change, are priced in the Shenzhen carbon market. Compared with the other studies focusing on Chinese ETSs, this appears to be inconsistent with the findings of Chen et al. (2016), which suggested that extreme weather level has no significance in terms of carbon prices. However, their data series were collected at daily frequency rather than weekly level.

- ***Policy interactions***

Regarding policy event dummies, three categories of announcements were considered: policies promoting renewable energy, notifications on compliance dates and policies with respect to the use of carbon offsets (i.e. CCER). First, the coefficient for renewable energy policy dummies in the Guangdong and Hubei’s markets were proven to be positive at the 5% and 10%

significance levels, respectively. This seems to be inconsistent with the studies that suggest that renewable energy development will lower the carbon price by reducing the demand for allowances. However, the result of this study to some extent supports the findings of Jiang et al. (2018), as stakeholders consider that it is possible for the carbon market to translate the debut of a renewable energy policy into a signal for rising carbon prices. However, this point of view is contrary to the fundamental economic theory that reduced demand for emission allowances caused by increasing renewables would cause the allowance price to slump. It indicates a market failure within the pilot that the allowance price reacts abnormally to changes in demand and supply.

Another possible rationale is that a constant emphasis on promoting renewable energy reveals China's ambitions and determination in addressing climate change. The results in Chapter 2 on stakeholder views indicate that market participants may not be fully aware of the operating principles of ETSs, and the main motivation for participating is to fulfil government obligations or social responsibilities. Therefore, the government's ambitions and determination will send a signal of a more stringent emission trading scheme in the future, hence participants would expect the price of emission permit to rise, thus lifting the market price.

Second, notifications of compliance dates were found to influence price variations in the Shenzhen market at the 5% significance level. This further supports the observations of Ren and Lo (2017) that transactions fluctuate with the approach of the compliance date, and the participation of most covered entities is to serve a regulatory purpose instead of exploring the benefit of carbon trading. Finally, the dummy of the CCERs policy in Tianjin accounts for the increase in carbon price at the 10% significance level. This may be explained by the fact that on 14 March 2017 the release of the notice suspending verification of voluntary carbon offsets (i.e. CCERs) removed the possibility of the increasing use of CCERs for compliance and thus decreased the alternative supply of carbon allowances.

- ***Market characteristics***

Similar to previous research, this study recognises the immature nature of the seven carbon markets in China, and that secondary markets are somewhat poorly developed. First, the seven carbon markets are highly segmented, and price determinants and market performance in each market are largely heterogeneous. For example, among the considered factors, extreme weather is the only priced factor that has a statistically significant effect on the Shenzhen market while the gas price is significant in the Guangdong market only. Second, fundamental-based econometric models tend to have limited effectiveness over total variance, as illustrated by the low R-squared across models. Therefore, ETS pilots in China are less efficient markets in terms of informational structure. Third, more advanced financial instruments, such as futures and options, have not currently been introduced. Thus, market participants are exposed to higher risks due to the lack of hedging choices and an incomplete hybrid structure. Meanwhile, the immature nature makes it difficult to divert potential investment capital to carbon trading. Therefore, most of the capped entities, especially large state-owned enterprises, participate in emission trading activities in order to control their total emissions and meet compliance obligations instead of achieving cost-efficient abatement or the embedded investment purpose. In other words, few participants recognise the benefits of carbon trading and may have limited knowledge about ETS policy; thus, essentially, they are driven by responsibility rather than a market-based solution to reduce marginal abatement cost.

- ***Regional heterogeneity***

Regional disparity across China is a prominent source of uncertainty because the more than 30 provinces have distinct economic structures, resource endowments and market conditions (Yi et al., 2011, Zhang et al., 2013a). Any unified low-carbon policy scheme at the national level would mean different abatement costs in each province (Wei et al., 2012).

All of the regional ETS pilots include heat and electricity production, iron and steel, nonferrous metals, petrochemical and chemical, pulp and paper, and cement. However, each of the ETS pilots have certain striking divergences in the sectoral coverage. The Beijing pilot covers education, medical, and public utilities; the Shanghai pilot covers financial companies, airports and harbours; the Shenzhen pilot covers road transportation; and the Tianjin and Chongqing pilots include coal, oil and gas exploration (Duan et al., 2014, Qi et al., 2014a). Different coverage may imply varying sensitivity to exogenous price drivers.

Moreover, the shadow price is positively correlated with regional economic development levels in China. That is, the shadow prices of carbon emissions in high-income provinces, such as Shanghai, Beijing, Jiangsu, Zhejiang, Fujian, are significantly higher than those of the other provinces, while the shadow prices of carbon emissions in low-income provinces are very low (Zhang et al., 2014b). Higher shadow prices in Shanghai and Beijing imply higher abatement costs compared to other regions, therefore the ETS pilots in these two regions would prefer offsets from other regions with lower abatement costs, and tend to be less sensitive to other climate actions or changes in exogenous factors, and vice versa (Wang et al., 2016).

3.5 Conclusions

This paper examines the effect of price fundamentals that have been shown to be relevant to the EU ETS and it presents an empirical analysis of the impact of parallel low-carbon policy. To begin with, econometric analysis of market fundamentals was conducted, based on sample data drawn from September 2014 to June 2017. The regression results, to some extent, align with similar studies of the EU ETS; for example, the energy price factors are positively linked to allowance prices in the Chinese ETS pilots (i.e. Beijing, Shanghai and Guangdong) to varying degrees.

Second, this paper demonstrates the influence of extreme weather and renewable energy supply levels in some of China's carbon markets. Empirical results suggest that a significant positive correlation exists between the renewable energy supply level and carbon prices in the Tianjin market, which appears to diverge from the findings of mainstream studies in the EU ETS. However, to some extent, the result aligns with the context in China. First, due to the fast-growing economy, the higher production level of renewable energy may signal an increase in demand for electricity. Further, since China has plentiful coal reserves but insufficient gas resources, more renewable energy being introduced to the power grid suggests a higher demand for coal-fired plants with higher flexibility and excellent resilience to load changes to serve as an alternative power source.

As the first empirical research investigating price interactions between renewable energy policy and ETS policy for Chinese ETS pilots, this paper also sheds light on two points. First, the announcement of a renewable energy policy positively contributes to an increase in carbon price in the Guangdong and Hubei markets; second, the announcements of ETS policy, such as surrender date notice and the use of CCERs, influence carbon price variations in Shenzhen and Tianjin to varying degrees. However, the findings overall are in line with previous research suggesting the ETS pilots in China are segmented and remain relatively inefficient. On the other hand, given the fact that carbon spot prices do reflect some underlying conditions for micro- and macro-level factors, market participants may not be as rational as some scholars suggest.

The main limitation of the study is that, due to the lack of comprehensive literature on price behaviour discovery in China's ETS market, it is difficult to generate sufficient analysis of the results, therefore no cogent conclusions could be drawn. The scarcity of literature provides an opportunity to fill the evidence gap, however, the large heterogeneities in the results of seven pilot ETSs mean that there are huge difficulties in explaining the results.

Meanwhile, the event-based study could be further improved, as announcements of ETS institutional policy and CCERs offset regulation could be divided into two groups: hypothetically, one has a positive influence on carbon prices (such as tightening caps, stringent allowances allocation, auction rather than free allocation and reducing offsets limitation), while hypothetically the other group has a negative influence on carbon prices (such as loosening caps or allowance allocation plan and increasing offset limitation etc.).

Chapter 4

Impact of emission trading market linkage on the carbon price

4.1 Introduction

Although China is currently piloting ETS designs at the provincial level, a trading market at the national level was set up at the end of 2017. Additionally, China has indicated that it would consider participating in an international carbon market. Given the scale of China's economy and energy system, its energy trends and climate policies will have a significant impact on global climate change mitigation (Qi et al., 2013).

Moreover, all of the existing emission trading markets are at a regional or national level or at the level of a single economic group. The potential benefits of linking emissions markets across countries and regions are well recognised (Carbon Trust, 2009, Haita, 2013, Borghesi et al., 2016). A global market provides more flexibility for parties to achieve emissions reductions at the lowest marginal cost across all covered sectors.

In addition, as the largest emission trading scheme in the world, the EU ETS continues to negotiate with ETSs in other regions, attempting to establish an international emission trading market. The prospects for linking carbon markets between developed and developing countries have been widely discussed and are seen as a way to encourage the participation of developing countries in tackling global climate change. However, carbon market linkage may not only impact the emission permit price, but also impact total emissions and welfare, and such effects may depend on the regions' own situation, for instance, the emission level and policy strength of emission reduction in the two regions (Babiker et al., 2004).

Therefore, quantifying the impact of emission trading linkage between China and the world through a computable general equilibrium (CGE) model would generate insights for forming a global emission trading market. Driven by the above motivations, this chapter simulates the case of linking the Chinese ETS with global emission trading by employing the GTAP-Energy (GTAP-E) model (Burniaux and Truong, 2002), and demonstrates the impact on the carbon market in China.

This chapter is organised as follows: Section 4.2 summarises the current literature on analysing climate change policy interactions using general equilibrium models; Section 4.3 illustrates the methodology including general features, conditions for model equilibrium and policy constraints in the CGE model; subsequently, the model description is demonstrated in section 4.4 followed by results and findings in section 4.5. Conclusions are drawn in the last section.

4.2 Literature review

Parallel to the growing number of ETS, governments are starting to link or consider linking their respective ETSs (Mehling and Görlach, 2016). Emissions trading schemes therefore have the potential to play an important role in international climate change cooperation. Linkage offers several advantages; economic efficiency gains, a broader and more liquid carbon market, potentially lower risks of carbon leakage and lock-in of the climate policy (Hawkins and Jegou, 2014). However, linkage also comes with disadvantages, including distributional issues and a loss of regulatory control (Flachsland et al., 2009).

In terms of the impact of linkages on those participating in cap-and-trade systems, numerous studies have tried to probe the benefits and challenges of linkage from environmental, macroeconomic and political aspects respectively.

First, studies assessed the emissions reduction effect by simulating linkage among ETSs, and carbon leakage was found to be the main concern. Blyth and Bosi (2004) doubted the real emission reduction effect of linkage, as they found overall emissions would be larger if linking parties have looser caps and over-allocate emission permits. Carbone et al. (2009) added further weight to their result by suggesting an international collaborative trading system would not be helpful to the environment within large trading systems; however, collaboration between the Chinese and the EU ETSs would improve cost-effectiveness because China has a relatively low abatement cost. Therefore the EU ETS, with a higher abatement cost, could benefit from purchasing emission allowances from the Chinese market. Marschinski et al. (2012) supplemented Carbone et al. (2009) argument that linking ETSs with an intensity target rather than an absolute cap may lead to rising emissions because of leakage risk. Further, Liu and Wei (2016) proposed that linkage between the EU ETS and Chinese ETS without an absolute cap may cause an increase in overall carbon emission from fossil fuels.

On the other hand, one of the most obvious benefits of linking ETSs is economic efficiency gain in reducing emissions. Theoretical analyses show that linking ETSs would improve the reduction efficiency within the cap-and-trade system (Ranson and Stavins, 2016, Dellink et al., 2013). Simulations based on general equilibrium models provided evidence for this theoretical finding. It is demonstrated that uneven carbon prices resulting from fragmented carbon markets would reduce economic welfare, while linking carbon markets would make it possible to prevent economic loss from emission constraints for all participating parties (Lanzi et al., 2012). Qi and Weng (2016) simulated the equilibrium carbon price in a global ETS and concluded that the reduced cost for Annex I countries would be significantly reduced in this global ETS (Qi and Weng, 2016). Another research based on a CGE model also showed that the linked carbon market comprising Russia, China and Annex B countries had a lower carbon price compared to the price in the Russian domestic carbon market (Bernard et al., 2008). Hübler et al. (2014) analysed the best design for linking the Chinese and EU ETSs and suggested that the optimal volume of tradable allowances should be limited to 300 Mt/year. However, different linkage conditions may affect economic welfare (Alexeeva and Anger, 2016). For example, allowance allocation plans would impact economic benefits and overall compliance costs when linking the EU ETS to emerging emission trading systems such as the Chinese ETS (Anger et al., 2009).

Moreover, ETS linkage can smooth distributional effects among sectors. Regulated sectors may lose competitiveness internationally compared to the sectors excluded from the emission cap and therefore generate competitiveness distortions (Kachi et al., 2015). By linking emission trading systems, these market distortions are supposed to be adjusted. For example, a unilateral link with CDM is beneficial for the regulated energy-intensive and export-oriented industries under the EU ETS to strengthen their competitiveness in global trade, since obtaining offsets from CDM are usually more cost-effective than purchasing EUAs (Alexeeva-Talebi et al., 2010). Choosing the linking parties is of great importance in linking ETSs as abatement costs vary between countries. Alexeeva-Talebi and Anger (2007) found that sectoral competitiveness faces challenges after integrating emerging schemes in Japan and Canada, but it can be controlled by including the Russian ETS as it supplies permits with a much lower price. Finally, linkage has a positive effect on carbon market liquidity, (Ranson and Stavins, 2013), but appears to have the risk of importing price volatility (Mundaca and Richter, 2013).

Besides, linkage not only serves as a catalyst for lower emission reduction costs but also a political cornerstone for international collaboration for climate change mitigation (Flachsland et al., 2009). However, Jiang et al. (2016) considered that linking the Chinese ETS with other trading systems would facilitate Chinese climate action but might have adverse effects on

China's energy-intensive industries (Jiang et al., 2016). What's more, linkage appears to dilute the control of a national government over the carbon market (Tuerk et al., 2009).

Existing research focuses on the evaluation of linking ETS among a small scope of regions, mainly the EU or US, although there is a handful of papers examining a global ETS covering a wider scope of regions from developed economies to emerging countries (Ellis and Tirpak, 2006, Dellink et al., 2013, Borghesi et al., 2016). As the effects of linkage mainly rely on the relative emission mitigation costs across regions, a broader market provides more flexibility for parties to achieve emission reductions at the lowest marginal cost across all covered sectors (Qi and Weng, 2016), the difference of research region scope would result in significant different evaluation results. Therefore, a multi-regional CGE model (specifically the GTAP-Energy or GTAP-E model) is employed to capture the impact on emission reductions, abatement costs as well as economic growth from ETS linkage among a global scope of regions.

The CGE model was developed from input-output modelling and can primarily be used to analyse the impact of policies on the economy (Wing, 2004). It has been widely used in analysing the efficiency of low-carbon policies in the last decade (Bernard et al., 2008, Wang et al., 2009, Morris et al., 2010, Hübler, 2011, Jin, 2012, Li et al., 2014a) due to its ability to simulate the impact of prospective policies, taking into account inter-sectoral and international interactions (Beckman et al., 2011). The extension to the GTAP-E model adds a module for substitution effects towards more energy-efficient capital and a module of CO_2 emissions resulting from the use of emission-generating commodities in the production process (Burniaux and Truong, 2002).

Nijkamp et al. (2005b) tried to extend the basic GTAP-E framework by introducing tradable emission permits, joint implementation (JI), and clean development mechanisms (CDM). Later, the basic GTAP-E model was modified and improved by incorporating CO_2 emissions from the combustion of fossil fuels as well as a mechanism to trade emission internationally (McDougall and Golub, 2007).

Uses of the GTAP-E model have ranged from policy options for reducing carbon leakage (Antimiani et al., 2013), to the costs of climate mitigation policies (Nijkamp et al., 2005a), to the environmental and economic effects of European emissions trading (Kemfert et al., 2006), to the effects of the US proposed withdrawal from the Paris Agreement (Nong and Siriwardana, 2018)

4.3 Methodology

The GTAP-E model is an extension of a base model constructed by the Global Trade Analysis Project (GTAP) team, which offers a general equilibrium model with a detailed treatment of international trade flows (Burniaux and Truong, 2002, McDougall and Golub, 2007). The GTAP-E model modifies the production structure of the standard GTAP model in order to mimic more closely the ability of firms to substitute among alternative fuels as well as between labour, capital and energy.

As a CGE model, it can capture policy impacts across interlinked sectors of the economy, including commodity and factor market interactions and bilateral trade relationships, and is a well-established tool used to undertake a quantitative analysis of the economic impact of energy and environmental policies (Wing, 2004). The basic structure of the model is derived from the Walrasian general equilibrium model (Avinash and Norman, 1980). In this study the GTAP-E model uses version 5 of the GTAP database, which consists of 66 regions and 57 sectors.

4.3.1 General features of the CGE Model

The CGE model is widely used to analyse the aggregate welfare and distributional impacts of policies whose effects may be transmitted through multiple markets. The fundamental conception for a CGE model is the circular flow of commodities in a closed economy (Figure 4-1). Households own the factors of production (e.g. labour and capital) and are the final consumers of produced commodities. Industries produce goods and services by employing the factors of production from households. There is also government, which collects taxes and disburses these revenues to industries and households as subsidies and lump-sum transfers.

A fundamental feature of the CGE model is its representation of the ability of individuals to make trade-offs among the inputs to both production and consumption to achieve Walrasian general equilibrium. This kind of equilibrium has three important assumptions: zero profit, market clearance and income balance.

