ANALYSIS OF GREENHOUSE GAS EMISSIONS REDUCTION OPPORTUNITIES AND MARGINAL ABATEMENT COSTS OF THE ENERGY INTENSIVE INDUSTRIAL SECTORS IN THE HUBEI PROVINCE

Part II: Forecasting Future Marginal Abatement Costs, Technology and the Calculation of Co-Benefit

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Background

Like the rest of the world, China and the Hubei Province are facing multiple environmental challenges in the coming years. In particular, reducing greenhouse gas emissions and particulates is of crucial importance for the local and global environmental health.

China's National Development and Reform Commission (NDRC) launched the world's second largest carbon emissions trading scheme (ETS) program in 2013 to respond to the increasing need to address climate change and air quality issues. The NDRC designated seven provinces and cities to test an ETS, including, Beijing, Shanghai, Tianjin, Chongqing, Guangdong, Hubei and Shenzhen. Collectively, the program will cover seven pilot regions and 700 million tons of carbon emissions-equivalents by 2014.

The NDRC authorized the Hubei Provincial Development and Reform Commission as the main government entity to oversee implementation, coordinate ETS development, and approve of the ETS regulations. The Hubei Provincial Development and Reform Commission will launch the Hubei ETS pilot program in early 2014, regulating 130 enterprises and covering 39 percent of emissions in the province. The principal actors in the program are the energy-intensive industrial sectors, including, cement, glass, chemicals, power, steel, aluminum, and automobile industries.

Hubei's economy is heavily dependent on the energy-intensive industries which account for a high proportion of the emissions in the province. GHG emissions are increasing on average by 12 percent per year, and in 2010, the total carbon emissions in Hubei reached 35.5 billion tons of carbon emissions-equivalents (a 20 percent increase from 2009). The implementation of the Hubei ETS is a critical step towards achieving emissions reductions in Hubei and will allow regulated enterprises to meet emissions reductions goals at a minimum cost to the enterprise.

Analysis of Greenhouse Gas Emissions Reduction Opportunities and Marginal Abatement Costs of the Energy Intensive Industrial Sectors in the Hubei Province

Part II: Forecasting Future Marginal Abatement Costs, Technology and the Calculation of Co-Benefits

Introduction

The joint research between Wuhan University and the Center for Clean Air Policy (CCAP) is divided into two key research areas. Wuhan University developed Part I of the research, which calculates the average marginal abatement cost (MAC) for each sector of the economy based on the calculation of carbon emissions in each sector and a shadow carbon price. CCAP developed Part II of the research, which introduces a practical application to forecast future MACs, identifies examples of sector-specific technologies deployable in target sectors, and proposes a methodology to measure co-benefits from an ETS policy. Co-benefits include the avoidance of other air pollutants, and the corresponding health impacts from emissions reductions.

In an ETS, the calculation of the MAC is effective as a guide to inform government, regulators, and enterprises on a suggested carbon price. An economy-wide marginal abatement cost curve conveys the degree to which MACs vary across industries and determines the cost-savings potential that can be achieved for each analyzed sector in an ETS.

In Hubei, a sector-wide or company-level MAC can be used as a reference value for the allowance price to help enterprises prioritize and guide investment opportunities based on the least cost option to mitigate, either by trading allowances or implementing energy efficiency or renewable energy measures.

Methodology to Forecast Future Marginal Abatement Cost Curves

The Long-range Energy Alternatives Planning System (LEAP) developed at the Stockholm Environment Institute is a widely used tool for energy policy analysis and climate change mitigation assessment. LEAP can be applied to one sector or multiple sectors of the economy, and combines both macro- and microeconomic data to estimate future outputs in the economy, including energy consumption, emissions, production and resource extraction.

The LEAP tool can forecast macro- and microeconomic data points (gross domestic product, emissions, capital stock, enterprise-level production, energy consumption, etc.) under different scenarios. This study proposes the following scenarios: a base case scenario using historical data, a 10-year alternative scenario with ETS cap constraints, and a second 10-year alternative scenario with the inclusion of ETS cap constraints and technology advancements.

The forecasted data points are then used as input variables in the Hubei ETS environmental directional distance function model to calculate future marginal abatement costs. An environmental directional distance function model is an input-output tool used to determine a firm's optimal level of output on a production frontier curve, where the maximum level of output can be generated at a minimum level of emissions. The model's outputs can change with the inclusion of environmental related inputs, such as the cost of new technologies and the corresponding energy and emissions reductions.

