Integrated assessment of China's provincial low-carbon economy development towards 2030: Jiangxi Province as an example

中国の省を対象とした 2030 年に向けた低炭素経済開発の統合評価：江西省を例に

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SYNOPSIS

This study assesses China's low-carbon economy development towards 2030 with Jiangxi Province as an example. For this purpose a two-region computable general equilibrium (CGE) model is constructed for China. Scenario analysis shows that with the economy growing by around 6-7 times over 2005-2030 periods, the primary energy consumption would increase by 2.5 times in Jiangxi Province and 2.7 times in the rest of China in the baseline scenario, accordingly carbon emissions would increase by 2.4-2.6 times in both regions. GDP loss in the carbon mitigation scenarios depends on many factors such as carbon constraints, burden share schemes and low-carbon countermeasures. The more the reduction is, the more GDP loss there would be. It's beneficial for an under-developed region like Jiangxi Province to adopt per capita emission based burden share scheme. Moreover, in the absence of additional countermeasures carbon price resulted from deep carbon reduction would be unacceptably high at around over 850 US dollar/ton and the corresponding GDP loss would be 25%; however, with various low-carbon countermeasures, carbon price and GDP loss would be brought down significantly to about 380 US dollar/ton and 12%, respectively. In addition, remarkable co-benefits associated with low-carbon economy are identified in terms of improvement in air quality and energy security.

CHAPTER 1 INTRODUCTION

About twenty years ago scientists found with confidence that the atmospheric concentrations of the greenhouse gases have grown significantly since pre-industrial times. Although the bulk of accumulative greenhouse gases have been emitted from the developed countries, emissions from developing countries will take up a rising share in the future. In order to effectively control global emissions, it is unavoidable to involve the developing countries to take a low-carbon development pathway, especially for China.

Over the past few decades, China has become a major economy. At the same time, it has become the top energy consumer and emitter of greenhouse gases in the world. This trend is likely to continue in the future, making it clear that any meaningful climate stabilization will not be possible without China's participation. In fact, in the face of environmental concerns, energy security and international pressures, the Chinese government has made huge efforts to formulate energy-saving and climate policies in the past years. At present the Chinese government is making endeavor to promote low-carbon economy development at provincial level. An integrated assessment framework is therefore required by the decision makers to assess the low-carbon countermeasures.

In such contexts, the objective of this study is to assess China's provincial low-carbon economy development towards 2030 in an integrated way. There are several purposes corresponding to the objective: 1) to review the historical evolution of economy, energy and emissions in China and the target province; 2) to develop a model framework that includes the target province and the rest of China to assess low-carbon policies in an integrated and quantitative manner; 3) to establish plausible scenarios of future economy, energy and emissions for China and the target province; 4) to assess the effectiveness and economic impacts of potential low-carbon policies by using the model and scenarios; 5) to provide policy recommendations for promoting low carbon economy development.

Jiangxi Province is selected as the study area and a two-region dynamic hybrid CGE model is constructed. The model is used to address the following questions for China and Jiangxi Province: first, if China continues to develop in a conventional way, how will the future scenario of energy demand and emissions be? Second, how a low-carbon pathway could be achieved and what are the key technologies and countermeasures? Third, what is the economic cost of low-carbon economy development without additional low-carbon countermeasures? Fourth, how the cost could be lowered by introducing different kinds of low-carbon countermeasures? Fifth, what are the benefits and co-benefits of developing low-carbon economy?

CHAPTER 2 LITERATURE REVIEW

2.1 Concept of low-carbon economy

A low-carbon society or economy should "take actions that are compatible with the principles of sustainable development ensuring that the development needs of all groups within society are met; make an equitable contribution towards the global effort to stabilize the atmospheric concentration of CO_2 and other greenhouse gases at a level that will avoid dangerous climate change through deep cuts in global emissions; demonstrate a high level of energy efficiency and use low-carbon energy sources and production technologies; and adopt patterns of consumption and behavior that are consistent with low levels of greenhouse gas emissions".

Earlier studies in developed and developing countries reveal that along with the economic growth, energy demand and CO_2 emissions would continue to increase in the Business as Usual (BaU) scenario; by contrast, by introducing various mitigation policies and technologies emissions could be reduced by large scale. However, these studies have critical drawbacks which need to be improved. Firstly, most of the country-level studies employ bottom-up or top-down models to explore future emission scenarios. The parameters used in these models usually represent the average features of a whole country and lack sub-country level details, which may be greatly different from the national average features, especially for those countries with huge regional diversity. Secondly, most of the local level studies employ bottom-up type models, in which the economic impacts of carbon reduction could not be assessed and they usually ignore the interaction between the target region and the rest of the country or world. Therefore, in order to better understand low-carbon economy and contribute to the existing studies, more attention needs to be paid to local regions, and more sophisticated approaches, which are capable of assessing the economic impacts of carbon reduction, examining various low-carbon options as well as taking into account the interaction between the target region and the rest of the country or world, is needed.