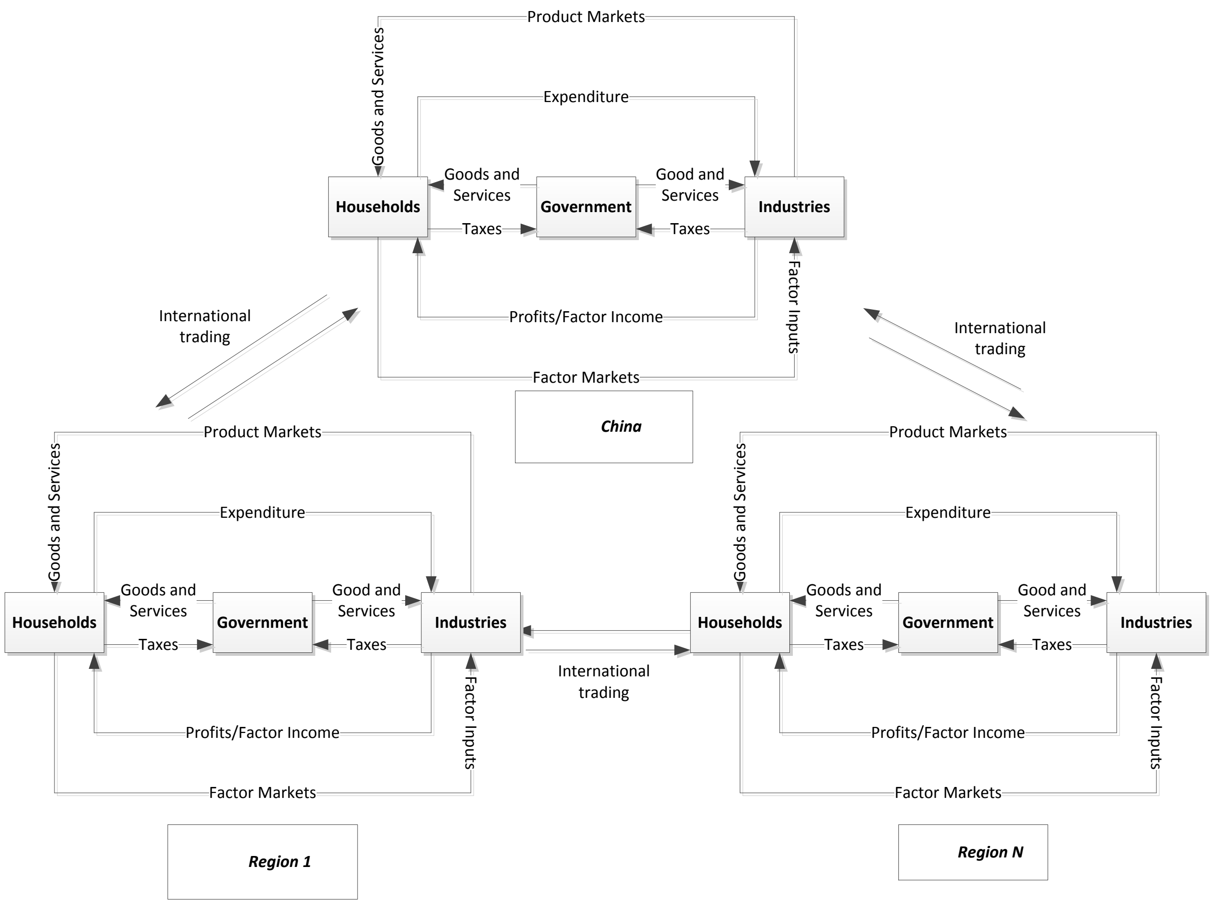


Figure 4-1 Circular flow of goods and services in the model

- ***Market clearance***

For a given commodity the quantity produced must equal the sum of the quantities that are demanded by other industries and households in the economy. Analogously, for a given factor the quantities demanded by industries must equal the aggregate supply endowed to the households.

- ***Zero profit***

In a fully competitive market, producers cannot have any excess profits. The value of commodities in the economy must be equal to the total value of all the inputs used to produce the commodity. The profits made from production much be allocated either to households for factor rentals, other industries for intermediate inputs, or to the government as taxes.

- ***Income balance***

Income balance defines the equilibrium from the household utility side, which means households' factors are fully employed for producing, and households spend all their income on commodity purchases or for the purpose of saving.

In the model, households are modelled as representative agents that are assumed to have Cobb-Douglas preferences, while industry sectors are modelled as representative agents that are assumed to have Cobb-Douglas production technologies. Specifically, the equilibrium prices will be estimated by allowing substitution between goods and primary factors, such as capital and labour. Substitution allows an assessment of the indirect effect of policies across different economic sectors.

Therefore, households maximise utility U by choosing the levels of consumption of the N commodities (c) in the economy, subject to the constraints of income m, ruling commodity prices p and saving s:

$max_{c_i} U(c_1, \ldots, c_n)$, Subject to $m = \sum_{i=1}^{N} p_i \,(c_i + s_i)$ (4-1)

Meanwhile, producers maximise profits π by choosing the level of intermediate inputs x and primary factors v to produce output, subject to the constraint of its production technology $\emptyset$:

$max_{x_{ij}, v_{ij}} \pi_j = p_j y_j - \sum_{i=1}^{N} p_i x_{ij} - \sum_{f=1}^{F} w_f v_{fj}$, Subject to $y_j = \emptyset_j\left(X_{1j,}, \ldots, X_{Nj}; v_{1j}, \ldots, v_{Fj}\right)$ (4-2)

International trade links the various regions; products from one region can be exported to the rest of the world, and imported goods can enter domestic product markets following the Armington assumption (Armington, 1969).

4.3.2 Model equilibrium

China is a hypothetical closed free-market economy that is composed of N industries, each of which produces its own type of commodity and an unspecified number of households that own F different types of factors, and households can spend their income to purchase the N commodities for the purpose of satisfying D types of demands. All production sectors and final consumption are modelled using nested Constant Elasticity of Substitution (CES) production functions, or Cobb-Douglas and Leontief forms, which are special cases of the CES. The model is solved using the Mathematical Programming System for General Equilibrium (MPSGE) modelling language.

Thus, we can have the indices:

$i = \{1, \ldots, N\}$ denotes the set of commodities;

$j = \{1, \ldots, N\}$ denotes the set of sectors;

$f = \{1, \ldots, F\}$ denotes the set of primary factors;

$d = \{1, \ldots, D\}$ denotes the set of final demands.

Therefore, the circular flow in this economy can be completely characterised by three data matrices: $N \times N$ input-output matrix of industries' use of commodities as intermediate inputs, denoted by $\overline{X}$; $F \times N$ matrix of primary factor inputs to industries, denoted by $\overline{V}$; and $N \times D$ matrix of commodity uses by final demand activities, denoted by $\overline{G}$.

Under the above three conditions, market clearance, zero profit and income balance, the three matrixes $\overline{X}$,$\overline{V}$ and $\overline{G}$ should be arranged according to a social accounting matrix (SAM), which is a snapshot of inter-industry and inter-activity flows of value within an economy that is in equilibrium in a particular benchmark period (Wing, 2004).

		←	*j*	→	←	*d*	→	*Total*
		1	…	*N*	*1*	…	*D*	
↑	*1*							$\overline{y_1}$
i	⋮		$\bar{X}$			$\bar{G}$		⋮
↓	*N*							$\overline{y_N}$
↑	*1*							$\overline{V_1}$
f	⋮		$\bar{V}$					⋮
↓	*F*							$\overline{V_F}$
Total		$\overline{y_1}$	…	$\overline{y_N}$	$\overline{G_1}$	…	$\overline{G_D}$	

Figure 4-2 Illustration of Social Accounting Matrix (SAM)

4.4 Model description

4.4.1 Regions

Regions in the GTAP-E model are aggregated based on the basis of economic structural similarities, membership in trade blocks, and geographical relationships. The model disaggregates the world into nine regions, as shown in Table 4-1.

Table 4-1 Regions covered in the model

Regions	***Description***
USA	United States
EU27	European Union
EEFSU	Eastern Europe and Former Soviet Union
JPN	Japan
RoA1	Other Annex 1 Countries
EEx	Net Energy Exporters
CHN	China
IND	India
RoW	Rest of the World

4.4.2 Sectors

Production within each region is comprised of eight industry sectors, as shown in Table 4-2. The aggregation includes a variety of non-energy sectors and energy sectors.

Table 4-2 Sectors covered in the model

Type	***Sector***	***Description***
Non-Energy	Agriculture	Aggregation of all agriculture products, plus managed forest land and logging activities.
	Energy-intensive industry	Iron and steel, non-metallic minerals products, non-ferrous metals products, chemical rubber products and fabricated metal products.
	Other industries and services	All other industries not included elsewhere, e.g. food, tobacco, construction, mining, equipment and others; all other services not included elsewhere, e.g. communication, finance, public services, dwellings and others.
Energy	Oil	Extraction of petroleum.
	Coal	Mining and agglomeration of hard coal, lignite and peat.
	Nature Gas	Extraction of natural gas.
	Petroleum	Refined oil and petrochemical products.
	Electricity	Electricity and heat generation, transmission and distribution. Electric generation technologies include coal, gas, refined oil, hydro, nuclear, wind, solar, biomass.

4.4.3 Scenarios

GTAP-E has been specifically designed to simulate policies in the context of GHG mitigation (McDougall and Golub, 2007). The scenarios discussed in this section, as shown in Table 4-3, are primarily illustrative.

The first scenario refers to the initial version of the Kyoto Protocol, including the US and China, however multilateral trading of emission is not allowed among these countries. The second scenario allows multilateral trading between these countries; China is not included in these countries. The third scenario includes China in the above global emission trading system in scenario 2, in order to compare the impacts of the linkage of a Chinese ETS and the global market.

Table 4-3 Scenarios in the model

Scenario		*1*	*2*	*3*
ETS in the model	USA	✓	✓	✓
	EU27	✓	✓	✓
	JPN	✓	✓	✓
	RoA1	✓	✓	✓
	CHN	✓	×	✓
	EEFSU	×	×	×
	EEx	×	×	×
	IND	×	×	×
	RoW	×	×	×
Multilateral trading		×	✓	✓
Description		ETS adopted separately in these countries	Chinese ETS is not included in the global carbon market	Chinese ETS is included in the global carbon market

Beckman et al. (2011) examined the ability of the GTAP model to reproduce historical price volatility in a specific commodity market (wheat). Results of the stochastic simulations indicated that the existing GTAP-E model does not perform well against the historical record, leading to the conclusion that the energy parameters in the original GTAP-E specification are mis-specified. The CGE model may have its drawbacks in an accurate representation of the real economy, but it is suitable for climate change policy analysis because forecasting from model simulations is a better solution for assessing emission trading market linkage compared to empirical analysis when there is a lack of empirical data.

In the original and standard GTAP-E, where emission mitigation actions are not defined in the model, the only way to reduce emissions is by substitution, while the abatement cost is modelled implicitly. Specifically, industries (sectors in the model) are allowed to change fuels and factors for production and consumption behaviours of private households and the government.

The model with the standard GTAP database 5 contains data of millions of tonnes of carbon, fossil fuel-derived CO_2 emissions, including commodities and vehicles. CO_2 emissions for electricity are equal to zero and equal for all other energy consuming products. Sets, parameters, variables and basic functions and initial values are already defined and assigned. Simulations need to be carried out by setting the scenarios.

First of all, in order to assess how emission mitigation shifts the burden from carbon-efficient countries to less efficient countries, sectors and regions aggregation have been defined using RunGTAP software, which could help generate SAMs for model calibration.

Second, it is assumed that CO_2 emissions in the model are produced by energy consumption of industries, government and private households. CO_2 emissions can be treated as one of the commodities and are proportional to usage, and modelled exogenously by assigning emission factor parameters. In the model, an economy-wide cap can be independently set for each region as the total CO_2 emissions, and the model can be solved to find an equilibrium carbon price in each region or, allowing for international trade, a global price.

The EU and China already have existing emission trading systems, therefore, CO_2 emission allowances allocated in each regional market are based on their national reduction targets in 2020. For the EU, the 2020 target is a 21% reduction in GHG emissions from 2010 levels, while China's target is to reduce CO_2 intensity by 40%-45% by 2020 based on 2005 levels. Since China's GDP growth maintains a rising trend, we simply set an absolute cap of 40% reduction target for China in the model.

Since CO_2 emissions represent, after an ETS is effectively implemented, a cost to the production sectors, these sectors will demand cost-minimising amounts of tradable emissions in order to be able to fulfil the demand for their output goods.

4.5 Results and findings

Tables 4-4 and 4-5 report the emission changes and the corresponding marginal abatement costs of meeting the emission limitations. In the first scenario, where the Annex 1 countries, the USA and China have their own emission reduction targets and no multilateral trading of emission is allowed, the marginal abatement costs corresponding to these reductions range from \$24.10 in the US and \$121.91 in Japan. Marginal costs are lower in the US than in other regions because the US uses relatively more coal and taxes energy less heavily. In more carbon-efficient countries, such as Annex 1 countries, the marginal abatement costs are higher. The abatement cost is \$29.97 in China to meet the 40% reduction target.

In terms of the second scenario, where the Chinese carbon market is not included in the global carbon trading market and only the Annex 1 countries and the USA need to achieve their reduction targets, the marginal cost among those trading countries is \$27.62 per tonne of carbon. Allowing multilateral trading of emissions among these countries shifts the burden of reduction away from oil products in the relatively carbon-efficient economies (EU, Japan and the rest of the Annex 1 countries) towards coal in Eastern Europe and the Former Soviet Union. This induces a substantial reduction of the marginal abatement costs in the above economies. The abatement costs in Japan decrease from \$121.91 to \$27.62 per tonne of carbon while the costs in the rest of the Annex I countries (RoA1) drops from \$126.19 to \$27.62.

However, in scenario 3 the marginal cost significantly increases to \$40.08 if the Chinese carbon market is included in the global trading market.

In terms of economic considerations, the most important reason for linking is the increase in cost-effectiveness that results from the reallocation of abatement effort between systems with different marginal abatement costs. The system with the higher marginal cost benefits from purchasing relatively inexpensive allowances from the other system, allowing it to achieve its emission reduction goals at a lower cost. Conversely, the system with the lower marginal cost benefits from selling its allowances at higher prices, resulting in an inflow of revenue.

Practically, in the system with the higher pre-linkage allowance price, firms with high abatement costs will benefit from the linkage, and firms with low abatement costs will be hurt by linkage, since linking will lower allowance price in the high-price system. Nevertheless, although the abatement costs increase in the international ETS scenario, a strong carbon price could give investors a right price signal on the value of carbon emissions and incentivise the carbon market activity and improve the liquidity in a long-term.

Table 4-4 Marginal costs of achieving the reduction target

	Scenario 1	***Scenario 2***	***Scenario 3***
	1997 USD per ton of carbon	1997 USD per ton of carbon	1997 USD per ton of carbon
USA	24.1	27.62	40.08
EU27	40.37	27.62	40.08
EEFSU	0	27.62	40.08
JPN	121.91	27.62	40.08
RoA1	126.19	27.62	40.08
EEx	0	0	0
CHN	**29.97**	**0**	**40.08**
IND	0	0	0
RoW	0	0	0

It is interesting to find that while emissions are reduced in some countries that are subject to binding constraints, they increase in other countries; this suggests the presence of the 'carbon leakage' phenomenon, which implies that additional emissions will be emitted in those countries with no binding constraint relative to the emission reduction in countries with binding constraints. For instance, in scenario 1, the emissions in Eastern Europe and the Former Soviet Union increases by 1.91% while emissions in net energy exporting countries increases by 1.47%. The causes of carbon leakage are multiple and involve competitiveness effects as well as the reactions of the world energy markets (Burniaux and Truong, 2002).

Table 4-5 Emission reduction under different scenarios

	Scenario 1	***Scenario 2***	***Scenario 3***
	% reduction of emissions	% reduction of emissions	% reduction of emissions
USA	-17	-17	-17
EU27	-17	-17	-17
EEFSU	1.91	0	-28.79
JPN	-30	-30	-30
RoA1	-40	-40	-40
EEx	1.47	0.96	1.36
CHN	**-40**	**0.32**	**-40**
IND	-0.15	-0.13	-0.16
RoW	1.63	1.07	1.5

Finally, Chinese stakeholders' concern about implementing emission trading in China would have a negative impact on national GDP. In the scenario of enforcing an emission trading mechanism separately, GDP in China decreases by 0.88% (Table 5-6). However, linkage between the Chinese carbon market and the international carbon market leads to a considerably lower decrease in the GDP in China (0.04%).

Table 4- 6 GDP changes under different scenarios

	Scenario 1	***Scenario 2***	***Scenario 3***
	% GDP change	% GDP change	% GDP change
USA	-0.14	-0.17	-0.26
EU27	-0.22	-0.14	-0.21
EEFSU	-0.2	-0.46	-0.8
JPN	-0.87	-0.15	-0.22
RoA1	-1.1	-0.22	-0.32
EEx	-0.06	-0.04	-0.06
CHN	**-0.88**	**-0.03**	**-0.04**
IND	0.11	0.08	0.11
RoW	0.03	0.02	0.03

4.6 Conclusions

Price convergence and potential efficiency gains are the main drivers for linking carbon markets, as the linked schemes create a larger pool of compliance instruments and widen the options for carbon mitigation (Ranson and Stavins, 2016). In addition, a larger carbon market tends to be more liquid and resilient. The decision to link carbon markets entails political compromise and a trade-off between advantages and disadvantages (Haita, 2013)

Just like international trade in general, trade in emissions allowances has positive effects on some participants and negative effects on others. Linkage between emissions trading schemes has now been discussed for several years, and and there is an extensive body of literature on the merits, demerits, and requirements for linkage. Building on this largely theoretical literature, this paper contributes to the analysis and discussion of linking emerging carbon markets with international markets by using the GTAP-E model. The study provides an analysis of current linkage cases between the major economies, including the European Union, USA, China and India. This insight is then applied to assess the impact on marginal abatement cost, emission reduction and GDP from a linked international carbon market.