In this study, we propose using the LEAP "decoupled" approach, which takes a hybrid approach by using both top-down and bottom-up level data, and can capture technology-based policies.

Application of LEAP Tool:

Step 1) Combine the top-down and bottom-up data points listed below in the "Data Collection" section.

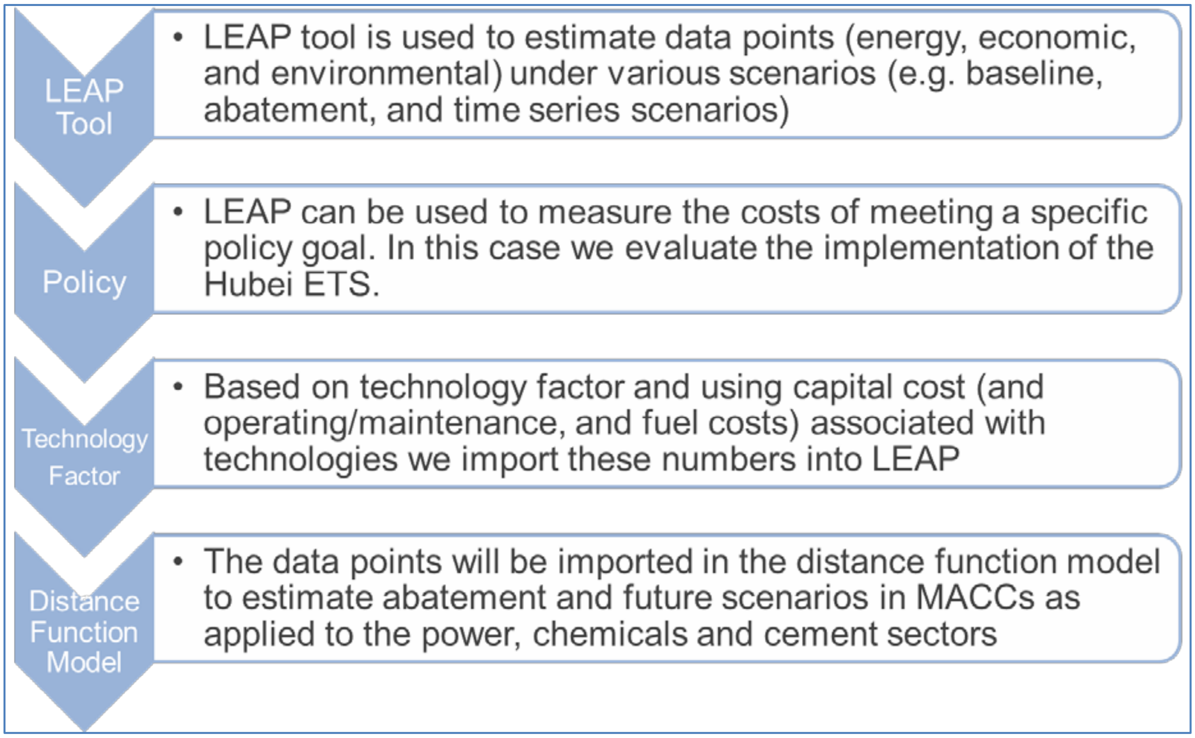
Step 2) Perform a mid-to-long term analysis based on three scenarios: a 10-year base case (given the current economic trajectory), 10-year alternative scenario with the ETS caps, and a second 10-year alternative control scenario with the inclusion of ETS caps and technology advancements. For the second alternative control scenario, a technology factor reflecting technology costs (capital, operating/maintenance, and fuel costs) will be imported into LEAP.

Step 3) Import the forecasted data from LEAP, including energy consumption, capital, staff, output value, and emissions into the Hubei ETS environmental directional distance function model to estimate the future MACs across sectors and/or enterprises.

Step 4) Apply a range of suggested carbon market prices to test the change in outputs.

Based on the three proposed scenarios in Step 2, the change in carbon market prices (the social cost of carbon) will be applied to forecast the change in GHG emissions, sector/enterprise production levels, and energy consumption given the internalization of the price of pollution. We propose applying varied carbon price assumptions of USD 0, USD 25, and USD 100 per ton CO_2 in the LEAP tool. These carbon price assumptions are based on the social cost of carbon estimates that have been applied internationally and in China.