2.2 Low-carbon countermeasures

Various low-carbon technologies and countermeasures are available for cutting GHGs emissions in different sectors (Table 1), including improving energy efficiency, more use of non-fossil energy, land use management in agriculture and forest sectors, and waste management. Also changes in lifestyle and behavior patterns can contribute to climate change mitigation across all sectors. In this study, the following low-carbon countermeasures will be focused: change in household consumption pattern from materialized style to dematerialized pattern, employment of carbon capture and storage (CCS) technology, use of non-fossil energy and domestic emissions trading among provinces.

2.3 CGE Model and its application in climate policy analysis

The costs of policies to mitigate anthropogenic emissions of GHGs are often assessed with computational simulations, which fall typically into two categories: bottom-up models which simulate the interactions among the technologies that make up the economy's energy system, and top-down models which simulate the market interactions among energy consumers, energy supply sectors and other industries in the economy. CGE model, which is employed by this study, belongs to the top-down type model. CGE model stems from the general equilibrium theory of Walras implying that supply and demand are equalized across all of the interconnected markets in the economy. It combines the abstract general equilibrium structure formalized by Arrow and Debreu with realistic economic data to solve numerically for the levels of supply, demand and price that support equilibrium across a specified set of markets. They are widely used in analyzing impacts of policies such as taxes, subsidies, quotas or transfer instruments. Examples of their use can be found in areas such as fiscal reform and development planning, international trade. CGE model is also a popular tool for analysis of long-term economic implications of climate change policy.

Table 1: Key Mitigation Technologies and Practices by Sector.

Sector	Key mitigation technologies and practices
Energy supply	Improved supply and distribution efficiency; fuel switching from coal to gas; nuclear power; renewable heat and power; combined heat and power; early applications of Carbon Capture and Storage.
Transport	More fuel efficient vehicles; hybrid vehicles; cleaner diesel vehicles; biofuels; modal shifts from road transport to rail and public transport systems; non-motorised transport; land-use and transport planning.
Buildings	Efficient lighting and daylighting ; more efficient electrical appliances and heating and cooling devices; improved cook stoves, improved insulation; passive and active solar design for heating and cooling; alternative refrigeration fluids, recovery and recycle of fluorinated gases.
Industry	More efficient end-use electrical equipment; heat and power recovery; material recycling and substitution; and a wide array of process-specific technologies.
Agriculture	Improved crop and grazing land management to increase soil carbon storage; restoration of cultivated peaty soils and degraded lands.
Forestry	Afforestation; reforestation; forest management; reduced deforestation; etc.
Waste management	Landfill methane recovery; waste incineration with energy recovery; composting of organic waste; controlled waste water treatment; recycling and waste minimization.

Source: Table SPM.3 in p10 of IPCC (2007). Climate Change 2007: Mitigation of Climate Change.

CHAPTER 3 A TWO-REGION CGE MODEL FOR JIANGXI PROVINCE

In this study, scenario analysis is conducted using a two-region recursive dynamic CGE model for Jiangxi Province and the Rest of China, which interact with each other through domestic trade. The model includes a production module, final demand modules by government and household, a domestic transaction module and an international transaction module (Figure 1). It is a hybrid model in which various key technologies are formulated in the energy intensive sectors, such as non-fossil electricity generation, alternative fuel production (bio-liquid and bio-gas), CCS technology. This model selects 2005 as the base year and is solved at one-year time step towards 2030 by GAMS/MPSGE.

3.1 Production

There are 41 sectors in this model, seven of which are energy sectors. They are aggregated or disaggregated from the more detailed input-output table in a way that focuses on agriculture and industry sectors while simplifies service sectors. Each producer maximizes profit subject to the production technology. Activity output of each sector follows a nested constant elasticity of substitution (CES) production function. Each sector has two types of production function; one uses the existing capital stock, and another uses new investment. The difference

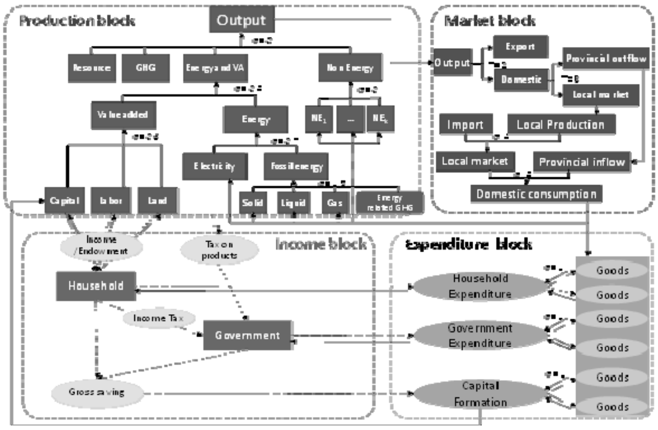

Figure 1: Overall Structure of 2-region CGE Model Used in this Study

between these two subsectors is the efficiency and mobility of capital among the sectors. Inputs are categorized into material commodities, energy commodities, land, labor, capital and resource. The producer maximizes its profit by choosing its output level and inputs use, depending on their relative prices subject to its technology.