The results show that in China the abatement cost is $29.97 to meet its 40% reduction target, and it significantly increases to $40.08 if the Chinese carbon market is included in the global trading market. However, allowing multilateral trading of emissions among these countries shifts the burden of the reduction away from oil products in the relatively carbon-efficient economies. The change in a system's allowance price, together with the role of participants as net buyers or sellers of allowances, determines whether participants win or lose as a result of linkage. Buyers in the pre-linkage higher-price scheme and sellers in the pre-linkage lower price scheme will benefit from linkage as the former will be able to purchase allowances at a lower price while the latter will receive a higher price for the allowances they sell. The results imply a win-win situation for both carbon-intensive and carbon-efficient economies.

Moreover, results from Chapter 2 suggest that stakeholders are concerned that linking the Chinese carbon market with the international carbon market might reduce the freedom of Chinese climate policy and constrain the Chinese position in future international climate policy negotiations. Industry stakeholders also showed concern about the negative impacts on the economy as a result of a stringent emissions trading scheme. However, the simulation results suggest negative impacts on GDP would be mitigated by the linkage between China and the world, as the decrease in GDP would be reduced from 0.88% to 0.04%.

The top-down GTAP-E model is a suitable method for assessing changes in emission reductions and regional economic growth driven by linking regional ETSs, given that empirical data are lacking for ex-post empirical studies on international ETS linkage. Meanwhile, a bottom-up linkage is an unlikely outcome in the near future due to the difficulties in achieving international agreement (Bosetti et al., 2013, Carraro and Sgobbi, 2008).

However, the model employed has several limitations. First, the CGE model can only work under a series of assumptions of the perfect market, which might lead to inaccurate simulation results compared to the real world. Second, due to funding constraints, the database used in the GTAP-E model is out of date (the benchmark year is 1997). However, the results can still generate references for policy consideration and future research directions. Third, the CGE model is inaccessible to non-economists, and it is expensive and difficult to operate. Additionally, many of the indirect economic relationships that CGE analyses seek to represent can be captured in simpler, more transparent models.

Finally, absolute caps are set in the used model rather than carbon-intensity caps, which might cause bias in the results. In addition, some regions covered in the model have renewed their emission reduction targets, such as the EU and China, which would weaken the indicative value of the study.

Chapter 5

Conclusion and policy recommendations

Policies to reduce GHG emissions and curb global warming are expanding around the world, and policy making takes place within increasingly complex systems. When policymakers are implementing their policy packages to deliver countries' own ambitions to move towards international climate change commitments, important issues that need to be taken into account are the interactions between carbon pricing and other climate change and energy policies, as well as uncertainties in integrating domestic carbon pricing systems with the international low-carbon policy environment.

ETS, as the main instrument of carbon pricing, is generally considered indispensable for enabling cost-effective emission reductions (Ranson and Stavins, 2016). However, it is also generally recognised that an ETS alone is not usually sufficient for short-term and long-term decarbonisation (Stavins, 2001). Where there is a case for integrated policy packages to tackle climate change, carbon pricing systems would interact with other low-carbon and energy policies to reduce emissions in the same sector over the same timeframe (Marcantonini et al., 2017). On the other hand, a global response to climate change is the general trend (Kachi et al., 2015). The last ten years have seen the growth of linkages between many of the ETSs around the world (Ranson and Stavins, 2016). Balancing the expected benefits of integrating domestic ETSs with a worldwide system with the expected costs is a priority for policymakers.

Poor policy integration will undermine energy security and affordability, leading to higher costs, investment uncertainty and increased risk of missing emission reduction targets; the performance of renewable energy policies and energy markets could also be affected (Schmidt and Fleig, 2018).

This thesis draws on the past few years of experience with carbon markets to examine whether other climate change and energy policies will interact with carbon markets, and either reinforce or undermine the emission trading systems. Furthermore, potential impacts on achieving emission reduction goals and regional economies within a global ETS have been modelled. The next section is the summary of the main findings of the thesis, which have implications for designing a package of policies that include emission trading systems, and implications for the future role that ETS linkage may play in international climate policy architecture.

5.1 Summary of findings

First of all, we conducted a survey with a focus on the interaction of low-carbon and energy policies in China, by which we hope to open the discussion and provide policymakers with a better understanding of some of the built-in biases and perceptions of key actors as they formulate new energy and low-carbon incentive mechanisms.

The results imply that there is a relatively limited understanding of how other mechanisms might affect the price of carbon allowances. Stakeholders believed that renewable targets would dampen the carbon price, but a majority expected a carbon tax to actually boost the carbon price seen in the market. The interactions between the carbon market and other energy and low-carbon policies are generally recognised by academic stakeholders as other policies may decrease 'demand' in emission trading markets, and such interactions will be a significant challenge for implementing a policy package to achieve emission reduction targets.

We also found that stakeholder understanding of mechanism interactions is associated with the time (reported by stakeholders themselves) spent working on energy-saving and emission reduction policies. The more working time spent on climate change-related policies, the more recognition of potential problems associated with the policy interactions was found among stakeholders.

Moreover, the survey results suggest the economic and energy consumption growth momentum was still expected to be strong. However, opinions varied from stakeholders in different sectors. Stakeholders from the government sector generally were more hopeful of success in significantly reducing GHG emissions in China in the future, and they were far more confident than industrial and academic stakeholders about the potential of carbon pricing in China. Academic stakeholders tended to consider the progress of ETS development in China to be slow, and generally felt pessimistic about Chinese carbon markets due to over-allocation in the market and imperfect auditing regulations, even though their expectations of the future market price in the Guangdong pilot were relatively higher compared with the expectations of other stakeholders. Similarly, industrial stakeholders also showed negative perceptions with regard to the impact of the economic cycle on carbon allowance prices.

The survey findings suggest there are still some important unresolved issues confronting the new national system. It would have been more desirable if in the process of implementing the national ETS, the Chinese authorities had been able to learn lessons from the pilot systems. The lack of transparency in disclosing market information, a lack of awareness among market participants, and an immature MRV system pose uncertainties for carbon markets. The inability of many stakeholders to understand that other low-carbon and renewable policies would reduce the price in the carbon market reflects the need for greater capacity development among industry participants.

The second study empirically examines the impact of low-carbon parallel policy in seven pilot ETSs in China, and looks into the explanatory power of price fundamentals. Based on an event-based regression, this paper finds contrary results to our hypothesis: the announcements of renewable energy policy positively contribute to an increase in carbon price in the Guangdong and Hubei markets; second, the empirical results suggest a positive correlation exists between the renewable energy supply level and carbon prices in Tianjin market.

This appears to be divergent from mainstream studies in the EU ETS. However, to some extent, the result aligns with the context in China. First, due to the fast-growing economy, the higher production level of renewable energy may signal an incremental aggregated demand for electricity. Further, given that China has plentiful coal reserves but insufficient gas resources, the introduction of more renewable energy to the power grid suggests an increasing demand for coal-fired plants as they have higher flexibility and excellent resilience to load changes to serve as an alternative power source.

Moreover, announcements of the use of CCERs and surrender dates influenced the carbon price in Shenzhen and Tianjin to varying degrees. The findings suggest that ETS pilots in China are segmented and remain relatively inefficient, that many enterprises are not fully aware of the benefits of carbon markets; they consider participation in the market as merely fulfilling the need for government, social responsibility or corporate strategy. On the other hand, given the fact that carbon spot prices do reflect some underlying conditions on micro- and macro-level factors, market participants may not be as irrational as some scholars suggest.

Linkage between ETSs offers several benefits that make it an attractive policy option. Linking domestic ETSs with an international one can also be considered as a form of policy integration. One key question about the decision to develop links between ETS systems is whether it can generate a sufficient quantity of GHG emission reductions at a reasonable cost.

Building on a substantial amount of theoretical literature, the third study contributes to the analysis and discussion of linking emerging carbon markets with the international market by using the GTAP-E model. The study provides an analysis of current linkage cases among the major economies, including the European Union, the USA, China, and India. This insight is then applied to assess the impact on marginal abatement cost, emission reduction and GDP from a linked international carbon market.

The results show that the abatement cost in China significantly increases when the Chinese carbon market is included in the global trading market. Allowing multilateral trading of emission among these countries shifts the burden of the reduction away from oil products in the relatively carbon-efficient economies. Buyers in the pre-linkage higher-price scheme and sellers in the pre-linkage lower price scheme will benefit from linkage as the former will be able to purchase allowances at a lower price while the latter will receive a higher price for the allowances they sell. The results imply a win-win situation for both carbon-intensive and carbon-efficient economies.

Moreover, results from the survey suggest that stakeholders are concerned that linking the Chinese carbon market with the international carbon market might reduce the freedom of Chinese climate policy and constrain the Chinese position in future international climate policy negotiations. Industry stakeholders also have concerns about the negative impact on the economy brought about by a stringent emission trading scheme. However, the simulation results suggest negative effects on GDP would be largely offset by the linkage between China and the world as the decrease in GDP is reduced.

5.2 Policy implications

There is no doubt that the costs of decarbonisation over the short term and long term can be reduced by implementing a package of policies including carbon pricing, energy efficiency, technology development and deployment, and support to overcome underlying infrastructure or financing barriers. A key question to ask in developing the policy package is what the objectives for each policy are. Policy makers need to uncover relevant policy overlaps which need to be taken into consideration. Additionally, policymakers need to have a better understanding of the degree of overlaps and interactions, and how to manage these interactions.

As national circumstances will make the optimal policy mix unique to each country, there is no single set of solutions to integrating the carbon market with other low-carbon and energy policies. Most of the research in this thesis has been conducted within the Chinese context. With such a short preparation period, the development of the seven pilot carbon markets in China has been an experiment for designing a nationwide ETS based on diverse economic structures through a learning-by-doing approach, which will provide valuable experience for building a robust national and integrated carbon market.

Drawing on the above findings, we offer the following policy recommendations:

- Government and other key stakeholders have focused too much on the price and volume of carbon allowances in China's pilot ETS schemes; stakeholders and policymakers should seek to continuously assess and improve the quality of regulation, market integrity and information disclosure. Therefore, stakeholders should reconsider 'what does a well-functioning carbon market look like?'
- The inability of many stakeholders to understand that other low-carbon and renewable policies would reduce the price in the carbon market reflects the need for greater capacity development among industry participants.
- As the carbon market is not likely to be the only major low-carbon policy instrument in China, a correct interpretation of the carbon pricing signal is needed as part of capacity development among industry participants.
- Given the fact that the current carbon price in China's ETSs is not market-efficient, alternative carbon pricing signals, such as a carbon floor price, should be proposed along with a carbon market allowance price to signal to industry the short-term and long-term cost of carbon emissions. Industry is also encouraged to develop an internal carbon price for investment valuation or project appraisal.
- Regulators and carbon exchanges should provide more transparent, real-time information for market participants to facilitate price setting.
- The Chinese Government should seek an efficient way to improve the MRV systems and establish a set of best practices to provide greater confidence for market participants.
- More effort should be placed on improving the compatibility of carbon markets. China has the relatively rare advantage of having conducted seven pilots with varying specifications, so it is important that time is taken to learn from the different pilots.
- As carbon market linkages could provide a more cost-effective way for achieving emission reduction targets, the Chinese government should ensure comprehensive analysis is conducted on the feasibility of carbon market linkage as well as sector or regional linkage pilots or demonstrations to gain empirical experiences.

5.3 Limitations and scope for future work

This section concludes with the limitations and self-reflections of my PhD study, with a discussion of potential future work for improving and expanding on the current research.

5.3.1 Comprehensive review on stakeholder views on carbon market

The sample size and the relatively low response rate are limitations of the current survey. However, from the literature there is no set-in-stone minimum sample size or response rate; suitable analytical methods and statistical options could help to control for limited coverage. Therefore, for future survey studies, the literature should be reviewed extensively to find optimal methodologies for studies according to the sample size; for instance, t-test could be an appropriate alternative statistical analysis technique for relatively small samples. Second, the main topic of the study is not prominent enough as many themes are covered in the survey, which weakens the valid lessons drawn from the study. Future studies will need to be more focused on specific research questions.

Since I conducted an in-depth assessment of the perspectives of different key stakeholders of the Guangdong pilot only, which was before launching the national system, a comprehensive review across all seven pilots or the newly released national ETS would be beneficial. In addition, there might be potential to identify shifting patterns in stakeholder perspectives.

The experience of carrying out the survey as my first PhD study was very meaningful for me. Qualitative research is not my expertise; the research idea was originally generated from the Research Design course during the first year of my PhD. The course provided a systematic introduction to qualitative research methods, from which I benefited a lot. The survey in Chapter 2 was originally generated as an assignment of the course, I did not lay it up after the course but to start to conduct the survey by polishing the questionnaire again and again. I still feel that the survey could have included many other questions of importance; however, once the questionnaires were sent, they could not be revised anymore. I spent a lot of time revising the questions and waiting for responses. However, such a low response rate became an obstacle for conducting in-depth statistical analysis. I finished the paper eventually, although there were lots of difficulties. This is the first qualitative research in my PhD study; it taught me a lot about doing qualitative research.

5.3.2 Quantitative assessment of policy interactions

As there are hardly any studies that have looked into price behaviour discovery in China's ETS market, it is difficult to find sufficient proof and examples to support the arguments in Chapter 3. Moreover, there are huge heterogeneities across the seven pilot ETSs; it is difficult to find evidence to explain the disparate results in different regions.

In addition, to further improve the study, the events (such as announcements of ETS institutional policy and CCERs offset regulations) adopted in the event-based study could be divided according to their potential effects (hypothetically positive or negative) on the market prices, in order to generate more accurate results.

Meanwhile, the insignificant results in the current regression could possibly be caused by inactive trading or trading driven by other external factors such as government commitment or media effects. Along with the establishment of a national ETS in China, public acceptance, market perception, and the design and operation of ETSs in China will be improved with larger size of dataset. Market trading would be more active, and the patterns and determinants of carbon prices for a longer trading period would be more easily identified. Therefore, a more comprehensive dataset could be employed in the future with updated market data to further investigate the dynamic relationship between energy and low-carbon policy. Additionally, an extended and revised CGE model could also be employed to quantitatively assess the impact from interactions between renewable energy obligations and carbon market mechanisms.

The idea of investigating price drivers in China's carbon market was my PhD application proposal. When I started my PhD, China started piloting ETSs. I worked on this study during the last year of my PhD, as I had to wait for empirical Chinese carbon market trading data after a certain trading period. The data collection was a difficult process, as information on China's pilot ETSs is incomplete and not transparent. Not only are the data in the carbon markets difficult to access, but also the energy markets. I have conducted on investigations into all seven pilots but most of the literature focuses on one or two pilots. However, doing more work does not mean better; the heterogeneous results among the seven pilots are very interesting but difficult to interpret.

5.3.3 Validating energy-oriented CGE models

In terms of the third study, which assessed the impact of carbon market linkage via a CGE model, learning to construct a CGE model was a difficult and long process for me. The original idea was to construct a multi-regional CGE model based on the General Algebraic Modelling System (GAMS), but it was too expensive to purchase a GAMS licence. Therefore, I chose

GTAP based on the General Equilibrium Modelling PACKage (GEMPACK) instead. The majority of CGE modelling work uses the GTAP database (in GAMS or GEMPACK), as it provides a user-friendly software, RunGTAP, for generating Social Accounting Metrics (SAMs) for the CGE model. However, the newly released GTAP database is very expensive, therefore the database used in this study is old. The main limitation of employing the CGE model for climate change policy assessment is that the models are inaccessible to non-economists, and expensive and difficult to operate.

Secondly, many of the indirect economic relationships that CGE analyses seek to represent can be captured in simpler, more transparent models; for instance, partial equilibrium techniques. Additionally, input-output relationships among industries have been analysed without the added layer of CGE techniques. Therefore, future studies could seek alternative techniques such as partial equilibrium for simulating policy interactions between ETSs and renewable energy in China by implementing renewable obligation or standard policy in the economy.

5.3.4 Bottom-up approach for ETS linking

As the top-down international linkage of ETSs is rather difficult due to political negotiation, future research could seek to develop a simple bottom-up approach for linking ETSs based on actual mitigation efforts. The benefits of linking are clear; a broader market provides more flexibility for parties to achieve emission reductions at the lowest marginal cost across all covered sectors. The following example explores efficiency gains from a two-way direct linkage.

The two oblique lines $MAC\ A$ and $MAC\ B$ (Figure 5-1) show the marginal abatement costs of reducing emissions in jurisdictions A and B respectively, and Q_{aut} is the quantity of emissions that a system would emit during a certain period. Before linking, the domestic allowance prices are $P_{aut}A$ and $P_{aut}B$ respectively. After linking, the system with the higher marginal cost ($MAC\ B$) benefits from purchasing relatively inexpensive allowances from the other system, which is shown as area X, allowing it to achieve its emission reduction goals at a lower cost. Conversely, the system with the lower marginal cost ($MAC\ A$) benefits from selling its allowances at higher prices, resulting in an inflow of revenue, which is shown as area Y. The free flow of allowances between systems results in an equalisation of prices P_{link} and leads to the cost-effective allocation of abatement efforts across the linked systems. Therefore, the efficiency gain from linkage in a compliance period is equal to the total difference between the sum of the mitigation costs of the two ETS jurisdictions before and after linkage, which is the total area of $(X + Y)$.