Figure 1. Flow Chart: Linking LEAP to estimate future MAC Curves



Data Collection

This section outlines the top-down and bottom-up data required to forecast future MACs with the LEAP tool.

Top-down Provincial Level Data (from the most current Hubei Statistical Yearbook)

- Inputs (macroeconomic): Provincial level key assumptions needed, include, income, population, household size, households, GDP, income growth rate, population growth rate, fuel prices, fuel use by sector, energy consumption, transportation requirements, capital and operating and maintenance costs, performance factors, and provincial-level/sector-level planning.

Bottom-up/Enterprise-level Data (from the most current annual reports, sector reports, enterprise reports)

- Inputs (microeconomic): Annual number of units produced and production volume, fuel consumption, GHG emissions, energy intensity, GHG emissions intensity, size of employees, growth rate of company, current technology mix and each technology's production/energy/emission performances.

- Technology Factor: Sector-specific technologies will be identified for the major sectors regulated under the Hubei ETS, and their production/energy/emission performances can be imported into the LEAP tool.

- Economic fluctuations: Perform assessment of economy-wide cost and economic impacts of technology and clean energy developments.

  Inputs: change in GDP, employment, consumer prices, structure of economy, and distribution.

Application of Technology Advancements in an ETS

Enterprises can achieve emissions reductions to meet ETS compliance requirements and provincial energy and carbon intensity targets through technology upgrades in energy efficiency, and the deployment of renewable energy. Under China's National 12th Five-Year Plan, the NDRC requires energy-intensive enterprises in Hubei to reduce energy consumption by 16 percent per unit of GDP and reduce carbon intensity by 17 percent per unit of GDP from 2011-2015.

Technology Advancements in the Cement Sector

In China, nearly 40 percent of cement plants utilize vertical shaft kiln technology. This type of technology is considered obsolete due its low efficiency rates and the high amount of coal that is required during the clinker production process. The remaining plants in China are modern rotary kiln plants, including plants with new suspension pre-heater and pre-calciner kilns.[1]

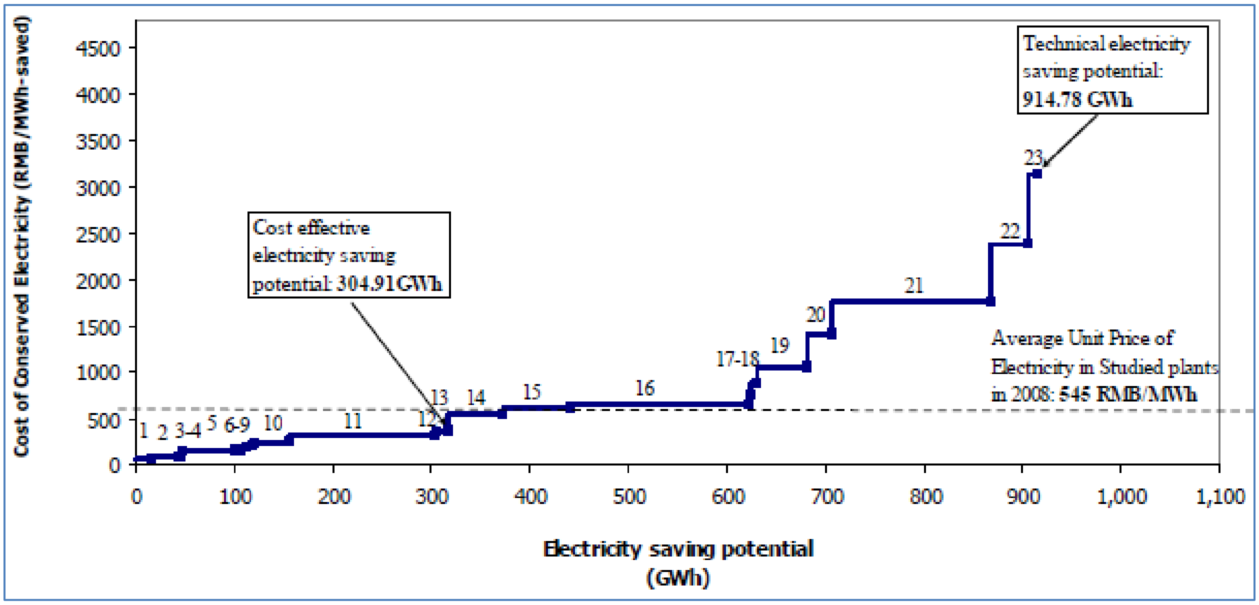
To assess mitigation options in the cement sector in Hubei, regulators can perform an audit to evaluate the current state of the cement sector to identify the type of technologies used, penetration of technologies, performance rates, and the respective technology costs. From a sample assessment, the Hubei ETS research team can then identify technologies most applicable and viable in Hubei, ranked based on the energy-savings potential, the associated costs, and the corresponding carbon emissions reductions.