3.2 Household consumption

Household and government are final consumers. The representative household endows primary factors to the firms and receives income from the rental of primary factors (labor and capital), rents from fixed factors (land and natural resources) and lump-sum transfer from the government (e.g. carbon tax revenue of government). The income is then used for either investment or final consumption. The objective of household consumption is to maximize utility by choosing levels of goods consumption following Cobb-Douglas preferences, subject to commodity prices and budget constraint.

3.3 Government

The government is assumed to collect taxes, including direct tax on household income, ad valorem production tax (indirect tax) on gross domestic output, ad valorem import tariff on imports and carbon tax. Based on a Cobb-Douglas demand function, the government spends its revenue on public services which are provided to the whole society and on the goods and services which are provided to the households free of charge or at low prices. The model assumes that the revenue from carbon tax is recycled to the representative agent as a lump-sum transfer.

3.4 Investment and savings

Investment is an important part of final demand. In the CGE model a virtual agent is assumed for investment which receives all the savings from the household, government and the external sector to purchase goods for domestic investment. The virtual investment agent is assumed to maximize the utility based on a Cobb-Douglas demand function subject to its (virtual) income constraint.

3.5 International transaction

The model is an open economy model that includes interaction of commodity trade with the rest of the world. Like most other country CGE models, this model assumes the small open economy, meaning that an economy is small enough for its policies not to alter world prices or incomes. The implicit implication of small-country assumption is that export and import prices are exogenously given for the economy.

3.6 Inter-provincial trade

An important feature of this model is that it is a two-region country model in which inter-provincial trade is treated. Similar to the case of international trade, Armington assumption is adopted to distinguish between locally produced commodity and commodity produced by firms in other provinces, and CES and CET functions are employed to describe commodity inflow from and outflow to all provinces, respectively.

3.7 Dynamic process

As a recursive dynamic CGE model in which the agents' behavior is based on adaptive expectations rather than forward-looking expectations, the model is solved one period at a time, and the selected parameters, including capital stock, labor force, land, energy efficiency, total factor productivity, labor productivity, land productivity and extraction cost of fossil fuels, are updated based on the modeling of inter-temporal behavior and results from previous periods.

3.8 Data

The data required for the base year include input-output table, energy balance table, GHGs emission factors, energy prices of coal, oil and gas, and cost of renewable energy technology.

CHAPTER 4 SCENARIO TOWARDS 2030

There are two sets of scenarios, including the reference scenario and the mitigation scenario (Table 2). All scenarios share the common assumptions in population, investment, Auto energy efficiency improvement (AEEI), total factor productivity (TFP), non-fossil fuel use etc.. GDP of Jiangxi Province and the Rest of China will continue to grow rapidly in the following decades, but the growth rate will gradually slowdown from around 8.0% before 2020 to around 6.7% after 2020. China's population follows the United Nations' 2008 medium projection, and the growth rates are assumed to be the same for Jiangxi Province and the Rest of China. An AEEI is assumed separately for liquid, solid and gas fuels . Non-fossil fuel supply potential, including nuclear power, hydro power, solar power, wind power and biomass, follows the assumption in the report by China's domestic researchers. I also assume the economy will in the future decouple from energy-intensive products such as cement, iron and steel, chemistry products and paper, reflecting the dematerialization trend. In addition, due to resource depletion

Table 2: Future Scenarios in this Study

Nr.	Scenario	Economic gap	Non-fossil energy	Consumption pattern	CCS	Emission trading	CO_2 emission constraint		Concern
1	RS_GAP_HC	Bigger	conventional scale	High carbon	off	off	off	No constraint	
2	RS_GAP_LC	Bigger	conventional scale	Low carbon	off	off	off	No constraint	
3	RS_BAL_HC	Smaller	conventional scale	High carbon	off	off	off	No constraint	
4	RS_BAL_LC	Smaller	conventional scale	Low carbon	off	off	off	No constraint	Consumption pattern
5	CM_CAP1	Bigger	2005 level	High carbon	off	off	on	Level1: intensity target	
6	CM_CAP2	Bigger	2005 level	High carbon	off	off	on	Level2: mild reduction	
7	CM_CAP3	Bigger	2005 level	High carbon	off	off	on	Level3: most stringent	
8	CM_CAP3_byGDP	Bigger	2005 level	High carbon	off	off	on	Level3, GDP intensity convergence	Burden share
9	CM_CAP3_byPOP	Bigger	2005 level	High carbon	off	off	on	Level3, Per capita intensity convergence	Burden share
10	CM_CAP3_HC	Bigger	2005 level	High carbon	off	off	on	Level3, GDP intensity convergence	
11	CM_CAP3_HC_RE	Bigger	Large scale develop	High carbon	off	off	on	Level3, GDP intensity convergence	Renewable energy
12	CM_CAP3_LC_RE	Bigger	Large scale develop	Low carbon	off	off	on	Level3, GDP intensity convergence	Consumption pattern
13	CM_CAP3_LC_CCS	Bigger	Large scale develop	Low carbon	on	off	on	Level3, GDP intensity convergence	CCS technology
14	CM_CAP3_LC_ET	Bigger	Large scale develop	Low carbon	on	on	on	Level3, GDP intensity convergence	Emission trading

the extraction cost of coal, crude oil and natural gas will gradually increase.