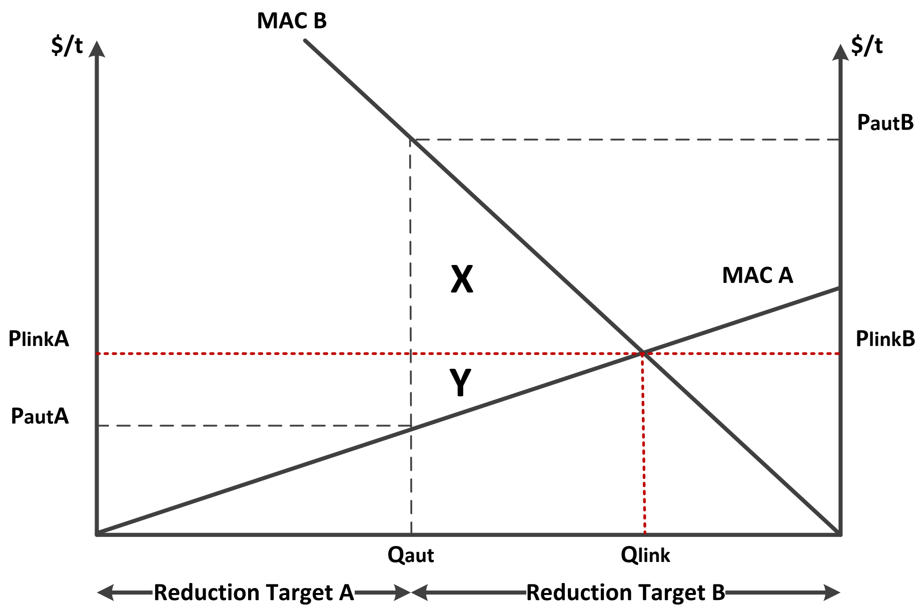


Figure 5-1 Simplified illustration of the distribution of efficiency gains when linking two ETSs (assuming carbon prices of two systems converge after linkage)

Given the combined reduction target of two jurisdictions is constant $C_{link} = C_{aut}$, the efficiency gains from linkage in a compliance period w is $(G_{l,w})$, which is equal to the total difference between the sum of mitigation costs of the two ETS jurisdictions before and after linkage, given as below (Equation 5-1).

$$G_{\,l.w}\left(P^A_{aut}, P^B_{aut}, P^A_{link}, P^B_{link}, Q^A_{aut}, Q^B_{aut}, Q^A_{link}, Q^B_{link}\right)^n = \left(\sum_{k=0}^{q^A_{aut}}(P^A_{aut} * Q^A_{aut}) + \sum_{k=0}^{q^B_{aut}}(P^B_{aut} * Q^B_{aut})\right) - \left(\sum_{k=0}^{q^A_{link}}\left(P^A_{link} * Q^A_{link}\right) + \sum_{k=0}^{q^B_{link}}(P^B_{link} * Q^B_{link})\right) \quad (5\text{-}1)$$

Benefits are determined by the price before linkage P^{Market}_{aut}, the price after linkage P^{Market}_{link} and the quantity of emission reductions, which implies that the extent to which linked systems yield efficiency gains depends on the heterogeneity of the linked systems. A larger, more diverse system will likely have more options with different associated abatement costs. In contrast, linking systems with similar abatement costs will likely have limited potential for efficiency gains (Ranson and Stavins, 2016, Burtraw et al., 2013, Blyth and Bosi, 2004)

This work may involve an in-depth evaluation of the strengths, weaknesses, opportunities and risks of measuring baseline and over-allocation of emissions at the individual entity level. Secondly, the practical challenges of measuring over-allocation should be addressed. This may involve exploring and comparing both top-down and bottom-up methodologies and identifying key indicators for estimating the amount of ‘leftover allowances’ that have resulted from the policy itself, and the amount that is caused by exogenous factors.

References

AATOLA, P., OLLIKAINEN, M. & TOPPINEN, A. 2013. Price determination in the EU ETS market: Theory and econometric analysis with market fundamentals. Energy Economics, 36, 380-395.

ABRELL, J., FAYE, A. N. & ZACHMANN, G. 2011. Assessing the impact of the EU ETS using firm level data. Bruegel Working Paper.

ADVANI, A., BASSI, S., FANKHAUSER, S., JOHNSON, P., LEICESTER, A. & STOYE, G. 2013. Energy use policies and carbon pricing in the UK. London: The Institute for Fiscal Studies.

AGLIETTA, M. & ESPAGNE, É. 2016. Climate and Finance Systemic Risks, more than an Analogy? The Climate Fragility Hypothesis. CEPII Working Paper. Paris: CEPII (Centre d'Etudes Prospectives et d'Informations Internationales).

AGORA ENERGIEWENDE 2017. Flexibility in thermal power plants –With a focus on existing coal-fired power plants. Berlin: Agora Energiewende.

ALBEROLA, E., CHEVALLIER, J. & CHÈZE, B. T. 2008. Price drivers and structural breaks in European carbon prices 2005–2007. Energy Policy, 36, 787-797.

ALEXEEVA-TALEBI, V. & ANGER, N. 2007. Developing Supra-European Emissions Trading Schemes: An Efficiency and International Trade Analysis. ZEW Discussion Paper No. 07-038. Mannheim: ZEW.

ALEXEEVA-TALEBI, V., ANGER, N. & LÖSCHEL, A. Alleviating Adverse Implications of EU Climate Policy on Competitiveness: The Case for Border Tax Adjustments or the Clean Development Mechanism? Vivek Ghosal Reforming Rules and Regulations, Reforming Rules and Regulations, CESifo Seminar Series, 2010. The MIT Press.

ALEXEEVA, V. & ANGER, N. 2016. The globalization of the carbon market: Welfare and competitiveness effects of linking emissions trading schemes. Mitigation and Adaptation Strategies for Global Change, 21, 905-930.

ALTON, T., ARNDT, C., DAVIES, R., HARTLEY, F., MAKRELOV, K., THURLOW, J. & UBOGU, D. 2014. Introducing carbon taxes in South Africa. Applied Energy, 116, 344-354.

ANGER, N., BROUNS, B. & ONIGKEIT, J. 2009. Linking the EU emissions trading scheme: economic implications of allowance allocation and global carbon constraints. Mitigation and Adaptation Strategies for Global Change, 14, 379-398.

ANTIMIANI, A., COSTANTINI, V., MARTINI, C., SALVATICI, L. & TOMMASINO, M. C. 2013. Assessing alternative solutions to carbon leakage. Energy Economics, 36, 299-311.

ARMINGTON, P. S. 1969. A Theory of Demand for Products Distinguished by Place of Production (Une théorie de la demande de produits différenciés d'après leur origine) (Una teoría de la demanda de productos distinguiéndolos según el lugar de producción). Staff Papers (International Monetary Fund), 16, 159-178.

BABIKER, M., REILLY, J. & VIGUIER, L. 2004. International Emissions Trading Always Beneficial? The Energy Journal, 25, 33-56.

BABIKER, M. H., REILLY, J. M., MAYER, M., ECKAUS, R. S., WING, I. S. & HYMAN, R. C. 2001. The MIT Emissions Prediction and Policy Analysis (EPPA) Model: Revisions, Sensitivities, and Comparisons of Results. Joint Program Report Series Report 71.

BARRAGÁN-BEAUD, C., PIZARRO-ALONSO, A., XYLIA, M., SYRI, S. & SILVEIRA, S. 2018. Carbon tax or emissions trading? An analysis of economic and political feasibility of policy mechanisms for greenhouse gas emissions reduction in the Mexican power sector. Energy Policy, 122, 287-299.

BECKMAN, J., HERTEL, T. & TYNER, W. 2011. Validating energy-oriented CGE models. Energy Economics, 33, 799-806.

BEL, G. & JOSEPH, S. 2015. Emission abatement: Untangling the impacts of the EU ETS and the economic crisis. Energy Economics, 49, 531-539.

BENZ, E. & TRÜCK, S. 2009. Modeling the price dynamics of CO2 emission allowances. Energy Economics, 31, 4-15.

BERDIN, D. & MUCKLEY, C. 2011. An emerging equilibrium in the EU emissions trading scheme. Energy Economics, 33, 353-362.

BERGH, K. V. D., DELARUE, E. & D'HAESELEER, W. 2013. Impact of renewables deployment on the CO2 price and the CO2 emissions in the European electricity sector. Energy Policy, 63, 1021-1031.

BERNARD, A., HAURIE, A., VIELLE, M. & VIGUIER, L. 2008. A two-level dynamic game of carbon emission trading between Russia, China, and Annex B countries. Journal of Economic Dynamics and Control, 32, 1830-1856.

BERNARD, A. L. & VIELLE, M. 2003. Measuring the Welfare Cost of Climate Change Policies: A Comparative Assessment Based on the Computable General Equilibrium Model GEMINI-E3. Environmental Modeling & Assessment, 8, 199-217.

BIEDENKOPF, K., EYNDE, S. V. & WALKER, H. 2017. Policy Infusion Through Capacity Building and Project Interaction: Greenhouse Gas Emissions Trading in China. Global Environmental Politics, 17, 91-114.

BLYTH, W. & BOSI, M. 2004. Linking Non-EU Domestic Emissions Trading Schemes with the EU Emissions Trading Scheme. Paris, France: OECD/IEA.

BOETERS, S. & KOORNNEEF, J. 2011. Supply of renewable energy sources and the cost of EU climate policy. Energy Economics, 33, 1024-1034.

BÖHRINGER, C., DIJKSTRA, B. & ROSENDAHL, K. E. 2014. Sectoral and regional expansion of emissions trading. Resource and Energy Economics, 37, 201-225.

BOHRINGER, C. & ROSENDAHL, K. E. 2010. Green promotes the dirtiest: on the interaction between black and green quotas in energy markets. Journal of Regulatory Economics, 37, 316-325.

BÖHRINGER, C. & ROSENDAHL, K. E. 2010. Green promotes the dirtiest: on the interaction between black and green quotas in energy markets. Journal of Regulatory Economics, 37, 316-325.

BORGHESI, S., MONTINI, M. & BARRECA, A. 2016. The EU ETS and its followers: Comparative Analysis and Linking Perspectives, Springer.

BOSETTI, V., CARRARO, C., CIAN, E. D., MASSETTI, E. & TAVONI, M. 2013. Incentives and stability of international climate coalitions: An integrated assessment. Energy Policy, 56, 44-56.

BOWEN, A. & RYDGE, J. 2011. Climate-Change Policy in the United Kingdom. OECD Economics Department Working Papers, 886, 42.

BP 2017. BP Statistical Review of World Energy 2017. BP.

BRETSCHGER, L. 2017. Climate policy and economic growth. Resource and Energy Economics, 49, 1-15.

BROOKS, C. 2008. Introductory Econometric for Finance, Cambridge, UK, Cambridge University Press.

BROUSERS, R., SCHOUBBEN, F., HULLE, C. V. & UYTBERGEN, S. V. 2016. The initial impact of EU ETS verification events on stock prices. Energy Policy, 94, 138-149.

BUNN, D. W. & FEZZI, C. 2007. Interaction of European Carbon Trading and Energy Prices. Milano: Fondazione Eni Enrico Mattei.

BURNIAUX, J.-M. & TRUONG, T. 2002. GTAP-E: An Energy-Environmental Version of the GTAP Model. Global Trade Analysis Project.

BURTRAW, D., PALMER, K. L., MUNNINGS, C., WEBER, P. & WOERMAN, M. 2013. Linking by Degrees: Incremental Alignment of Cap-and-Trade Markets. Resources for the Future Discussion Paper 13-04.

CADEZ, S. & CZERNY, A. 2010. Carbon management strategies in manufacturing companies: An exploratory note. Journal for East European Management Studies, 15, 348-360.

CAI, Y., DUDEK, D., MA, X., ZHANG, J., MARGOLIS, J., LIU, B. & JI, J. 2015. Research and practice on incorporating mobile sources into Shenzhen carbon emissions trading system. Journal of Renewable and Sustainable Energy, 7, 41502-41507.

CARBON TRUST 2009. Linking emission trading systems. Carbon Trust.

CARBONE, J. C., HELM, C. & RUTHERFORD, T. F. 2009. The case for international emission trade in the absence of cooperative climate policy. Journal of Environmental Economics and Management, 58, 266-280.

CARRARO, C. & SGOBBI, A. 2008. Modelling negotiated decision making in environmental and natural resource management: A multilateral, multiple issues, non-cooperative bargaining model with uncertainty. Automatica, 44, 1488-1503.

CHAMEIDES, W. & OPPENHEIMER, M. 2007. Carbon Trading Over Taxes. Science, 315, 1670.

CHANG, K., ZHANG, C. & CHANG, H. 2016. Emissions reduction allocation and economic welfare estimation through interregional emissions trading in China: Evidence from efficiency and equity. Energy, 113, 1125-1135.

CHANG, Y.-C. & WANG, N. 2010. Environmental regulations and emissions trading in China. Energy Policy, 38, 3356-3364.

CHEN, S. 2013. What is the Potential Impact of a Taxation System Reform on Carbon Abatement and Industrial Growth in China? Economic Sytems, 37.

CHEN, X., LIU, M. & LIU, Y. 2016. 碳交易价格的驱动因素与结构性断点一一基于中国七个碳交易试点的实证研究. 经济问题, 11, 29-35.

CHEN, Y., JIANG, P., DONG, W. & HUANG, B. 2015. Analysis on the carbon trading approach in promoting sustainable buildings in China. Renewable Energy, 84, 130-137.

CHENG, C. & ZHANG, X. 2011. A Study on the Construction of China's Carbon Emissions Trading System. Energy Procedia, 5, 1037-1043.

CHEVALLIER, J. 2009. Carbon futures and macroeconomic risk factors: A view from the EU ETS. Energy Economics, 31, 614-625.

CHEVALLIER, J. 2010. Banking and Borrowing in the EU ETS: a Review of Economic Modelling, Current Provisions and Prospects for Future Design. Journal of Economic Surveys, 26, 157-176.

CHEVALLIER, J. 2011. Macroeconomics, finance, commodities: Interactions with carbon markets in a data-rich model. Economic Modelling, 28, 557-567.

CHEVALLIER, J. 2012. Econometric Analysis of Carbon Markets, Springer Netherlands.

CLÒ, S., BATTLES, S. & ZOPPOLI, P. 2013. Policy options to improve the effectiveness of the EU emissions trading system: A multi-criteria analysis. Energy Policy, 57, 477-490.

CNREC 2013. China Renewable Energy Outline 2012. Bejing, China: China National Renewable Energy Centre (CNREC).

CONG, R.-G. & WEI, Y.-M. 2012. Experimental comparison of impact of auction format on carbon allowance market. Renewable and Sustainable Energy Reviews, 16, 4148-4156.

CONRAD, C., RITTLER, D. & ROTFUß, W. 2012. Modeling and explaining the dynamics of European Union Allowance prices at high-frequency. Energy Economics, 34, 316-326.

CRETI, A., JOUVET, P.-A. & MIGNON, V. 2012. Carbon price drivers: Phase I versus Phase II equilibrium? Energy Economics, 34, 327-334.

CUI, L.-B., FAN, Y., ZHU, L. & BI, Q.-H. 2014. How will the emissions trading scheme save cost for achieving China’s 2020 carbon intensity reduction target? Applied Energy, 136, 1043-1052.

DAFERMOS, Y., NIKOLAIDI, M. & GALANIS, G. 2018. Climate Change, Financial Stability and Monetary Policy. Ecological Economics, 152, 219-234.

DASKALAKIS, G., PSYCHOYIOS, D. & MARKELLOS, R. N. 2009. Modeling CO2 emission allowance prices and derivatives: Evidence from the European trading scheme. Journal of Banking & Finance, 33, 1230-1241.

DELLINK, R., JAMET, S., CHATEAU, J. & ROMAIN, D. 2013. Towards global carbon pricing: Direct and indirect linking of carbon markets. OECD Journal: Economic Studies, 1, 209-234.

DIETZ, S., BOWEN, A., DIXON, C. & GRADWELL, P. 2016. 'Climate value at risk' of global financial assets. Nature Climate Change, 6, 676.

DU, S., MA, F., FU, Z., ZHU, L. & ZHANG, J. 2015. Game-theoretic analysis for an emission-dependent supply chain in a 'cap-and-trade' system. Annals of Operations Research, 228, 135-149.

DU, S., ZHU, L., LIANG, L. & MA, F. 2013. Emission-dependent supply chain and environment-policy-making in the 'cap-and-trade' system. Energy Policy, 57, 61-67.

DUAN, M., TAO, P. & ZHANG, X. 2014. Review of Carbon Emissions Trading Pilots in China. Energy & Environment, 25, 527-550.

ELLERMAN, A. D. & BUCHNER, B. K. 2008. Over-Allocation or Abatement? A Preliminary Analysis of the EU ETS Based on the 2005–06 Emissions Data. Environmental and Resource Economics, 41, 267-287.

ELLERMAN, A. D., CONVERY, F. J. & PERTHUIS, C. D. 2010. Pricing Carbon: The European Union Emissions Trading Scheme, Cambridge, Cambridge University Press.

ELLERMAN, D. A. & DECAUX, A. 1998. Analysis of post-Kyoto CO_2 emissions trading using marginal abatement curves. MIT Joint Program on the Science and Policy of Global Change.

ELLIS, J. & TIRPAK, D. 2006. Linking GHG Emission Trading Schemes and Markets. France.

EUROPEAN COMMISSION 2012. Report from the Commision to the European Parliament and the Council. Brussels: European Commission.

EUROPEAN COMMISSION 2015. EU ETS Handbook. European Commission.

EUROPEAN COMMISSION 2017. Report on the functioning of the European carbon market. Brussels: European Commission.

EYGM 2014. Understanding China's Emissions Trading Schemes and Emissions Reporting. EYGM Limited.

FAN, J. H., AKIMOV, A. & ROCA, E. 2013. Dynamic hedge ratio estimations in the European Union Emissions offset credit market. Journal of Cleaner Production, 42, 254-262.