Researchers from the Lawrence Berkeley National Lab developed an energy-savings supply curve for the cement sector in Shandong, China. The cement energy-savings supply curve captures the environmental and economic potential of energy conservation (for both fuel and electricity savings) for 23 energy efficiency measures in the cement sector, including electricity savings and costs. See Figure 2. Each point on the curve represents a technology measure rated by a given technology's electricity reduction and the marginal cost for a unit of energy saved.

On the energy-savings supply curve the width of each measure (on the x-axis) represents the energy saved by a specific technology, and the height (on the y-axis) reflects the total cost of energy savings. The dotted line is the price of a unit of electricity, therefore, all technologies that fall below the line are "cost-effective" because they are cheaper to install than to pay for an additional unit of electricity. The technologies numbered 11, 16 and 21 have the highest energy savings per unit of energy consumed. Further, technologies 1 through 12 are the least cost options for cement companies, and technologies 19 through 23 are the highest cost options. See **Annex I** for the complete list of technology measures analyzed in the cement sector in Shandong.

[1]Analysis of Energy-Efficiency Opportunities for the Cement Industry in Shandong Province, China, Lawrence Berkeley National Laboratory, China Buildings Materials Academy, L.Price, A.Hasanbeigi, H.Lu, L.Wang (2009),

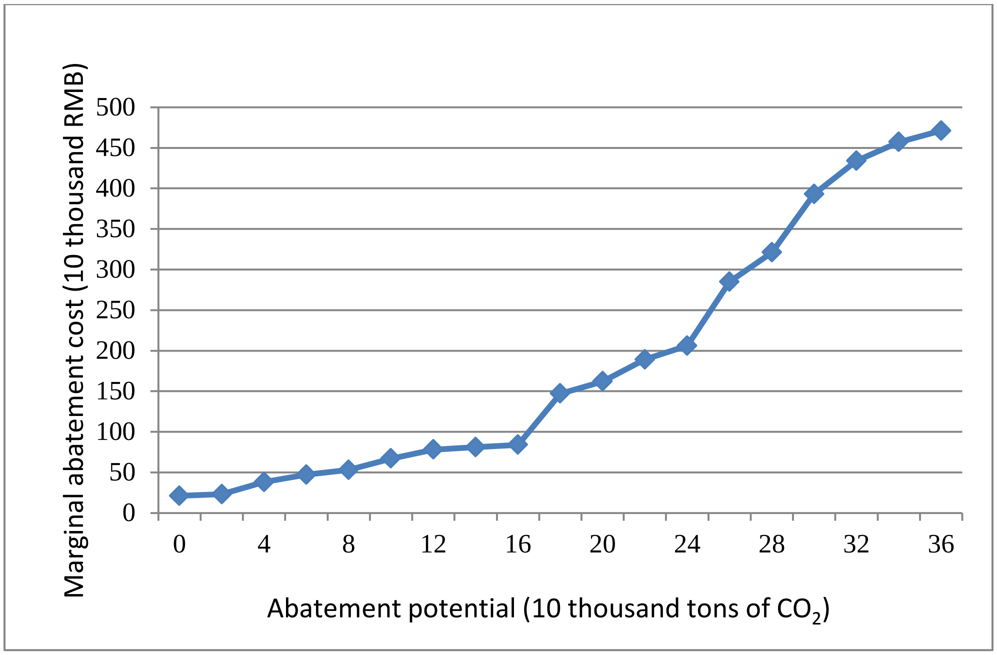
Figure 2. Energy-Savings Supply Curve in the Cement Sector



Analysis of the Power Sector in Hubei

The marginal abatement cost curve for the power sector in Hubei is displayed in Figure 3. The graph shows that the power plants that abate 0 to 160 thousand tons of CO_2 experience a relatively stable CO_2 abatement cost. However, when power plants emit over 160 thousand tons of CO_2 there is a steep increase in abatement costs. The change in the MAC demonstrates that the size and efficiency levels of power plants in Hubei experience a large range in abatement costs. Therefore, technology advancements serve as an option for enterprises to invest in to achieve emissions and energy reductions.