4.1 Reference scenario

Two dimensions are considered for the reference scenarios without carbon emission constraint; the first one is regional economic gap between Jiangxi Province and the rest of China: either the gap will become bigger (denoted as GAP in the scenario name) or smaller (denoted as BAL) in future. Bigger gap implies that Jiangxi's GDP share to the whole China will decrease in future as compared with 2005's level. Alternatively, the economic gap Jiangxi Province and the rest of China would become smaller due to more investment and faster technology improvement in Jiangxi. The second dimension is household consumption pattern. We assume two different but possible directions of China's household expenditure patterns. In the High-carbon (denoted as HC) direction, people tend to follow the traditional materialized lifestyles, spending less on food and housing and more on clothing, household facilities and services, transport and communications, and they have better health care and education opportunities. On the other hand, in the Low-carbon (denoted as LC) direction, a dematerialized lifestyle is preferred, in which less is spent on clothing, household facilities and transport and more on service commodities.

4.2 Mitigation scenario

For the mitigation scenarios three dimensions are considered, including carbon constraint, burden sharing scheme among provinces and additional low-carbon countermeasures.

The first one is how severe the carbon constraints are, in which three levels of carbon constraints are considered. Level 1 assumes China would continue to reduce its carbon intensity in a Copenhagen Commitment way and commits to reduce carbon intensity in terms of GDP by 45% in 2020 and following this speed by 62% in 2030 compared with 2005 level, yet the absolute emissions will keep increasing by 2030. Level 2 assumes China's CO_2 emission peaks in 2020 and then starts to fall, which reflects one of the most optimistic visions by Chinese domestic researchers. Level 3 is the most severe constraint where China's emissions in 2030 are reduced by 9.5% compared with 2005's level, which is in accordance with the global efforts to reduce carbon emissions in 2050 to half of 1990's level and the amount of emission allowance is allocated to China based on the assumption that each country's per capita CO_2 emissions converge in 2050.

The second dimension is burden sharing scheme among provinces. Two schemes are adopted, the first one assumes that per capita emissions of Jiangxi Province and the rest of China converge in 2030, while the second one assumes that carbon intensity in terms of GDP in both regions will reduce at the same pace.

The third dimension considers different low-carbon countermeasures such as non-fossil energy development, carbon capture and storage (CCS) technology, and inter-provincial emissions trading. In order to identify the effectiveness and impact of each countermeasure, they are added to the scenario one after another. Note that the penetration speeds of CCS technology are limited so as not to exceed a certain level.

CHAPTER 5 SIMULATION RESULTS OF LOW-CARBON ECONOMY DEVELOPMENT

5.1 Economy, energy and carbon emissions in the reference scenarios up to 2030

As assumed, over the next 25 years, GDP of Jiangxi province and the rest of China will grow by around 6-7 times (Figure 5 1). For Jiangxi Province, due to higher rate of investment and faster technology improvement, GDP growth rates in the "balanced" development scenarios are around 4.4% higher than the "gap" scenarios. On the other hand, GDP of the rest of China in the four scenarios is almost the same.

It is found that if the household expends more on services and less on clothing, household facilities and transport in the low-carbon consumption scenarios, a huge amount of energy (Figure 2) and CO_2 emissions (Figure 3) could be reduced. In the whole period of 2005-2030, the accumulative saved energy in China appears to be around 12230 mtce, which is about 5.2

times total primary energy supply in 2005, resulting in 36.7 billion tons of accumulative CO_2 reduction, or 5.5 times the 2005 level.

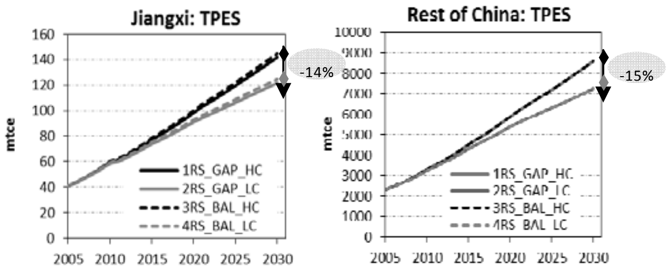

Figure 2: Total Primary Energy Supply (TEPS) (Unit: Million Ton Coal Equivalent)