FAN, J. H. & TODOROVA, N. 2017. Dynamics of China's carbon prices in the pilot trading phase. Applied Energy, 208, 1452-1467.

FAN, Y., JIA, J.-J., WANG, X. & XU, J.-H. 2017. What policy adjustments in the EU ETS truly affected the carbon prices? Energy Policy, 103, 145-164.

FAN, Y. & WANG, X. 2014. Which Sectors Should Be Included in the Ets in the Context of a Unified Carbon Market in China? Energy & Environment, 25, 613-346.

FANG, L. 2018. China starts collecting environment tax [Online]. State Administration of Taxation of The People's Republc of China. Available: http://www.chinatax.gov.cn/eng/n2367751/c3021312/content.html [Accessed 22 November 2018].

FENG, E. 2017. China moves towards launch of carbon trading scheme. Financial Times.

FISCHER, C. & PREONAS, L. 2010. Combining Policies for Renewable Energy: Is the Whole Less Than the Sum of Its Parts? International Review of Environmental and Resource Economics, 4, 51-92.

FLACHSLAND, C., MARSCHINSKI, R. & EDENHOFER, O. 2009. To link or not to link: benefits and disadvantages of linking cap-and-trade systems. Climate Policy, 9, 358-372.

FLUES, F., LÖSCHEL, A., LUTZ, B. J. & SCHENKER, O. 2014. Designing an EU energy and climate policy portfolio for 2030: Implications of overlapping regulation under different levels of electricity demand. Energy Policy, 75, 91-99.

FUJIWARA, N. 2016. Policy interaction between the EU Emissions Trading System and the Renewable Energy Directive Author. CARISMA Working Documents Series. CARISMA.

FUSS, S., SZOLGAYOVA, J., OBERSTEINER, M. & GUSTI, M. 2008. Investment under market and climate policy uncertainty. Applied Energy, 85, 708-721.

GAAST, W. V. D., CLOCHARD, G.-J., ALBEROLA, E., TÜRK, A., FUJIWARA, N. & SPYRIDAKI, N.-A. 2016. Effects of Interactions between EU Climate and Energy Policies. CARISMA Working Documents Series. CARISMA.

GIAEVER-ENGER, T. & BOOTH, D. 2008. Dated Brent as a solution to pricing of crude oil in Asia. Platts.

GONZÁLEZ-EGUINO, M. 2011. The importance of the design of market-based instruments for CO2 mitigation: An AGE analysis for Spain. Ecological Economics, 70, 2292-2302.

GREEN, F. & STERN, N. 2017. China's changing economy: implications for its carbon dioxide emissions. Climate Change, 17, 423-442.

GREEN, J. F., STERNER, T. & WAGNER, G. 2014. A balance of bottom-up and top-down in linking climate policies. Nature Climate Change, 4, 1064-1067.

GUAN, D., PETERS, G. P., WEBER, C. L. & HUBACEK, K. 2009. Journey to world top emitter: An analysis of the driving forces of China's recent CO2 emissions surge. Geophysical Research Letters, 36, L04709.

GUO, X., ZHU, Q., LV, L., CHU, J. & WU, J. 2017. Efficiency evaluation of regional energy saving and emission reduction in China: A modified slacks-based measure approach. Journal of Cleaner Production, 140, 1313-1321.

HAITA, C. 2013. Linking Emission Trading Schemes: Pros and Cons. Internaional Center for Climate Governance.

HAMMOUDEH, S., LAHIANI, A., NGUYEN, D. K. & SOUSA, R. M. 2015. An empirical analysis of energy cost pass-through to CO2 emission prices. Energy Economics, 49, 149-156.

HAN, G., OLSSON, M., HALLDING, K. & LUNSFORD, D. 2012. China's Carbon Emission Trading An Overview of Current Development, Stockholm, FORES.

HAOQI, Q., LIBO, W. & WEIQI, T. 2017. "Lock-in" effect of emission standard and its impact on the choice of market based instruments. Energy Economics, 63, 41-50.

HAWKINS, S. & JEGOU, I. 2014. Linking Emissions Trading Schemes: Considerations and Recommendations for a Joint EU-Korean Carbon Market. Geneva, Switzerland: International Centre for Trade and Sustainable Development (ICTSD).

HEINDL, P. & VOIGT, S. 2012. Supply and demand structure for international offset permits under the Copenhagen Pledges. International Environmental Agreements: Politics, Law and Economics, 12, 343-360.

HEPBURN, C. 2006. Regulation by Prices, Quantities, or Both: A Review of Instrument Choice. Oxford Review of Economic Policy, 22, 226-247.

HINTERMANN, B., PETERSON, S. & RICKELS, W. 2016. Price and Market Behavior in Phase II of the EU ETS: A Review of the Literature. Review of Environmental Economics and Policy, 10, 108-128.

HONE, D. 2013a. The real price of CO2 in the EU. Available: https://blogs.shell.com/2013/01/31/co2price/

HONE, D. 2013b. The real price of CO2 in the EU.

HOOD, C. 2013. Managing interactions between carbon pricing and existing energy policies. Paris, France: International Energy Agency.

HSIEH, F. Y., BLOCH, D. A. & LARSEN, M. D. 1998. A simple method of sample size calculation for linear and logistic regression. Statistics in Medicine, 17, 1623-1634.

HU, A.-G. 2016. The Five-Year Plan: A new tool for energy saving and emissions reduction in China. Advances in Climate Change Research, 7, 222-228.

HU, Y. & MONROY, C. R. 2012. Chinese energy and climate policies after Durban: Save the Kyoto Protocol. Renewable and Sustainable Energy Reviews, 16, 3243-3250.

HÜBLER, M. 2011. Technology diffusion under contraction and convergence: A CGE analysis of China. Energy Economics, 33, 131-142.

HÜBLER, M., VOIGT, S. & LÖSCHEL, A. 2014. Designing an emissions trading scheme for China—An up-to-date climate policy assessment. Energy Policy, 75, 57-72.

ICAP 2018a. China-Beijing pilot system. ICAP.

ICAP. 2018b. ETS Fact Sheets. Available: https://icapcarbonaction.com/en/ets-map.

IEA. 2017. World Energy Statistics and Balances online data service 2017 edition. Available: https://www.iea.org/statistics/relateddatabases/worldenergystatisticsandbalances/.

IETA 2012. Greenhou Gas Market 2012 New Markets, New Mechanisams, New Opportunities. IETA.

IETA 2014. GHG Market Sentiment Survey 2014 9th Edition: A survey of current market sentiment among IETA members. Geneva: International Emissions Trading Association.

IETA 2016. A Vision for the Market Provisions of the Paris Agreement. Genève, Switzerland: IETA.

IPCC 2014. Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the. Geneva, Switzerland: IPCC.

IPCC 2018. Special Report on Global Warming of 1.5 °C (SR15). Incheon, Republic of Korea: Intergovernmental Panel on Climate Change.

JACKSON, A., LLOYD, A., MACINANTE, J. & HÜWENER, M. 2018. Chapter 19 - Networked Carbon Markets: Permissionless Innovation With Distributed Ledgers? Transforming Climate Finance and Green Investment with Blockchains. Academic Press.

JIANG, J., XIE, D., YE, B., SHEN, B. & CHEN, Z. 2016. Research on China's cap-and-trade carbon emission trading scheme: Overview and outlook. Applied Energy, 178, 902-917.

JIANG, J., YE, B. & MA, X. 2014. The construction of Shenzhen′s carbon emission trading scheme. Energy Policy, 75, 17-21.

JIANG, J., YE, B., MA, X. & MIAO, L. 2015. Controlling GHG emissions from the transportation sector through an ETS: institutional arrangements in Shenzhen, China. Climate Policy, 16, 353-371.

JIANG, J., YE, B., XIE, D., LI, J., MIAO, L. & YANG, P. 2017. Sector decomposition of China's national economic carbon emissions and its policy implication for national ETS development. Renewable and Sustainable Energy Reviews, 75, 855-867.

JIANG, M., LIANG, X., REINER, D., LIN, B. & DUAN, M. 2018. Stakeholder views on interactions between low-carbon policies and carbon markets in China: lessons from the Guangdong ETS. Cambridge Working Paper Economics. University of Cambridge.

JIN, W. 2012. Can technological innovation help China take on its climate responsibility? An intertemporal general equilibrium analysis. Energy Policy, 49, 629-641.

JOTZO, F. & BETZ, R. 2009. Australia's emissions trading scheme: Opportunities and obstacles for linking. Climate Policy, 9, 402-414.

KACHI, A., UNGER, C., BÖHM, N., STELMAKH, K., HAUG, C. & FRERK, M. 2015. Linking Emissions Trading Systems: A Summary of Current Research. Berlin, Germany: International Carbon Action Partnership (ICAP).

KATHI, A. U., CHARLOTTE; BOHM, NIELS; STELMAKH, KOTERYNA; HAUG, CONSTANZE; FRERK, MICHEL 2015. Linking Emissions Trading Systems: A Summary of Current Research. Geermany: International Carbon Action Partnership.

KAUTTO, N., ARASTO, A., SIJM, J. & PECK, P. 2012. Interaction of the EU ETS and national climate policy instruments – Impact on biomass use. Biomass and Bioenergy, 38, 117-127.

KEMFERT, C., KOHLHASS, M., TRUONG, T. & PROTSENKO, A. 2006. The environmental and economic effects of European emissions trading. Climate Policy, 6, 441-455.

KEOHANE, N. O. 2009. Cap and Trade, Rehabilitated: Using Tradable Permits to Control U.S. Greenhouse Gases. Review of Environmental Economics and Policy, 3, 42-62.

KEPPLER, J. H. & MANSANET-BATALLER, M. 2010. Causalities between CO2, electricity, and other energy variables during phase I and phase II of the EU ETS. Energy Policy, 38, 3329-3341.

KESICKI, F. & EKINS, P. 2012. Marginal abatement cost curves: a call for caution. Climate Policy, 12, 219-236.

KIM, M.-K. & LEE, K. 2015. Dynamic Interactions between Carbon and Energy Prices in the U.S. Regional Greenhouse Gas Initiative. International Journal of Energy Economics and Policy, 5, 494-501.

KOCH, N., FUSS, S., GROSJEAN, G. & EDENHOFER, O. 2014. Causes of the EU ETS price drop: Recession, CDM, renewable policies or a bit of everything?—New evidence. Energy Policy, 73, 676-685.

L.SONNEBORN, C. 2004. Renewable energy and market-based approaches to greenhouse gas reduction—opportunity or obstacle? Energy Policy, 32, 1799-1805.

LAI, J. H. K. 2014. Mandatory reporting of greenhouse gas emissions from buildings: Stakeholders' opinions in Hong Kong. Energy Policy, 75, 278-288.

LAING, T., SATO, M., GRUBB, M. & COMBERTI, C. 2013. Assessing the effectiveness of the EU Emission Trading System. Centre for Climate Change Economics and Policy Working Paper No. 126 Grantham Research Institute on Climate Change and the Environment Working Paper No. 106.

LANZI, E., CHATEAU, J. & DELLINK, R. 2012. Alternative approaches for levelling carbon prices in a world with fragmented carbon markets. Energy Economics, 34, S240-S250.

LEE, M. & ZHANG, N. 2012. Technical efficiency, shadow price of carbon dioxide emissions, and substitutability for energy in the Chinese manufacturing industries. Energy Economics, 34, 1492-1497.

LEI, T., ZENG, C., CHEN, S., LI, J. & LI, B. The pricing discussion of carbon emissions trading for China. 2011 Yichang, China. IEEE.

LEIMBACH, M., ROMING, N., SCHULTES, A. & SCHWERHOFF, G. 2018. Long-Term Development Perspectives of Sub-Saharan Africa under Climate Policies. Ecological Economics, 144, 148-159.

LI, J., LIANG, X., COCKERILL, T., GIBBINS, J. & REINER, D. 2012. Opportunities and barriers for implementing CO2 capture ready designs: A case study of stakeholder perceptions in Guangdong, China. Energy Policy, 45, 432-251.

LI, J. F., WANG, X., ZHANG, Y. X. & KOU, Q. 2014a. The economic impact of carbon pricing with regulated electricity prices in China—An application of a computable general equilibrium approach. Energy Policy, 75, 46-56.

LI, M. W., LI, Y. P. & HUANG, G. H. 2011. An interval-fuzzy two-stage stochastic programming model for planning carbon dioxide trading under uncertainty. Energy, 36, 5677-5689.

LI, W. & LU, C. 2015. The research on setting a unified interval of carbon price benchmark in the national carbon trading market of China. Applied Energy, 155, 728-739.

LI, Y. P., HUANG, G. H. & LI, M. W. 2014b. An integrated optimization modeling approach for planning emission trading and clean-energy development under uncertainty. Renewable Energy, 62, 31-46.

LIANG, X., REINER, D. & LI, J. 2011. Perceptions of opinion leaders towards CCS demonstration projects in China. Applied Energy, 88, 1873-1885.

LIANG, X. & REINER, D. M. 2013. The Evolution of Stakeholder Perceptions of Deploying CCS Technologies in China: Survey Results from Three Stakeholder Consultations in 2006, 2009 and 2012. Energy Procedia, 37, 7361-7368.

LIAO, Z., ZHU, X. & SHI, J. 2015. Case study on initial allocation of Shanghai carbon emission trading based on Shapley value. Journal of Cleaner Production, 103, 338-344.

LIN, B. & JIA, Z. 2019. What are the main factors affecting carbon price in Emission Trading Scheme? A case study in China. Science of The Total Environment, 654, 252-534.

LIOBIKIENĖ, G. & BUTKUS, M. 2018. The challenges and opportunities of climate change policy under different stages of economic development. Science of The Total Environment, 642, 999-1007.

LIU, L., CHEN, C., ZHAO, Y. & ZHAO, E. 2015. China׳s carbon-emissions trading: Overview, challenges and future. Renewable and Sustainable Energy Reviews, 49, 254–266.

LIU, W.-P. & DAI, Y.-W. 2004. A Review on the Emission Permits Trade of Carbon in China. Problems of Forestry Economis, 04.

LIU, X., WANG, B., DU, M. & ZHANG, N. 2018. Potential economic gains and emissions reduction on carbon emissions trading for China's large-scale thermal power plants. Journal of Cleaner Production, 204, 247-257.

LIU, Y., FENG, S., CAI, S., ZHANG, Y., ZHOU, X., CHEN, Y. & CHEN, Z. 2013a. Carbon emission trading system of China: a linked market vs. separated markets. Fontiers of Earth Science, 7, 465-479.

LIU, Y. & WEI, T. 2016. Linking the emissions trading schemes of Europe and China - Combining climate and energy policy instruments. Mitigation and Adaptation Strategies for Global Change, 21, 135-151.

LIU, Z., GUAN, D., CRAWFORD-BROWN, D., ZHANG, Q., HE, K. & LIU, J. 2013b. Energy policy: A low-carbon road map for China. Nature, 500, 143-145.

LO, K. 2014. A critical review of China's rapidly developing renewable energy and energy efficiency policies. Renewable and Sustainable Energy Reviews, 29, 508-516.

LUTZ, B. J., PIGORSCH, U. & ROTFUß, W. 2013. Nonlinearity in cap-and-trade systems: The EUA price and its fundamentals. Energy Economics, 40, 222-232.

MACKENZIE, D. 2009. Making things the same: Gases, emission rights and the politics of carbon markets. Accounting, Organizations and Society, 34, 440-455.

MANSANET-BATALLER, M. & PARDO, A. 2009. Impacts of regulatory announcements on CO2 prices. The Journal of Energy Markets, 2, 75-107.

MANSANET-BATALLER, M., PARDO, A. & VALOR, E. 2007. CO_2 Prices, Energy and Weather. The Energy Journal, 28, 73-92.

MARCANTONINI, C., TEIXIDO-FIGUERAS, J., VERDE, S. F. & LABANDEIRA, X. 2017. The EU ETS and its Interactions with other Climate and Energy Policies. Robert Schuman Centre for Advanced Studies.

MARSCHINSKI, R., FLACHSLAND, C. & JAKOB, M. 2012. Sectoral linking of carbon markets: A trade-theory analysis. Resource and Energy Economics, 34, 585-606.

MARTIN, R., MUÛLS, M. & WAGNER, U. J. 2015. The Impact of the European Union Emissions Trading Scheme on Regulated Firms: What Is the Evidence after Ten Years? Review of Environmental Economics and Policy, 10, 129-148.

MASSETTI, E. & TAVONI, M. 2012. A developing Asia emission trading scheme (Asia ETS). Energy Economics, 34, S436-S443.

MCDOUGALL, R. & GOLUB, A. 2007. GTAP-E Release 6: A Revised Energy-Environmental Version of the GTAP Model. GTAP Research Memorandum, No. 15.

MEHLING, M. & GÖRLACH, B. 2016. Multilateral Linking of Emissions Trading Systems. CEEPR WP 2016-009.

MEHLING, M. & HAITES, E. 2011. Mechanisms for linking emissions trading schemes. Climate Policy, 9, 169-184.

METCALF, G. E. & WEISBACH, D. 2012. Linking Policies When Tastes Differ: Global Climate Policy in a Heterogeneous World. Review of Environmental Economics and Policy, 6, 110-129.

MILLER, D. C. & SALKIND, N. J. 2002. Causation and Multivariate Analysis: From Univariate and Bivariate Problems to Multivariate Analysis of Social Behavior. Handbook of research design & social measurement. Thousand Oaks, CA: SAGE Publications, Inc.

MO, J.-L., AGNOLUCCI, P., JIANG, M.-R. & FAN, Y. 2016. The impact of Chinese carbon emission trading scheme (ETS) on low carbon energy (LCE) investment. Energy Policy, 89, 271-283.