Figure 3. Hubei Power Sector Marginal Abatement Cost Curve



Data Collection for Technology Inputs

Energy-savings supply curves for the targeted sectors can be constructed with the data listed below. Assumptions can be applied from either domestic or international studies where no data is available.

- Capital and operating and maintenance costs, foreign exchange (assessment of imported or domestic technology), performance (efficiency, unit usage, capacity factor)
- Penetration rates of technology
- Percent of new or existing stock replaced per year
- Energy supply (extraction)
- Price of fuel
- Emission factors
- Emissions per unit energy consumed, produced, or transported

Application to the LEAP Tool

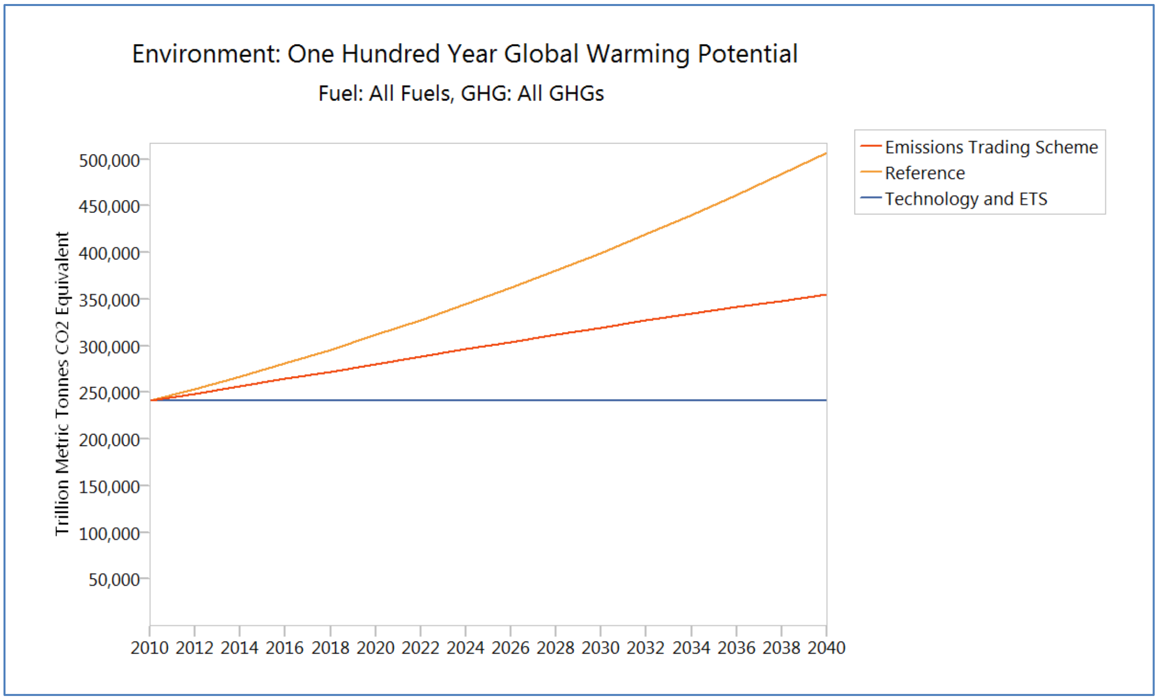
An energy-savings supply curve should be developed independent of the LEAP tool to ensure that the technology factor outcomes, such as technology-specific energy and emissions reductions are isolated, and changes in fuel consumption, costs, and emissions reductions are not influenced by other economic fluctuations. The technology-related outputs can then be imported into the LEAP tool to forecast different abatement scenarios. Table 1 lists the key data parameters required for the three proposed scenarios.