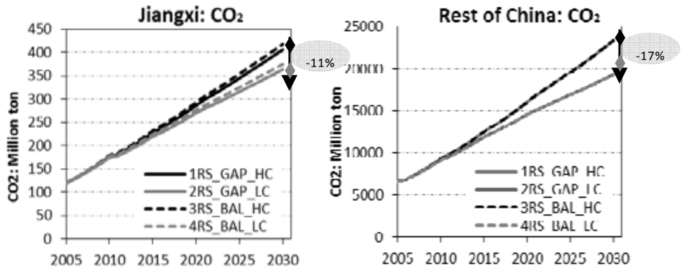

Figure 3: CO_2 Emission Trajectory (Million ton)

5.2 The economic impacts of carbon emissions reduction without low-carbon countermeasures

As the emission allowances become less from CAP1 to CAP3, carbon prices increases, especially after 2020 when absolute reduction is assumed in CAP2 and CAP3. In 2030, highest carbon price would be over 850 US dollars (Figure 4). Usually the economy suffers negative impacts due to the carbon price, and a higher carbon price will cause more losses in GDP. It is found that in CAP1 scenario where China is assumed to make Copenhagen type commitment that its carbon intensity in terms of GDP will reduce, the GDP loss will be relatively small However, if China is obligated to reduce its CO_2 emissions in absolute terms in CAP2 and CAP3's cases, the GDP loss will be remarkably high (Figure 5).

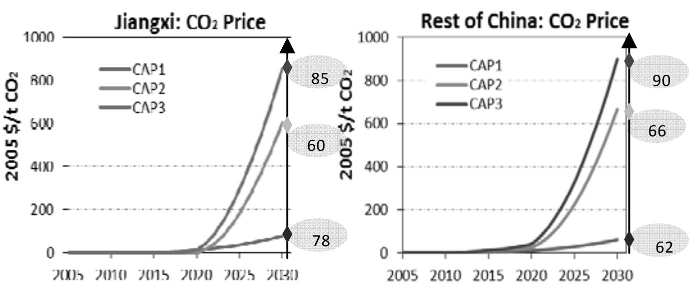

Figure 4: Carbon Prices under Different Levels of Emission Constraints.

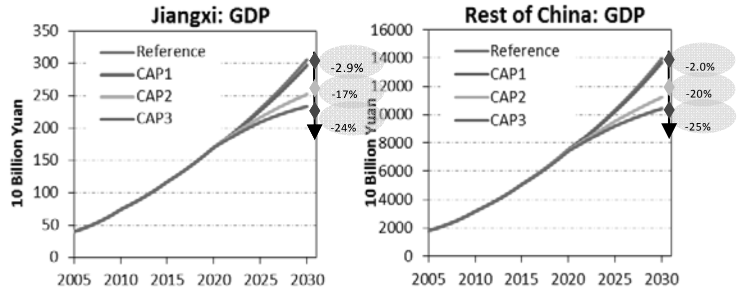

Figure 5: GDP under Different Levels of Emission Constraints.

5.3 The economic impacts of carbon emissions reduction with low-carbon countermeasures

Note that the above cases assume no additional low-carbon countermeasures; therefore, the results may overestimate carbon prices and the corresponding GDP loss. In order to assess in a more realistic context it is necessary to take into account more policy options.

Figure 6 shows how carbon price and GDP would change as the low-carbon countermeasures are added one after another. It is found that if there are no additional measures (the second pillar in each panel), carbon price would be the highest and the corresponding GDP loss would also be the largest. If non-fossil energy is developed in large scale, carbon prices would fall, e.g. in the rest of China, carbon price falls by 22% to 701 dollar per ton CO_2. Next if people favor low-carbon style consumption pattern carbon price would further reduce by around 20-29%. Moreover, with CCS technology being used, carbon prices would fall by another 20-24% in both regions. Lastly, if free domestic carbon emission trading is allowed, carbon price would become equal between Jiangxi Province and the rest of China. As the carbon price becomes lower, the negative impacts on GDP will be smaller. With all the above low-carbon countermeasures combined together, the GDP loss would be 10% for Jiangxi Province and 13% for the rest of China, which are much smaller than that without counter measures as showed in Figure 5.

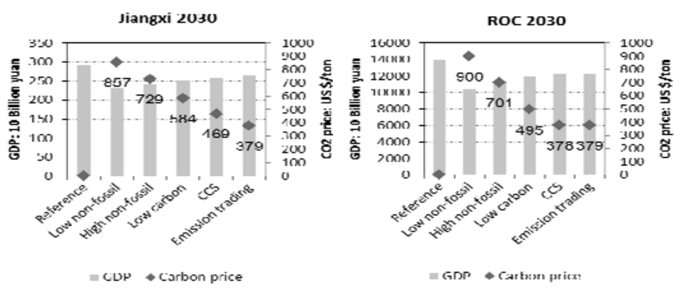

Figure 6: Impacts of Low-carbon Countermeasures on Carbon Price and Economy in 2030 (under CAP3).

5.4 Co-benefits of low-carbon economy

This section assesses the co-benefits of carbon reduction policy can simultaneously in terms of local air quality and energy security.