MO, J., ZHU, L. & FAN, Y. 2013. Carbon price stabilization mechanism and its implication for China. Advance Climate Change Research, 9, 368-375.

MORRIS, J. F., REILLY, J. M. & PALTSEV, S. 2010. Combining a Renewable Portfolio Standard with a Cap-and-Trade Policy: A General Equilibrium Analysis. Joint Program Report Series Report 187.

MOSELLE, B. 2011. Climate Change Policy-Time for Plan B. London: Policy Exchange.

MUNDACA, L. & RICHTER, J. L. 2013. Challenges for New Zealand's carbon market. Nature Climate Change, 3, 1006-1008.

NDRC 2011. Notice on launching carbon emissions trading pilot. www.ndrc.gov.cn.

NDRC. 2015. China's First NDC Submission. Available: http://www4.unfccc.int/ndcregistry/PublishedDocuments/China%20First/China's%20First%20NDC%20Submission.pdf [Accessed 6 30].

NDRC 2016a. The 13th Five-Year Plan for Economic and Social Development of the People's Republic of China (2016-2020). Beijing: Central Compliation & Translation Press.

NDRC 2016b. 国家发展改革委办公厅关于切实做好全国碳排放权交易市场启动重点工作的通知 Landmark Notice on National ETS Guidance. www.ndrc.gov.cn.

NDRC 2017a. Notice on price policy of DGPV. National Development and Regorm Commission.

NDRC 2017b. 全国碳排放交易体系启动 Launch of National ETS. www.ndrc.gov.cn.

NIJKAMP, P., WANG, S. & KRAMERS, H. 2005a. Modeling the impacts of international climate change policies in a CGE context: the use of the GTAP-E model. Economic Modelling, 22, 955-974.

NIJKAMP, P., WANG, S. & KREMERS, H. 2005b. Modeling the impacts of international climate change policies in a CGE context: The use of the GTAP-E model. Economic Modelling, 22, 955-974.

NONG, D. & SIRIWARDANA, M. 2018. Effects on the U.S. economy of its proposed withdrawal from the Paris Agreement: A quantitative assessment. Energy, 159, 621-629.

NORDHAUS, W. 2011. Designing a friendly space for technological change to slow global warming. Energy Economics, 33, 665-673.

O'KEEFFE, J. M., CUMMINS, V., DEVOY, R. J. N., LYONS, D. & GAULT, J. 2016. Stakeholder awareness of climate adaptation in the commercial seaport sector: A case study from Ireland. Marine Policy, In Press.

OBERNDORFER, U. 2009. EU Emission Allowances and the stock market: Evidence from the electricity industry. Ecological Economics, 68, 1116-1126.

ORLOV, A. & AAHEIM, A. 2017. Economy-wide effects of international and Russia's climate policies. Energy Economics, 68, 466-477.

PATRINOS, A. A. N. & BRADLEY, R. A. 2009. Energy and Technology Policies for Managing Carbon Risk. Science, 325, 949-950.

PATUELLI, R., NIJKAMP, P. & PELS, E. A. J. H. 2005. Environmental Tax Reform and the Double Dividend: A Meta-Analytical Performance Assessment. Ecological Economics, 55, 564-583.

PETHIG, R. & WITTLICH, C. 2009. Interaction of carbon reduction and green energy promotion in a small fossil-fuel importing economy. No 2749, CESifo Working Paper Series from CESifo Group Munich. Siegen: Universität Siegen.

PEZZEY, J. C. V. & JOTZO, F. 2012. Tax-versus-trading and efficient revenue recycling as issues for greenhouse gas abatement. Journal of Environmental Economics and Management, 64, 230-236.

PING, Y. & ZHENNAN, Q. 2011. Using Carbon Trading to Seize the Commanding Heights of Economic Development. Energy Procedia, 5, 74-78.

PIZER, W. A. 1999. The optimal choice of climate change policy in the presence of uncertainty. Resource and Energy Economics, 21, 255-287.

PIZER, W. A. 2002. Combining price and quantity controls to mitigate global climate change. Journal of Public Economics, 85, 409-434.

POLLITT, M. G., YANG, C.-H. & CHEN, H. 2017. Reforming the Chinese Electricity Supply Sector: Lessons from International Experience. University of Cambridge Energy Policy Research Group (EPRG) Working Paper Series 1704. University of Cambridge Energy Policy Research Group (EPRG) Working Paper Series.

QI, S., WANG, B. & ZHANG, J. 2014a. Policy design of the Hubei ETS pilot in China. Energy Policy, 75, 31-38.

QI, T. & WENG, Y. 2016. Economic impacts of an international carbon market in achieving the INDC targets. Energy, 109, 886-893.

QI, T., WINCHESTER, N., KARPLUS, V. & ZHANG, X. 2013. The Energy and Economic Impacts of Expanding International Emissions Trading. Tsinghua-MIT China Energy & Climate Project.

QI, T., ZHANG, X. & KARPLUS, V. J. 2014b. The energy and CO2 emissions impact of renewable energy development in China. Energy Policy, 68, 60-69.

QUIRION, P. 2010. Complying with the Kyoto Protocol under uncertainty: Taxes or tradable permits? Energy Policy, 38, 5166-5173.

RANSON, M. & STAVINS, R. N. 2013. A Post-Durban Climate Policy Architecture Based on Linkage of Cap-and-Trade Systems. The Chicago Journal of International Law, 13, 403-438.

RANSON, M. & STAVINS, R. N. 2016. Linkage of greenhouse gas emissions trading systems: learning from experience. Climate Policy, 16, 284-300.

RAUFER, R. & LI, S. 2009. Emissions trading in China: A conceptual ‘leapfrog’ approach? Energy, 34, 904-912.

REBOREDO, J. C. & UGANDO, M. 2015. Downside risks in EU carbon and fossil fuel markets. Mathematics and Computers in Simulation, 111, 17-35.

REINER, D. & LIANG, X. 2012. Stakeholder Views on Financing Carbon Capture and Storage Demonstration Projects in China. Environ. Sci. Technol., 46, 643-651.

REN, C. & LO, A. Y. 2017. Emission trading and carbon market performance in Shenzhen, China. Applied Energy, 193, 414-425.

REN, S., LI, X., YUAN, B., LI, D. & CHEN, X. 2018. The effects of three types of environmental regulation on eco-efficiency: A cross-region analysis in China. Journal of Cleaner Production, 173, 245-255.

RICHSTEIN, J. C., CHAPPIN, É. J. L. & VRIES, L. J. D. 2015. Adjusting the CO2 cap to subsidised RES generation: Can CO2 prices be decoupled from renewable policy? Applied Energy, 156, 693-702.

RICKELS, W., G€ORLICH, D. & PETERSON, S. 2014. Explaining European Emission Allowance Price Dynamics: Evidence from Phase II. German Economic Review, 16, 181-202.

SCHLEICH, J., ROGGE, K. & BETZ, R. 2009. Incentives for energy efficiency in the EU Emissions Trading Scheme. Energy Efficiency, 2, 37-67.

SCHLESINGER, W. H. 2006. Editorial: Carbon Trading. Science New Series, 314, 1217.

SCHMIDT, N. M. & FLEIG, A. 2018. Global patterns of national climate policies: Analyzing 171 country portfolios on climate policy integration. Environmental Science & Policy, 84, 177-185.

SCHUMAN, S. & LIN, A. 2012. China's Renewable Energy Law and its impact on renewable power in China: Progress, challenges and recommendations for improving implementation. Energy Policy, 51, 89-109.

SHAHNAZARI, M., MCHUGH, A., MAYBEE, B. & WHALE, J. 2017. Overlapping carbon pricing and renewable support schemes under political uncertainty: Global lessons from an Australian case study. Applied Energy, 200, 237-248.

SHINKUM, T. & SUGETA, H. 2016. Tax versus emissions trading scheme in the long run. Journal of Environmental Economics and Management, 75, 12-24.

SIJM, J. 2005. The interaction between the EU Emissions Trading Scheme and national energy policies. Climate Change, 5, 79-96.

SORRELL, S. 2003. Interactions between the EU Emissions Trading Scheme and the UK Renewables Obligation and Energy Efficiency Commitment. Energy & Environment, 14, 677-703.

SORRELL, S. 2015. Reducing energy demand: A review of issues, challenges and approaches. Renewable and Sustainable Energy Reviews, 47, 74-82.

SPRINGER, C., EVANS, S., LIN, J. & ROLAND-HOLST, D. 2019. Low carbon growth in China: The role of emissions trading in a transitioning economy. Applied Energy, 235, 1118-1125.

STAVINS, R. N. 2001. Experience with Market-Based Environmental Policy Instruments Washington, D.C.: Resources for the Future

STERN, N. 2006. Stern Review on the Economics of Climate Change. Cambridge: Cambridge University Press.

STRANLUND, J. K. & BEN-HAIM, Y. 2008. Price-based vs. quantity-based environmental regulation under Knightian uncertainty: An info-gap robust satisficing perspective. Journal of Environmental Management, 87, 443-449.

SYRI, S. & CROSS, S. Weak EU emissions trading with strong renewables obligation compromises long-term CO2 mitigation. 2013 Stockholm, Sweden. IEEE.

TAN, X. & WANG, X. 2017. The market performance of carbon trading in China: A theoretical framework of structure-conduct-performance. Journal of Cleaner Production, 159, 410-424.

TANG, B.-J., WANG, X.-Y. & WEI, Y.-M. 2019. Quantities versus prices for best social welfare in carbon reduction: A literature review. Applied Energy, 233-234, 554-564.

TENG, F. & GU, A. 2008. Climate change: national and local policy opportunities in China. Environmental Sciences, 4, 183-194.

THE WORLD BANK 2014. State and Trends of Carbon Pricing 2014. Washington, DC: World Bank.

THE WORLD BANK 2016. Emissions Trading in Practice: A Handbook on Design and Implementation. Washington, DC

TIAN, H. & WHALLEY, J. 2009. Level versus Equivalent Intensity Carbon Mitigation Commitments. NBER Working Paper No. 15370. The National Bureau of Economic Research.

TIETENBERG, T. H. 2006. Emissions Trading: Principles and Practice, New York, Routledge.

TOMÁS, R. A. F., RIBEIRO, F. R., SANTOS, V. M. S., GOMES, J. F. P. & BORDADO, J. C. M. 2010. Assessment of the impact of the European CO2 emissions trading scheme on the Portuguese chemical industry. Energy Policy, 38, 626-632.

TU, Q. & MO, J.-L. 2017. Coordinating carbon pricing policy and renewable energy policy with a case study in China. Computers & Industrial Engineering, 113, 294-304.

TUERK, A., MEHLING, M., FLACHSLAND, C. & OBERGASSEL, W. 2009. Linking carbon markets: Concepts, case studies and pathways. Climate Policy, 9, 341-357.

TURNER, R. K. & DAILY, G. C. 2008. The Ecosystem Services Framework and Natural Capital Conservation. Environmental and Resource Economics, 39, 25-35.

UNEP 2011. Towards a Green Economy: Pathways to Sustainable Development and Poverty Eradication - A Synthesis for Policy Makers. France.

UNFCCC 1998. Kyoto Protocal to the United Nations Framework Convention on Climate Change. Kyoto, Japan: United Nations.

UNITED NATIONS 1992. United Nations Framework Convention on Climate Change. Rio: Uinted Nations.

UNITED NATIONS 2015. The Paris Agreement. Paris: United Nations.

UNRUH, G. C. 2000. Understanding carbon lock-in. Energy Policy, 28, 817-830.

W.H.PARRY, I. & III, R. C. W. 1999. A second-best evaluation of eight policy instruments to reduce carbon emissions. Resource and Energy Economics, 21, 347-373.

WANG, K., WANG, C. & CHEN, J. 2009. Analysis of the economic impact of different Chinese climate policy options based on a CGE model incorporating endogenous technological change. Energy Policy, 37, 2930-2940.

WANG, K., ZHANG, X., WEI, Y.-M. & YU, S. 2013. Regional allocation of CO2 emissions allowance over provinces in China by 2020. Energy Policy, 54, 214-229.

WANG, K., ZHANG, X., YU, X., WEI, Y.-M. & WANG, B. 2016. Emissions trading and abatement cost savings: An estimation of China's thermal power industry. Renewable and Sustainable Energy Reviews, 65, 1005-1017.

WANG, P., DAI, H.-C., REN, S.-Y., ZHAO, D.-Q. & MASUI, T. 2015. Achieving Copenhagen target through carbon emission trading: Economic impacts assessment in Guangdong Province of China. Energy, 79, 212-227.

WANG, Q. & CHEN, X. 2015. Energy policies for managing China's carbon emission. Renewable and Sustainable Energy Reviews, 50, 470-479.

WANG, Q. & LU, J. 2015. 中国碳配额价格影响因素的区域性差异 Regional differences in impact factors of emission allowance prices in China. Zhejiang Academic Journal.

WANG, Z. & WANG, C. 2015. How carbon offsetting scheme impacts the duopoly output in production and abatement: analysis in the context of carbon cap-and-trade. Journal of Cleaner Production, 103, 715-723.

WEI, C., NI, J. & DU, L. 2012. Regional allocation of carbon dioxide abatement in China. China Economic Review, 23, 552-565.

WEI, Q. & TIAN, M. M. 2013. Building Carbon Emissions Trading System for China under the Experience of EU Emissions Trading System. Applied Mechanics and Materials, 411-414, 2505-2510.

WEIGT, H., ELLERMAN, D. & DELARUE, E. 2013. CO2 abatement from renewables in the German electricity sector: Does a CO2 price help? Energy Economics, 40, S149-S158.

WEITZMAN, M. L. 1974. Prices vs. Quantities. Review of Economic Studies, 41, 477-491.

WEITZMAN, M. L. 1978. Optimal Rewards for Economic Regulation. The American Economic Review, 68, 683-691.

WING, I. S. 2004. Computable General Equilibrium Models and Their Use in Economy-Wide Policy Analysis. MIT Joint Program on the Science and Policy of Global Change.

WU, G., LIU, L.-C., HAN, Z.-Y. & WEI, Y.-M. 2012. Climate protection and China's energy security: Win–win or tradeoff. Applied Energy, 97, 157-163.

WU, L., QIAN, H. & LI, J. 2014a. Advancing the experiment to reality: Perspectives on Shanghai pilot carbon emissions trading scheme. Energy Policy, 75, 22-30.

WU, L., QIAN, H. & LI, L. 2014b. Advancing the experiment to reality: Perspectives on Shanghai pilot carbon emissions trading scheme. Energy Policy, 75, 22-30.

XIE, K., LI, W. & ZHAO, W. 2010. Coal chemical industry and its sustainable development in China. Energy, 35, 4349-4355.

XIONG, W., ZHANG, D., MISCHKE, P. & ZHANG, X. 2014. Impacts of Renewable Energy Quota System on China's Future Power Sector. Energy Procedia, 61, 1187-1190.

XU, J., QIU, R. & LV, C. 2016. Carbon emission allowance allocation with cap and trade mechanism in air passenger transport. Journal of Cleaner Production, 131, 308-320.

XU, J., YANG, X. & TAO, Z. 2015a. A tripartite equilibrium for carbon emission allowance allocation in the power-supply industry. Energy Policy, 82, 62-80.

XU, X., ZHANG, W., HE, P. & XU, X. 2017. Production and pricing problems in make-to-order supply chain with cap-and-trade regulatio. Omega, 66, 248-257.

XU, Z., TIAN-YU, Q., XUN-MIN, O. & XI-LIANG, Z. 2015b. Research on the Energy and Economic Impacts of Multi-region Linked Emissions Trading System. Energy Procedia, 75, 2495-2503.

YANG, C.-J. & OPPENHEIMER, M. 2007. A "Manhattan Project" for climate change? Climate Change, 80, 199-204.

YANG, L., LI, F. & ZHANG, X. 2016. Chinese companies' awareness and perceptions of the Emissions Trading Scheme (ETS): Evidence from a national survey in China. Energy Policy, 98, 254-265.

YANG, Z., JU, M., ZHOU, Y., WANG, Q. & MA, N. 2010. An Analysis of Greenhouse Gas Emission Trading System from the Perspective of Stakeholders. Procedia Environmental Sciences, 2, 82-91.

YE, L.-C., RODRIGUES, J. F. D. & LIN, H. X. 2017. Analysis of feed-in tariff policies for solar photovoltaic in China 2011–2016. Applied Energy, 203, 496-505.

YI, B.-W., XU, J.-H. & FAN, Y. 2016. Determining factors and diverse scenarios of CO2 emissions intensity reduction to achieve the 40–45% target by 2020 in China – a historical and prospective analysis for the period 2005–2020. Journal of Cleaner Production, 122, 87-101.

YI, W.-J., ZOU, L.-L., GUO, J., WANG, K. & WEI, Y.-M. 2011. How can China reach its CO2 intensity reduction targets by 2020? A regional allocation based on equity and development. Energy Policy, 39, 2407-2415.

YU, L., LI, J., TANG, L. & WANG, S. 2015. Linear and nonlinear Granger causality investigation between carbon market and crude oil market: A multi-scale approach. Energy Economics, 51, 300-311.

YU, S., WEI, Y.-M. & WANG, K. 2014. Provincial allocation of carbon emission reduction targets in China: An approach based on improved fuzzy cluster and Shapley value decomposition. Energy Policy, 66, 630-644.

YUAN, X. & ZUO, J. 2011. Transition to low carbon energy policies in China—from the Five-Year Plan perspective. Energy Policy, 39, 3855-3859.

ZAPFEL, P. & VAINIO, M. 2002. Pathways to European Greenhouse Gas Emissions Trading History and Misconceptions. FEEM Working Paper No. 85.