Table 1. List of Key Parameters for the Three Proposed Scenarios

Scenario	Key Parameters
Base case – Current economic trends	• Top-down Provincial level data – see Data Collection section • Bottom-up Enterprise-level data – see Data Collection section • Economic fluctuations – see Data Collection section
Alt 1 – alternative scenario under ETS emissions cap for each sector	• Top-down Provincial level data – see Data Collection section • Bottom-up Enterprise-level data – see Data Collection section • Economic fluctuations – see Data Collection section • CO_2 emissions cap • Inclusion of a CO_2 price
Alt 2 – alternative scenario including ETS emissions cap and technology advancements	• Top-down Provincial level data – see Data Collection section • Bottom-up Enterprise-level data – see Data Collection section • Economic fluctuations – see Data Collection section • CO_2 emissions cap • Inclusion of a CO_2 price • Technology cost parameters – see Data Collection for Technology Inputs section

Once the ETS caps and technology changes are imported into LEAP, the changes will be reflected in the LEAP output model. Figure 4 is a hypothetical output model from LEAP reflecting the three proposed scenarios for a given sector. The x-axis depicts is the year and y-axis is the forecasted level of carbon emissions. The reference case (top/orange line) is the business-as-usual scenario, Alt1 (middle/red line) is the scenario with the integration of the Hubei ETS policy, and Alt2 (bottom/blue line) is the inclusion of the Hubei ETS policy and sector-based technology advancements.

Figure 4. Time-series Scenario Analysis



Calculating Externalities and Sustainable Development Co-benefits

Part A: Internalizing the Cost of Air Pollutants

A positive or negative externality is a cost or benefit that is imposed on a third party, such as society, other than the producer or consumer of a good or service.[2] Air pollution is a negative externality and imposes the greatest cost on society. Since GHG emissions are typically not valued in the overall cost of production this results in an over-supply of emissions, and distorts the true costs of pollution.

An ETS places a price on emissions to influence the cost-effectiveness of energy savings potential, such as investments in energy efficiency and renewable energy technologies. Government policies, such as an ETS encourage reductions in carbon emissions and investments in energy efficiency and renewable energy by making technology advancements and mitigation options more economically attractive.

A cost-benefit analysis compares the costs and benefits associated with a specific policy and/or technology investment. By only measuring the impact of reduced CO_2 emissions this approach does not cover all externalities relevant in the industrial and power sectors, including the avoidance of other air pollutants, SO_2, NO_X, and particulate matter. A cost-benefit analysis illustrates a more comprehensive picture by quantifying all the potential co-benefits from reductions in energy use, and assigns a monetary value to the reduced and avoided emissions associated with a specific policy and/or technology development.

[2] MBAEcon, J. Butcher, R. Hill, Positive and Negative Externalities (2006)

This study proposes two methods to calculate the benefits of avoided emissions. The first method utilizes the LEAP tool option by assigning a price to air pollutants. This option calculates environmental externalities based on an integrated cost-benefit analysis and assigns costs to various pollutants. Pollutants can include, CO_2, SO_2, NO_X and particulate matter ($PM_{2.5}$ and PM_{10}). The second method is an environmental impact analysis approach.

Method 1: Cost-Benefit Analysis in LEAP

A cost-benefit model compares the economics between a base case (business-as-usual) and an alternative case scenario. In this case, the alternative case includes the ETS policy which places a market value on a ton of CO_2, and quantifies the marginal change in energy consumption (energy savings) from technology changes.

The alternative case scenario assesses the following outcomes based on the change in technology:

- Change in energy mix
- Reduced energy supply: the alternative scenario will result in decrease of primary energy supply replaced with an increased supply of clean energy sources and increased energy efficiency
- Quantification of avoided emissions based on the imported market value (e.g. USD 50/ton of CO_2)

Methodology

Step 1) Import the variables into LEAP to extract a cost-benefit analysis and determine the net present value (NPV) between the base case and the alternative case scenarios, based on the integration of the social costs and benefits of the policy and/or technology advancements.

Step 2) LEAP will calculate the NPV, the sum of all costs in all years of the study discounted to a common base year for the base case and two alternative cases.

Step 3) Add suggested externality costs. For example, the cost of a ton of CO_2 can be valued at USD 15.

After the assumptions are imported into LEAP, the cost-benefit tool assesses the costs and benefits listed in Figure 5. The internalization of the cost of pollution is reflected in the analysis. If the benefits exceed costs, then the policy or technology investment should be pursued.

Figure 5. Overview of a Cost Benefit Analysis applied to a Technology Advancement

Costs	Benefits (measured incrementally)
• Costs of technology (inclusion of discount rate) • Costs of operating and maintenance of technology	• increased energy efficiency = less investment in new generating plants • reduced electricity costs (evaluated by amount reduced and price of electricity) • less fossil fuels to be produced or imported • reduced emissions (due to less fuel combustion)

Method 2: Environmental Impact Analysis

An environmental impact analysis can be performed to measure the economic and environmental impacts that result from the Hubei ETS program and technology changes. Multiple air pollutants can be analyzed, of which include, CO_2, NO_X, SO_X, and particulate matter ($PM_{2.5}$ and PM_{10}).