The results in Table 3 suggest that the emissions of most other air pollutants would also decrease as a result of CO_2 emission reduction. In 2030, compared with the reference scenario, the gases with the most reduction magnitude include carbon monoxide, methane, non-methane volatile organic compounds, nitrogen oxide and sulfur dioxide. Among them, the emission of nitrogen oxide and sulfur dioxide would be even lower than 2005's level. The reduction magnitude of nitrous oxide is mild. Surprisingly, different from all other gases, emissions of ammonia would increase slightly due to higher output level of agriculture product and consequently more use of fertilizer.

Table 3: Co-benefits of air pollutants reduction

	CO	NH3	NMVOC	CH4	N2O	NOX	SO2	CO2
JX								
2005	2.85	0.28	0.27	1.17	0.04	0.41	0.62	120
2030RS	9.81	0.60	1.34	4.25	0.09	1.14	0.98	378
2030CM	5.64	0.60	0.90	3.53	0.09	0.57	0.41	159
Reduction Rate	-42%	-1%	-33%	-17%	-8%	-50%	-59%	-58%
Rest of China								
2005	98.85	10.73	16.89	62.22	1.35	22.01	35.55	6528
2030RS	310.38	19.93	58.52	192.00	2.93	58.97	72.22	20256
2030CM	145.05	20.48	29.76	123.84	2.71	25.21	22.73	6296
Reduction Rate	-53%	3%	-49%	-36%	-8%	-57%	-69%	-69%

As Figure 7 shows, the oil import dependency of Jiangxi Province and the rest of China would continue to increase to 70% and 76% in the reference scenario, respectively, which is much higher than the redline of 65% suggested by the domestic expert. In the carbon mitigation scenario, oil import in 2030 would reduce by 83% and 61% in Jiangxi Province and the rest of China, respectively. It is also found that oil import dependency in 2030 would reduce to 39% and 50% in Jiangxi Province and the rest of China, respectively.

Another co-benefit is that the coal dominated energy supply would be diversified to promote larger shares of natural gas, oil, biomass and nuclear energy in the primary energy supply.

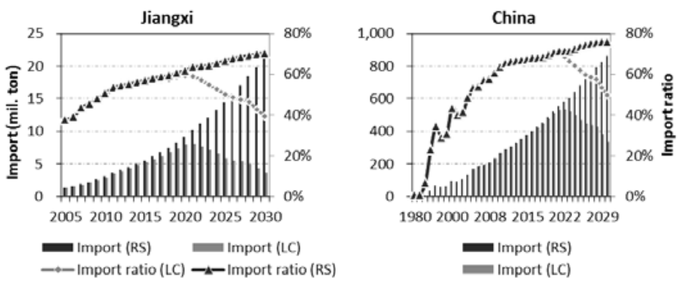

Figure 7: Co-benefit: Oil Import and Import Dependency

CHAPTER 6 DISCUSSION

This chapter mainly compares this study with China's own historical trend and sensitivity analysis.

The future evolution of Kaya factors is showed in the bright areas of Figure 8. In the reference scenario, both China and Jiangxi province will continue to witness steady growth in per capita GDP and carbon emissions, whereas energy intensity will keep falling below the current global and OECD levels and carbon intensity of energy decreases slightly. In the mitigation scenario, all kaya factors are barely influenced compared with the reference scenario before 2020 when carbon intensity target is adopted, and significant differences appear after 2020 when absolute reduction target is pursued.

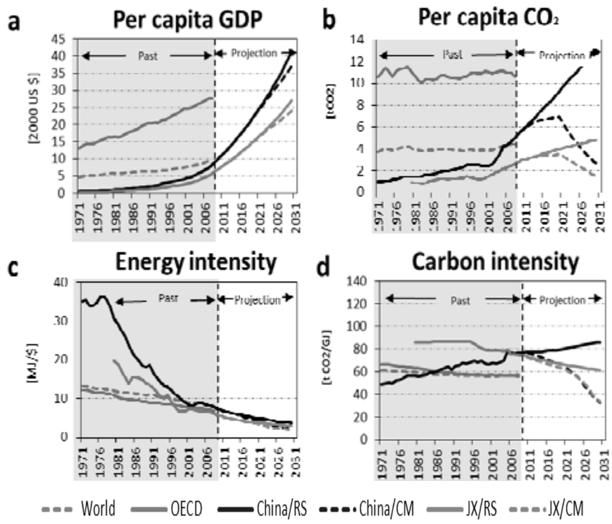

Figure 8: Kaya factors of the economy of world, OECD countries, China and Jiangxi province. (a) GDP per capita; (b) Per capita emissions; (c) Energy intensity and (d) Carbon Intensity.