ZEITLBERGER, A. C. M. & BRAUNEIS, A. 2014. Modeling Carbon Spot and Futures Price Returns with GARCH and Markov Switching GARCH Models. Evidence from the First Commitment Period (2008-2012). Central European Journal of Operations Research, 24, 149-176.

ZENG, M., LIU, X., LI, N. & XUE, S. 2013. Overall review of renewable energy tariff policy in China: Evolution, implementation, problems and countermeasures. Renewable and Sustainable Energy Reviews, 25, 260-271.

ZENG, T. 2010. China's CO2 emissoins trading status and the relevant legal issues. In: HOU, M. Z., XIE, H. & YOON, J. (eds.) Underground Storage of CO2 and Energy. CRC Press.

ZHANG, B. & XU, L. 2013. Multi-item production planning with carbon cap and trade mechanism. International Journal of Production Economics, 144, 118-127.

ZHANG, D., KARPLUS, V. J., CASSISA, C. & ZHANG, X. 2014a. Emissions trading in China: Progress and prospects. Energy Policy, 75, 9-16.

ZHANG, D., RAUSCH, S., KARPLUS, V. J. & ZHANG, X. 2013a. Quantifying regional economic impacts of CO2 intensity targets in China. Energy Economics, 40, 678-701.

ZHANG, F., DENG, H., MARGOLIS, R. & SU, J. 2015. Analysis of distributed-generation photovoltaic deployment, installation time and cost, market barriers, and policies in China. Energy Policy, 81, 43-55.

ZHANG, F., GUO, Y. & CHEN, X. 2011. Research on China's Power Sector Carbon Emissions Trading Mechanism. Energy Procedia, 12, 127-132.

ZHANG, L. 2014. CO2 Abatement Allocation among Different Provinces of China Based on MACC. Applied Mechanics and Materials 675-677, 1869-1874.

ZHANG, S., ANDREWS-SPEED, P., ZHAO, X. & HE, Y. 2013b. Interactions between renewable energy policy and renewable energy industrial policy: A critical analysis of China's policy approach to renewable energies. Energy Policy, 62, 342-353.

ZHANG, X., XU, Q., ZHANG, F., GUO, Z. & RAO, R. 2014b. Exploring shadow prices of carbon emissions at provincial levels in China. Ecological Indicators, 46, 407-414.

ZHANG, Y.-J., HAO, J.-F. & SONG, J. 2016. The CO2 emission efficiency, reduction potential and spatial clustering in China’s industry: Evidence from the regional level. Applied Energy, 174, 213-223.

ZHANG, Y.-J., PENG, Y.-L., MA, C.-Q. & SHEN, B. 2017. Can environmental innovation facilitate carbon emissions reduction? Evidence from China. Energy Policy, 100, 18-28.

ZHANG, Y.-J. & WEI, Y.-M. 2010. An overview of current research on EU ETS: Evidence from its operating mechanism and economic effect. Applied Energy, 87, 1804-1814.

ZHANG, Y. 2015a. 中国碳金融交易价格机制研究 Study on pricing mechanism of ETS in China. University of Jilin.

ZHANG, Z. 2015b. Carbon emissions trading in China: the evolution from pilots to a nationwide scheme. Climate Policy, 15, S104-S126.

ZHAO, X.-G., JIANG, G.-W., NIE, D. & CHEN, H. 2016. How to improve the market efficiency of carbon trading: A perspective of China. Renewable and Sustainable Energy Reviews, 59, 1229-1245.

ZHAO, X., YIN, H. & ZHAO, Y. 2015. Impact of environmental regulations on the efficiency and CO2 emissions of power plants in China. Applied Energy, 149, 238-247.

ZHAO, X., ZOU, Y., YIN, J. & FAN, X. 2017. Cointegration relationship between carbon price and its factors: evidence from structural breaks analysis. Energy Procedia, 142, 2503-2510.

ZHENG, S. 2013. China Emission Trading Scheme: Policies and Challenges. Available: http://businessdocbox.com/67196359-Green_Solutions/China-emission-trading-scheme-policies-and-challenges.html.

ZHOU, J., DUAN, M. & LIU, C. 2011. Output-based Allowance Allocations under China's Carbon Intensity Target. Energy Procedia, 5, 1904-1909.

ZHOU, P., ZHANG, L., ZHOU, D. Q. & XIA, W. J. 2013. Modeling economic performance of interprovincial CO2 emission reduction quota trading in China. Applied Energy, 112, 1518-1528.

Appendices

Appendix A: Questionnaire results

Q1.	**Which of the following options best describe your sector?**						
	Industry	Academia	Government	Consulting	Finance	NGO	None of above, please specify
% of respondents to Q1 (%)	26.67	13.33	10.00	25.00	20.00	10.00	3.33
Number of respondents to Q1	8	4	3	5	6	3	1
Q2	**Which of the following options best describe your role within your organisation?**						
	Economics or finance	Engineering	Managerial	Research	None of above, please specify		
% of respondents to Q2	26.67	23.33	16.67	30.00	3.33		
Number of respondents to Q2	8	7	5	9	1, low-carbon certification and verification		
Q3	**How much of your working time have you spent on energy saving and emission reduction policies in China in the past year?**						
	Less than 20%	20% to 50%	>50% to 70%	>70% to 90%	More than 90%		
% of respondents to Q3	36.67	30.00	23.33	10.00	0.0		
Number of respondents to Q3	11	9	7	3	0		
Q4	**How much of your working time on Chinese carbon trading system occupied in your total working time on energy saving and emission reduction policies in China according to question 3?**						
	Less than 20%	20% to 50%	>50% to 70%	>70% to 90%	More than 90%		
% of respondents to Q4	76.67	13.33	6.67	0.0	3.33		

Number of respondents to Q4	23	4	2	0	1			
Q5	**Which channels do you use to obtain up-to-date information about Chinese carbon market?**							
	Books	Newspapers	TV news	Internet	Conference	Government notice	Personal network	None of above, please specify
Votes	7	17	10	24	20	6	8	0
Q6	**To what extent do you consider yourself be familiar with the portfolio of carbon reduction incentive mechanisms? e.g. Emission Trading Scheme, carbon taxation, etc.**							
	Not familiar at all	Relatively not familiar	Average	Relatively familiar	Very familiar			
% of respondents to Q6	10.00	23.33	20.00	36.37	10.00			
Number of respondents to Q6	3	7	6	11	3			
Q7	**To what extent, do you believe that climate policy in China could achieve deep cuts in greenhouse gas emissions intensity in the next 10 years?**							
	Very unlikely	Unlikely	Not sure	Likely	Very likely			
% of respondents to Q7	23.33	26.67	20.00	26.67	3.33			
Number of respondents to Q7	7	8	6	8	1			
Q8	**Which of the following do you think would be the most cost-effective policy instrument to reduce greenhouse gas emissions in China? (If not sure, you can skip the question)**							
	Emission Trading Scheme	Carbon Taxation	Feed-in Tariffs (FITs)	Renewable Energy subsidy or binding obligation	Preferential policy for natural gas and encouragement policy for nuclear power	Industrial Emission performance standard	Others, please specify	
% of respondents to Q8	33.33	26.67	3.33	16.67	16.67	3.33	0.0	

Number of respondents to Q8	10	8	1	5	5	1	0
Q9	**Which of the following do you think would be the second most cost-effective policy instrument to reduce greenhouse gas emissions in China? (If not sure, you can skip the question)**						
	Emission Trading Scheme	Carbon Taxation	Feed-in Tariffs (FITs)	Renewable Energy subsidy or binding obligation	Preferential policy for natural gas and encouragement policy for nuclear power	Industrial Emission performance standard	Others, please specify
% of respondents to Q9	33.33	33.33	3.33	10.00	16.67	3.33	0.0
Number of respondents to Q9	10	10	1	3	5	1	0
Q10	**The EU ETS is the largest carbon market in the world, but the price of carbon emission is volatile and has been at a low level in the last two years. Which of the following factors do you think would be the main reasons that explain the collapse of the carbon price in the EU ETS? (If not sure, you can skip the question)**						
	Global economic downturn	Excess allocation of carbon emission permits by individual countries	Large volume of Certification Emission Reduction (CER) due to the increase in CDM projects	Alternative emission reduction mechanism such as carbon tax, renewable target or FITs	Failure of United Nations negotiations to set binding international targets	Others, please specify	
Votes	18	12	5	5	9	0	
Q11	**How optimistic are you about the future success of the upcoming seven cities pilot carbon trading system project in China?**						
	Very pessimistic	Relatively pessimistic	Not sure	Relatively optimistic	very optimistic		
% of respondents to Q11	6.67	23.33	36.67	33.33	0.0		
Number of respondents to Q11	2	7	11	10	0		
Q12	**How you would assess progress in the seven cities pilot carbon trading system project in China?**						
	Too slow	Relatively slow	Average	Relatively fast	Too fast		

% of respondents to Q12	13.33	26.67	23.33	26.67	10.00
Number of respondents to Q12	4	8	7	8	3
Q13	**Taking Guangdong pilot carbon market as example, which range of average carbon price in the seven cities pilot carbon market do you think would be expected by the end of 2014? (If not sure, you can skip the question)**				
	0-25CNY/t CO2	26-50 CNY/t CO2	51-100 CNY/t CO2	101-200 CNY/t CO2	Above 200 CNY/t CO2
% of respondents to Q13	3.33	26.67	36.37	13.33	0.0
Number of respondents to Q13	1	8	11	4	0
Q14	**If a higher than expected short-term renewable energy target is enacted in the pilot cities (e.g. renewable energy target increases from 10% to 15%), what would be the most likely impact on carbon price in the pilot carbon market? (If not sure, you can skip the question)**				
	Large decrease	Small decrease	unchanged	Small increase	Large increase
% of respondents to Q14	3.33	46.67	20.00	23.33	3.33
Number of respondents to Q14	1	14	6	7	1
Q15	**If an unexpected national carbon tax is suddenly announced for immediate implementation across all major industry sectors (power, cement, refinery, etc.), what do you think will be the most likely immediate impact on the carbon price in these pilot carbon markets? (If not sure, you can skip the question)**				
	Large decrease	Small decrease	unchanged	Small increase	Large increase
% of respondents to Q15	13.33	10.00	13.33	36.67	16.67
Number of respondents to Q15	4	3	4	11	5
Q16	**To what extend do you agree with the following statement: Multiple Energy Saving and Emission Reducing incentives, such as 'cap and trade' system, carbon taxation, renewable energy obligation, emission performance standard etc., may be conflicting, and generate different cost and benefit under different situations.**				
	Strongly disagree	disagree	Not sure	agree	Strongly agree
% of respondents to Q16	0.0	23.33	33.33	43.33	0.0

Number of respondents to Q16	0	7	10	13	0
Q17	**To what extend do you agree with the following statement: Integrating the Chinese carbon trading market into the international trading system could help reduce the adverse impact on carbon price from the interactions of other national carbon reduction incentive mechanisms.**				
	Strongly disagree	disagree	Not sure	agree	Strongly agree
% of respondents to Q17	0.0	13.33	50.00	36.67	0.0
Number of respondents to Q17	0	4	15	11	0
Q18	**In regard to the monitoring, report and verification (MRV) system, please give rank from 1 t0 6 the following potential challenges that you think would negatively affect the carbon market from the most important to the least important. You can also tick 'Not sure' if you are not sure about the question. (If not sure, you can skip the question)**				
	Incorrect and incomplete historical database	Incorrect carbon auditing methodology	Lack of third party verification and auditing institutes	Lack of skilled workers in carbon auditing	Corruption during auditing process
Average ranking	1.81	2.58	2.85	3.96	3.73
Q19	**In regard to the implementation of Chinese carbon trading market, please give rank from 1 t0 5 the following potential challenges that you think would negatively affect the carbon market from the most important to the least important. You can also tick 'I do not know' if you are not sure about the question. (If not sure, you can skip the question)**				
	Enterprises still confused about carbon emission trading, and worried it may	The 'Cap' implies decreased energy consumption, may negative influence GDP growth	Limited relevant financial institutions that are familiar with carbon markets	Limited relevant financial institutions	Other energy and low-carbon policies such as emission performance standard and renewable energy obligation may decrease demand of emission reduction in carbon trading market;

	increase costs				
Average ranking	1.70	2.27	3.38	3.92	3.69
Q20	**Can you indicate any other challenges you think are relevant that an ETS in China might confront?**				
	Yes, please specify	No, I think the challenges listed above already covered them all			
% of respondents to Q20	36.67	73.33			
Number of respondents to Q20	8	22			
Q21	**Would you like to be invited in the future to take part in further research?**				
	Yes, I'm glad to	Sorry, I don't want to be invited			
% of respondents to Q21	63.33	36.67			
Number of respondents to Q21	19	11			

Appendix B: Regression results

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Variables	**Chongqing**	**Beijing**	**Shanghai**	**Guangdong**	**Shenzhen**	**Tianjin**	**Hubei**
Gas	0.154	0.276	0.408	**1.878*** **	-0.111	-0.290	-0.0763
	(0.395)	(0.276)	(0.331)	(0.632)	(0.433)	(0.581)	(0.168)
Coal	0.498	0.0937	-0.680	-0.155	-0.214	-0.163	-0.162
	(1.187)	(0.193)	(0.726)	(0.408)	(0.321)	(0.310)	(0.162)
Crude Oil	0.108	**0.462** **	**0.444** **	0.113	-0.0132	-0.452	-0.181
	(0.417)	(0.216)	(0.182)	(0.208)	(0.163)	(0.371)	(0.165)
CSI_300	0.619	-0.0749	-0.479	0.0687	0.0258	-0.205	0.0455
	(0.398)	(0.143)	(0.339)	(0.140)	(0.124)	(0.167)	(0.125)
Extreme weather	0.0250	-0.00384	0.00453	0.000880	**0.00921***	-0.00217	0.00199
	(0.0203)	(0.00336)	(0.00572)	(0.00739)	(0.00482)	(0.00367)	(0.00259)
Re_prdct	0.00197	-0.000319	0.000807	-0.000560	0.000136	**0.00129***	0.000290
	(0.00130)	(0.000306)	(0.000598)	(0.000525)	(0.000309)	(0.000756)	(0.000250)
Renewable policy	0.0164	-0.0204	0.0248	**0.0649** **	-0.0169	0.00480	**0.0169***
	(0.0246)	(0.0287)	(0.0345)	(0.0256)	(0.0277)	(0.0182)	(0.00901)
Surrender Date	-0.0368	0.00760	0.00778	0.0454	**-0.0663** **	-0.115	0.00303
	(0.0444)	(0.0199)	(0.0702)	(0.0536)	(0.0261)	(0.158)	(0.0266)
CCER	0.0268	0.00247	0.0390	(0.0256)	(0.0277)	**0.0344***	0.0260
	(0.0597)	(0.0132)	(0.0468)	0.0247	0.00492	(0.0205)	(0.0197)

R-squared	0.061	0.060	0.063	0.144	0.037	0.080	0.032
Observations	155	155	155	155	155	155	155

Energy	0.115	0.112	0.115	0.0159	0.0126	-0.360	-0.291
	(0.410)	(0.436)	(0.410)	(0.423)	(0.309)	(0.370)	(0.256)
Material	-0.213	0.0603	-0.213	0.455	0.0599	-0.452	-0.266
	(0.355)	(0.394)	(0.355)	(0.737)	(0.331)	(0.453)	(0.223)
Consumption	-0.262	-0.167	-0.262	-0.180	-0.107	-0.0205	0.228
	(0.395)	(0.373)	(0.395)	(0.641)	(0.314)	(0.494)	(0.184)
State-owned	-0.120	-0.0695	-0.120	-0.253	0.0925	**0.567***	**0.376***
	(0.339)	(0.212)	(0.339)	(0.392)	(0.227)	(0.303)	(0.193)
R-squared	0.018	0.002	0.018	0.006	0.001	0.027	0.029

HAC standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Appendix C: Policy events data

DATE	RENEWABLE ENERGY POLICY EVENTS
2014/6/7	国务院办公厅关于印发能源发展战略行动计划（2014-2020）的通知
	(General Office of the State Council) Notice on Issuing the Strategic Action Plan for Energy Development (2014-2020)
2014/5/15	国务院办公厅关于印发 2014-2015 节能减排低碳发展行动方案的通知
	(General Office of the State Council) Notice on Issuing the 2014-2015/Action Plan for energy conservation Emission-reduction and Low-carbon Development
2015/10/29	中共中央关于制定国民经济和社会发展第十三个五年规划的建议
	(Central Committee of Communist Party of China) Suggestion for Formulating the 13th Five-Year Plan of National Economy and Social Development
2015/5/12	关于印发《节能减排补助资金管理暂行办法》的通知
	Notice on issuing the Interim Measures for Management of Energy-conversation Emission-reduction subsidiaries
2015/3/20	国家发展改革委 国家能源局关于改善电力运行调节促进清洁能源多发满发的指导意见
	(National Development Reform Commission, National Energy Administration) Guiding opinion on improving the electrical operation and regulation, promoting the full power generation of the clean energy
2016/12/29	国家能源局 国家海洋局关于印发《海上风电开发建设管理办法》的通知
	(National Energy Administration, State Oceanic Administration) Notice on issuing the Administrative Measures for Offshore Wind Power Development and Construction
2016/12/26	国家发展改革委 国家能源局关于印发能源发展“十三五”规划的通知
	(National Development Reform Commission, National Energy Administration) Notice on issuing the “13th Five-Year” Plan for Energy Development
2016/12/8	《太阳能发展“十三五”规划》的通知
	Notice on the “13th Five-Year” Plan for Solar Energy Development
2016/11/29	水电发展“十三五”规划
	The “13th Five-Year” Plan for Water Power Development
2016/11/16	国家能源局关于印发《风电发展“十三五”规划》的通知
	(National Energy Administration) Notice on issuing the “13th Five-Year” Plan for Wind Power Development
2016/11/7	电力发展“十三五”规划
	The “13th Five-Year” Plan for Wind Power Development
2016/10/28	国家能源局关于印发《生物质能发展“十三五”规划》的通知
	(National Energy Administration) Notice on issuing the “13th Five-Year” Plan for the Biomass Energy Development
2016/10/17	下达第一批光伏扶贫项目的通知
	Notice on issuing the first group of PV poverty alleviation projects
2016/7/22	《可再生能源调峰机组优先发电试行办法》
	Trial Measures for Preferential Power Generation of the Renewable Energy Cycling Unit
2016/7/11	关于做好 2016 年度煤炭消费减量替代有关工作的通知
	Notice on performing the work relevant to reduction and substitution of coal consumption in 2016
2016/6/3	国家能源局关于下达 2016 光伏发电建设实施方案的通知
	(National Energy Administration) Notice on issuing the implementation schemes for 2016/ PV power generation construction
2016/5/27	国家发展改革委 国家能源局关于做好风电、光伏发电全额保障性收购管理工作的通知
	(National Development Reform Commission, National Energy Administration) Notice on performing the full indemnificatory acquisition management of the wind power and PV power generation
2016/4/5	关于实施光伏发电扶贫工作的意见
	Some opinions on implementing the PV power generation poverty - relief work