Kaya-decomposition analysis is conducted to further understand the driving forces of future emissions changes (Figure 9). It reveals that in the reference scenario, emissions change is mainly attributed to changes in per capita GDP and energy intensity, which work in opposite directions. In addition, since the population growth of China and Jiangxi province is projected to slow down, its contribution to emission growth fades gradually towards 2030. On the contrary, the effect of carbon intensity is reversal as compared to historical trend, as the Chinese government declares more ambitious targets to develop renewable energy in large scale in future, carbon intensity of energy will contribute negatively to emissions growth. In the mitigation scenario, inter-provincial emissions trading and CCS technology play an important role.

Sensitivity analysis shows that the model is quite robust to most parameters, with most of the results varying within 2% despite 10% variation of elasticity parameters and depreciation rate. Elasticity of substitution between capital and labor, and elasticity of substitution between value added and energy bundle will affect the results substantially, while other parameters have relatively small influence.

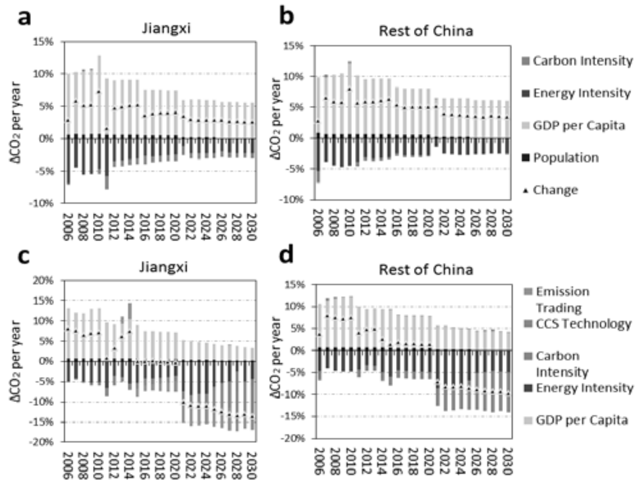

Figure 9: Kaya-decomposition of per year CO_2 emissions change in Jiangxi (a, c) and the rest of China (b, d) in the reference (upper two) and mitigation (lower two) scenarios as a sum of contributions from population (dark blue), GDP per capita (yellow), energy intensity (red), carbon intensity (green), CCS technology (light blue), and emission trading (dark yellow). Black triangles indicate the resulting net change of CO_2 emissions in the time period.

CHAPTER 7 FINDINGS, CONCLUSIONS AND FUTURE WORK

This study develops a hybrid two-region CGE model incorporating sophisticated representation of technologies to investigate China's provincial low-carbon economy development towards 2030 with Jiangxi Province as an example. At first the future energy demand and carbon dioxide emissions of Jiangxi Province and the rest of China are projected in the reference scenarios without climate policy intervention and then the economic impacts of carbon emissions reduction are estimated.

7.1 Major findings

The results show that over the periods of 2005-2030, GDP of Jiangxi province and the rest of China will grow by around 6-7 times. However, without additional investment and technology improvement in Jiangxi Province, the gap between Jiangxi Province and the Rest of China would widen.

Without climate policy intervention the primary energy consumption will increase by around 2.5 times in Jiangxi Province and 2.7 times in the rest of China, accordingly the total CO_2 emissions will increase by 2.4-2.6 times in both regions. If household consumption shifts to low-carbon pattern where less is spent on clothing, household facilities and transport and more on service commodities, a large amount of energy would be saved (around 15% in 2030) and CO_2 emissions would be reduced (around 17% in 2030) for the whole China.

The economic cost of carbon reduction is also examined. It is found that the more stringent carbon constraint is, the higher carbon prices and GDP loss would be. Under the most severe carbon constraint the carbon prices in 2030 in Jiangxi Province and the rest of China will be as high as 857 and 900 US dollars per ton CO2, respectively, and the corresponding GDP losses in 2030 will be around 25% for both regions compared with the reference scenario.

With introduction of various low-carbon countermeasures the above high economic costs of carbon reduction would be reduced. The results reveal that non-fossil energy is one of the major contributors to carbon reduction and thereby reduces economic costs in both regions. Furthermore, inter-provincial emissions trading plays an important role. For example, after 2024, Jiangxi province needs to import large amount of emission credits from the rest of China in order to achieve its reduction target in the most cost-effective way. In addition, CCS technology starts to play a vital role after around 2024. In the period of 2025-2030, CCS technology would induce an emissions reduction of 5-8% per year in Jiangxi province and 5-9% per year in the rest of China. If all these low-carbon countermeasures are adequately implemented, carbon price would fall by over half to 379 US dollars, and the GDP losses will be around 10% for Jiangxi Province and 13% for the rest of China.

The study finds remarkable co-benefits brought about by carbon reduction in terms of improvement in air quality and energy security. The emissions of most other air pollutants would decrease as a result of CO_2 emission reduction. In addition, oil import dependency of China in 2030 will drop from 76% to 50%, and the primary energy supply system would be diversified towards lower use of coal and higher use of natural gas, biomass and nuclear fuels, hydro power, wind and solar energy.