2016/3/24	国家发展改革委关于印发《可再生能源发电全额保障性收购管理办法》的通知 (National Development Reform Commission) Notice on issuing the Full Indemnificatory Acquisition Management Measures for the Renewable Energy Power Generation
2016/3/22	国家能源局关于印发 2016/能源工作指导意见的通知 (National Energy Administration) Notice on issuing the 2016/ guiding opinions on energy work
2016/3/17	国家能源局关于下达 2016 全国风电开发建设方案的通知 (National Energy Administration) Notice on issuing the 2016 national schemes for wind power development construction
2016/3/17	中华人民共和国国民经济和社会发展第十三个五年规划纲要 The 13th Five-Year Plan outline for the national economy and social development of the People's Republic of China
2016/3/11	国家能源局关于做好 2016 度风电消纳工作有关要求的通知 (National Energy Administration) Notice on performing the requirements relevant to wind power assimilating in 2016
2016/2/29	国家能源局关于建立可再生能源开发利用目标引导制度的指导意见 (National Energy Administration) Guiding opinions on establishing the goal-directed system of renewable energy development and utilization
2016/2/5	国家能源局关于做好"三北"地区可再生能源消纳工作的通知 (National Energy Administration) Notice on performing the renewable energy assimilating in the "three northern areas of China"
2017/5/27	国家能源局关于加快推进分散式接入风电项目建设有关要求的通知 (National Energy Administration) Notice on promoting the requirements relevant to the distributed-access wind power project construction
06/06/2017	国家能源局综合司关于开展北方地区可再生能源清洁取暖 Cleaning and warming of renewable energy developed in the Northern areas by the National Energy Administration, Comprehensive Department
25/04/2017	国家发改委、国家能源局印发《能源生产和消费革命战略（2016-2030） Energy Production and Consumption Revolution Strategies (2016-2030) issued by the National Development Reform Commission, National Energy Administration
14/03/2017	暂缓受理温室气体自愿减排交易备案申请 Filing application for suspended accepting of greenhouse gas voluntary emission reduction trading
21/02/2017	国家发展改革委 住房城乡建设部关于印发气候适应型城市建设试点工作的通知 (National Development Reform Commission, Ministry of Housing and Urban-Rural Development Notice on issuing the pilot work of climate-adapted city construction
	Guangdong ETS Policy Events: Surrender Date & CCER
20/06/2017	2016 年度配额履约截止日期 Allowance surrender for the year of 2016
14/04/2017	广东省发展改革委关于碳普惠制核证减排量管理的暂行办法》 (Guangdong Development Reform Commission) Interim Measures for the Management of Carbon GSP and Certification Emission Reduction
09/01/2017	广东省发展改革委关于印发《广东省控排企业使用国家核证自愿减排量（CCER）抵消 2016 年度实际碳排放工作指引》的通知 (Guangdong Development Reform Commission) Notice on issuing the Working Instruction for the Emission-control Enterprises in Guangdong Province Adopting the National Certification for Voluntary Emission Reduction and Set-off in 2016
20/06/2016	2015 年度配额履约截止日期 Allowance surrender for the year of 2015
23/06/2015	2014 年度配额履约截止日期 Allowance surrender for the year of 2014
15/07/2014	2013 年度配额履约截止日期 Allowance surrender for the year of 2013

	Shenzhen ETS Policy Events: Surrender Date & CCER
30/06/2017	Allowance surrender for the year of 2016
12/06/2017	深圳市发展和改革委员会关于按时足额提交配额完成 2016 年度碳排放履约义务有关事宜的公告
	(Shenzhen Development Reform Commission) Announcement about submitting the quota on time in full and completing the matters relevant to the obligations of 2016 Carbon emission fulfilment
30/06/2016	2015 年度配额履约截止日期
	Allowance surrender for the year of 2015
30/06/2015	2014 年度配额履约截止日期
	Allowance surrender for the year of 2014
10/06/2015	深圳排放权交易所核证自愿减排量(CCER)项目挂牌上市细则（暂行）
	Detailed rules and regulations for public listing of voluntary emission reduction projects certified by Shenzhen emission right exchange (Interim)
08/06/2015	深圳市发展改革委关于印发《深圳市碳排放权交易市场抵消信用管理规定（暂行）》的通知
	(Shenzhen Development Reform Commission) Notice on issuing the Administrative Regulations for Set-off Credit of Shenzhen Carbon Emission Right Trading Market (Interim)
30/06/2014	Allowance surrender for the year of 2013
	Beijing ETS Policy Events: Surrender Date & CCER
15/06/2016	2015 年度配额履约截止日期
	Allowance surrender for the year of 2015
15/06/2015	2014 年度配额履约截止日期
	Allowance surrender for the year of 2014
01/09/2014	关于印发北京市碳排放权抵消管理办法（试行）的通知
	Notice on issuing the management methods for CCER in Beijing (Trail)
15/06/2014	2013 年度配额履约截止日期
	Surrender Data for the year of 2013
	Chongqing ETS Regulatory Events: Surrender Date & CCER
10/11/2016	关于下达 2015 年度审定碳排放量和碳排放配额（调整）的通知
	Notice on issuing the audited Carbon emission and Carbon Allowance Quota (adjustment) in 2015
18/11/2016	2015 年度履约截止
	Allowance surrender for the year of 2015
23/06/2015	2013-2014 年度履约截止
	Allowance surrender for the year of from 2013 to 2014
25/05/2015	关于抓紧做好 2013 - 2014 年 度碳排放配额清缴工作的通知
	Notice on performing the clearance of Carbon emission quota from 2013 to 2014
15/02/2015	关于开展 2014 年度碳排放报告工作的通知
	Notice on developing the reports on the Carbon emission in 2014
12/02/2015	关于下达重庆市 2014 年度碳排放配额的通知
	Notice on issuing the Carbon emission quota of Chongqing in 2014
11/12/2014	关于下达 2013 年度审定碳排放量和碳排放配额（调整）的通知
	Notice on issuing the audited Carbon emission and Carbon emission quota (adjustment) in 2013
	Shanghai ETS Regulatory Events: Surrender Date & CCER
30/06/2017	2016 年度配额履约截止日期
	Allowance surrender for the year of 2016
30/06/2016	2015 年度配额履约截止日期
	Allowance surrender for the year of 2015
30/06/2015	2014 年度配额履约截止日期
	Allowance surrender for the year of 2014

01/06/2015	关于本市碳交易试点企业使用国家核证自愿减排量进行 2014 年度履约清缴有关工作的通知
	Notice on the Carbon trading pilot enterprises in this city using the national CCER for voluntary emission reduction and performing the work relevant to the fulfilment clearance in 2014
21/04/2015	关于本市碳排放交易试点期间进一步规范使用抵消机制有关规定的通知
	Notice on further regulating use of the rules relevant to the carbon offsets mechanism (CCER)
08/01/2015	关于本市碳排放交易试点期间有关抵消机制使用规定的通知
	Notice on rules of use for the relevant carbon offsets mechanism (CCER)
30/06/2014	2014 年度配额履约截止日期
	Allowance surrender for the year of 2013
	Tianjin ETS Regulatory Events: Surrender Date & CCER
30/06/2017	2016 年度配额履约截止日期
	Allowance surrender for the year of 2016
30/06/2016	2015 年度配额履约截止日期
	Allowance surrender for the year of 2015
10/07/2015	2014 年度配额履约截止日期
	Allowance surrender for the year of 2014
25/07/2014	2013 年度配额履约截止日期
	Allowance surrender for the year of 2013
	Hubei ETS Regulatory Events: Surrender Date & CCER
07/06/2017	省发展改革委关于 2017 年湖北省碳排放权抵消机制有关事项的通知
	(Provincial Development Reform Commission) Notice on CCER Mechanism of Carbon Emission in Hubei Province in 2017
25/07/2016	碳排放履约截止日期
	Surrender date for the carbon emission for the year of 2015
10/07/2015	碳排放履约截止日期
	Allowance Surrender for the year of 2014
17/04/2015	关于 2015 年湖北省碳排放权 抵消机制有关事项的通知
	Notice on Matters Relevant to CCER Mechanism in Hubei Province in 2015

Appendix D: Cross-correlation of all variables[11]

	CQ	BJ	SH	GD	SZ	TJ	HB	ew_bj	ew_hb	ew_cq	ew_tj	ew_sz	ew_gd	ew_sh	mon_re_cn	S_300	oil_ara	coal	gas	s_energy	s_material	s_consum	s_50
Panel A: Carbon Prices																							
CQ	1.000																						
BJ	0.030	1.000																					
SH	0.007	0.055	1.000																				
GD	0.126	-0.020	0.093	1.000																			
SZ	0.130	0.004	0.082	-0.004	1.000																		
TJ	-0.060	-0.015	-0.110	-0.089	-0.050	1.000																	
HB	0.006	-0.117	0.008	-0.084	0.074	0.250	1.000																
Panel B: General Model																							
ew_bj	-	-0.048	-	-	-	-	-	1.000															
ew_hb	-	-	-	-	-	-	0.034	0.276	1.000														
ew_cq	0.171	-	-	-	-	-	-	0.177	0.362	1.000													
ew_tj		-	-	-	-	-0.088	-	0.728	0.178	0.140	1.000												
ew_sz		-	-	-	0.144	-	-	0.111	0.063	0.158	0.087	1.000											
ew_gd		-	-	0.068	-	-	-	0.128	0.167	0.125	0.087	**0.822**	1.000										
ew_sh		-	0.105	-	-	-	-	0.136	0.293	0.152	0.159	0.350	0.432	1.000									
re	0.145	-0.032	0.089	-0.035	-0.031	0.180	0.061	-0.221	-0.039	0.015	-0.213	-0.167	-0.281	-0.138	1.000								
s_300	0.059	-0.025	-0.139	0.020	0.035	-0.099	0.023	-0.039	-0.054	-0.047	0.060	0.090	0.075	-0.173	-0.111	1.000							
oil_ara	0.018	0.199	0.129	0.048	0.014	-0.138	-0.099	0.046	0.133	0.020	0.043	0.075	0.163	0.180	-0.002	0.048	1.000						
coal	0.066	-0.002	-0.059	-0.003	-0.059	0.044	-0.013	-0.167	-0.026	-0.057	-0.094	-0.070	-0.049	-0.073	0.295	-0.055	-0.118	1.000					
gas	0.050	0.066	0.091	0.309	-0.014	-0.023	-0.016	0.070	0.109	0.094	0.024	0.085	0.092	0.053	0.161	-0.064	0.060	0.125	1.000				

[11] Panel A: CQ, BJ, SH stand for Chongqing, Beijing, Shanghai ETS pilots, respectively. GD, SZ, TJ, HB refer to ETS pilot in Guangdong, Shenzhen, Tianjin and Hubei. Carbon prices refer to weekly returns of each pilot.
Panel B: ew_location refers to the extreme weather level calculated at a weekly frequency for each pilot. re stands for the aggregated national production level of renewable energy. S_300 is weekly average closing prices from CSI 300 index which incorporates stocks in Shenzhen and Shanghai exchanges. Oil_ara represents weekly average spot prices of the Arabian Dubai Fateh Crude Oil. Coal denotes weekly average prices of China Qinhuangdao 5500 kcal/kg. Gas refers to the weekly average prices of China commodities Liquid Nature Gas (LNG).

Appendix E: Equilibriums of CGE model

In the CGE model, households are modelled as representative agents that are assumed to have Cobb-Douglas preferences, while industry sectors are modelled as representative agents that are assumed to have Cobb-Douglas production technologies. Specifically, the equilibrium prices will be estimated by allowing substitution within goods and primary factors, such as capital and labour. Substitution allows an assessment of the indirect effect of policies across different economic sectors.

- ***Household Behaviour: maximize utilities***

Therefore, households maximize utility by choosing the levels of consumption of the N commodities in the economy, subject to the constraints of income$m$, ruling commodity prices p and saving s:

$$max_{c_i} U(c_1, \dots, c_n),$$

$$\text{Subject to } m = \sum_{i=1}^{N} p_i \, (c_i + s_i)$$

Thus, the demand function for the consumption of the i^{th} commodity is:

$$c_i = \alpha_i \frac{(m - \sum_{i=1}^{N} p_i s_i)}{p_i}$$

Where the parameters α_i are the share of each good in expenditure on consumption, in which $\alpha_1 + \cdots \alpha_n = 1$

- ***Industry Behaviour: maximize profits***

Producers maximize profits π by choosing the level of intermediate inputs x and primary factors v to produce output, subject to the constraint of its production technology$\emptyset$:

$$max_{x_{ij}, v_{ij}} \pi_j = p_j y_j - \sum_{i=1}^{N} p_i x_{ij} - \sum_{f=1}^{F} w_f v_{fj},$$

$$\text{Subject to } y_j = \emptyset_j (X_{1j,}, \dots, X_{Nj}; v_{1j}, \dots, v_{Fj})$$

Therefore, the demand for intermediate inputs of commodities is:

$$x_{ij} = \beta_{ij} \frac{p_j y_j}{p_j}$$

And the demand for primary factor inputs is:

$$v_{fj} = \gamma_{fj} \frac{p_j y_j}{w_f}$$

Where parameters β_{ij} and $\gamma_{fj}$are shares of each input in the cost of production, in which $\beta_{1j} + \cdots \beta_{Nj} = 1$ and $\gamma_{1j} + \cdots \gamma_{Nj} = 1$

- ***General Equilibrium***

Market clearance, zero profit and income balance are the three conditions for general equilibrium. Therefore, the quantity of each commodity produced must equal the sum of the quantities of that commodity demanded by j producers in the economy as an intermediate input, and by households as an input to consumption and saving activities:

$$\mathrm{y}_i = \sum_{J=1}^{N} x_{ij} + c_i + s_i$$

In addition, the quantities of primary factor f must equal to the endowment of that factor:

$$\mathrm{V}_f = \sum_{j=1}^{N} v_{fj}$$

Meanwhile, the value of output must equal the value of input of intermediate and primary factors:

$$\mathrm{p}_j y_j = \sum_{i=1}^{N} p_i x_{ij} - \sum_{f=1}^{F} w_f v_{fj}$$

At last, the income must equal the payment for the use of primary factors:

$$m = \sum_{f=1}^{F} w_f V_f$$

Let's substituting the equations of demand functions for consumption, intermediate input and primary factors input into above equations, we can obtain the divergence Δ_i^C between commodity supply and demand, Δ_f^F between primary factor supply and demand, Δ_j^π excess profit and Δ^mexcess income.

$$\Delta_i^C = \sum_{j=1}^{N} \beta_{ij} \, p_j y_j + \alpha_i \left(\sum_{f=1}^{F} w_f V_f - \sum_{j=1}^{N} p_j s_j \right) + p_i s_i - p_i y_i$$

$$\Delta_f^F = \sum_{j=1}^{N} \gamma_{fj} \frac{p_j y_j}{w_f} - V_f$$

$$\Delta_j^\pi = p_j - Aj \prod_{i=1}^{N} (p_i/\beta_{ij})^{\beta_{ij}} \prod_{f=1}^{F} (w_f/\gamma_{fj})^{\gamma_{fj}}$$

$$\Delta^m = \sum_{f=1}^{F} w_f V_f - m$$

Hence, the general equilibrium can be generated by jointly minimizing the above equations.

Table details of variables denotations

Variables	*Denotation*
$\boldsymbol{c}$	Consumption of commodity
$\boldsymbol{m}$	Households' income
$\boldsymbol{p}$	Commodity price
$\boldsymbol{s}$	Households' saving
$\boldsymbol{v}$	Households' primary factors
$\boldsymbol{w}$	Households' wages for factors
$\boldsymbol{x}$	Intermediate inputs
$\boldsymbol{y}$	Outputs of industry
$\boldsymbol{U}$	Households' utility
$\boldsymbol{\alpha}$	Share of each good in expenditure on consumption
$\boldsymbol{\beta}$	Share of each intermediate inputs in the cost of production
$\boldsymbol{\gamma}$	Share of each factor inputs in the cost of production
$\boldsymbol{\pi}$	Enterprises' profit
$\emptyset$	Constraints of production technology