This study also tests the plausibility of the results and robustness of the model in various ways such as comparing the projected and historical trends of Kaya factors and sensitivity analysis. It appears that the projected trends in Jiangxi Province and China are consistent with historical trends, implying this study's projection has relatively sound empirical baking. By sensitivity analysis it is found that the model is relatively sensitive to international prices, elasticity of substitution between capital and labor, and elasticity of substitution between value added and energy bundle, whereas other parameters have relatively small influences. Overall the model is quite robust to most parameters, with most of the results varying within 2% despite 10% variation of tested parameters.

7.2 Conclusions

The methodology developed by this study proves to be capable of addressing a lot of questions associated with low-carbon economy development in a fast developing country like China.

First, it shows that although the bulk of accumulative greenhouse gases have been emitted from the developed countries, emissions from developing countries like China will take up a rising share in the future. This study shows that the future emissions growth in China can mainly be attributed to per capita GDP increase, whereas energy intensity of GDP is confirmed as the dominant contributor to the decline in CO_2 emissions, which are consistent with the historical trends. The role of population in emissions change is small due to slowdown of its growth rate. In contrast to historical trends, due to large scale of non-fossil energy development, carbon intensity of energy contributes to decrease in future CO_2 emissions. Low-carbon consumption pattern also contributes to reduction in emissions. Given the fact that China's emissions are likely to continue growing rapidly, any meaningful climate stabilization will not be possible without China's participation. Therefore, it's very important for the China to take a low-carbon development pathway.

Second, this study gives the insights that under the most stringent carbon reduction scenario in which the global emissions in 2050 halve to 1990's level, without additional low-carbon countermeasures, GDP loss for both Jiangxi Province and the rest of China would be over 24%, or equivalent to around 1% lower annual growth rate; even if all low-carbon countermeasures are adequately implemented, the GDP loss would be 10-13%. It should be noted that in either case the projected losses are much higher than those projected for developed countries (generally 1-3% under similar global emissions target).

Thirdly, the countermeasures identified in this study appear to be of great importance for both Jiangxi Province and the rest of China. In order to cut carbon emissions substantially, China will have to adjust the energy structure to lower the dependency upon fossil fuels, especially coal, and switch to lower carbon-intensive energy such as natural gas and non-fossil fuels. CCS technology is important in the medium and long run. In addition, given certain emission allocation scheme, inter-provincial emissions trading is very important to ensure carbon reduction to be achieved in the lowest-cost way.

Fourthly, a crucial motivation to develop low-carbon economy is the co-benefits it may bring, given the fact that China is now faced with a lot of environmental problems resulted from fossil fuel combustion and is more dependent on oil import. This study shows that many other air pollutants will be reduced by large percentage as result of deep carbon reduction, which is beneficial to people's health. It also demonstrates that oil import dependency will fall and primary energy mix will be diversified towards lower use of coal and higher use of natural gas, biomass and nuclear fuels, hydro power, wind and solar energy, thus improving the energy security significantly.

Fifthly, one purpose of this study is to develop a methodology that can be applied to any other province. The precondition is that the model behavior should be robust. In such a concern this study has tested the robustness of the model in various ways, e.g. by sensitivity analysis and by applying it to Guangdong province whose economic size is much larger than Jiangxi. It is found that the model behaves relatively robust regardless of the economic size. Therefore, it may be concluded that given the data this model can be applied to any other province, although in practice special attention must be paid to each province's specific situation.

From the above results this study concludes that in the mid-term China's energy demand and emissions would continue to increase at both national and provincial levels. Therefore, China's participation is quite important to achieve global target of climate stabilization. It could be also concluded that low-carbon economy development is achievable in China, and it would bring various co-benefits of improving air quality and enhancing energy security, although there would be huge economic cost if no additional low-carbon countermeasures are introduced. The economic impacts of carbon reduction at provincial level would be different depending on the carbon reduction amount, burden sharing scheme of carbon reduction among provinces, non-fossil energy resource potential of each province, behavior patterns and so on. In order to mitigate the economic costs, it is highly recommended to adopt the low-carbon countermeasures and practices evaluated in this study.

7.3 Future work

There are many aspects remaining to be improved in future work, including scenario setting and model modification.

For scenario setting, more realistic data should be collected concerning each region's future economic growth rate, renewable energy resource potential and development plan etc.

For model modification, current model only considers inter-provincial flow in the form of commodity trade. However, inter-provincial labor flow and investment are very important driving forces of local economy. They should be included in future model framework. Moreover, low-carbon technologies in this study are mainly considered in power generation and cement production, more sophisticated treatment of end-use technologies is also a possible direction. For example, transport sector is one of the key sectors where large amount of CO_2 emissions could be reduced if key technologies such as hybrid vehicle and electric vehicle are employed, these kinds of technologies in transport sector should be included in future work. Last but not least, since China is a country with great diversity among provinces, in order to better understand the impacts of low-carbon economy development at provincial level and get observable implications of findings in this study, more case studies of different provinces should be conducted. If possible, a multi-region model in which the country is divided into 31 provinces is better to address this problem.