Environmental impacts can be assessed from both the reduction in emissions associated with end-use combustion of fuels (primary energy sources), and the reduction in emissions from power plants (secondary energy sources) for electricity and heat. When calculating the total emissions from secondary energy sources, it is important to account for inter-regional electricity trade to accurately reflect the origin from which the electricity is generated, and the amount of electricity that is traded across regions.

In China, the State Grid Corporation of China dominates 85 percent of the power sector market share, and is the primary electricity provider in Hubei. Hubei is only involved in inter-regional trading through electricity exports, specifically through the export of hydropower electricity to the coastal provinces, therefore, the emissions accounted from reduced electricity consumption in Hubei will remain in the province. If electricity is imported into the province, then emissions reductions would remain at the source of power generation.

Methodology to calculate avoided emissions

Step 1) Estimate reductions in energy consumption.

Step 2) Estimate fuel and end-use emissions factors.

Emissions coefficients will be associated with each fuel source and catalogued as follows in Table 2. Factors impacting the emissions profile are dependent on the profile of the plant (type of fuel combusted, environmental controls in place, and efficiency of the boilers). See Annex I for list of estimated CO2 emission factors in Hubei.

Table 2. Air pollutants emission factors from primary sources

Fuel (kgCO2/kg or kgCO2/m3)	CO_2	NO_X	SO_X	$PM_{2.5}$ PM_{10}
Coal				
Natural Gas				
Oil				
LPG				
Diesel				
Others				

Table 3. Air pollutant emission estimates from secondary sources

	CO2	NOX	SOX	PM2.5 PM10
Electricity (tCO_2/kWh)				
Heat (tCO_2/kJ)				

Step 3) Total emissions and reductions.

The power sector is the highest emitting sector in Hubei, therefore the environmental impact of electricity generation in Hubei is significant. Carbon emissions are regulated through the Hubei ETS and the provincial carbon intensity target, however the power sector is responsible for producing a large share of other air pollutants, including, NO_X, SO_2, and the formulation of particulate matter. Together these air pollutants adversely affect local air quality, and also contribute to transboundary pollution, causing negative health and environmental impacts in distant areas. The reduction of carbon emissions leads to the avoidance of other air pollutants, and these co-benefits can be quantified to justify the importance of a CO_2 mitigation policy.

The Chinese Ministry of Education's Key Laboratory for Earth System Modeling and Tsinghua University developed a methodology to quantify grid-based emission factors of air pollutants based on lessons drawn from Clean Development Mechanism (CDM) projects. The study shows that for every 1 percent reduction in CO_2 in China's power sector, a co-reduction in SO_2, NO_X, and $PM_{2.5}$ respectively occurs by 1.1, 0.5, and .8 percent.

The correlation is quantified based on an analysis of CDM renewable energy and fuel switching projects that were implemented in China from 2008-2010. The CDM projects replaced existing electricity, and displaced future power production from traditional fossil-fuel power plants with new technology.[1] The grid emissions factors are applied in each region in China. In Hubei, the following co-abatement rates apply:[3]

- For every gigaton of CO_2 reduced in the power sector, 2.21 megaton of **SO_2** is reduced;
- for every gigaton of CO_2 reduced in the power sector, 1.9 megaton of **NO_X** is reduced; and
- for every gigaton of CO_2 reduced in the power sector, 0.35 megaton of **$PM_{2.5}$** is reduced.

Step 4) Quantify the value of avoided emissions based on the market value associated to each air pollutant.

The market value can be determined by the current market price for the specific air pollutant, such as CO_2. For other air pollutants with no clear market price, these pollutants can be valued by the measurement of other co-benefits, such as health impacts that result from reduced exposure to air pollutants.

The willing-to-pay (WTP) approach can be applied to the measurement of co-benefits. This approach calculates co-benefits associated with avoided health risks from improved air quality. This risk assessment method is used to evaluate the link between emissions reductions and human exposure to particulate matter and ambient distributions from various sources. The benefits from reduced health risks are then translated into economic terms by applying economic valuation methods.

WTP can be applied through two valuations, mortality risk and morbidity risk.[4] Mortality risk valuation estimates the price people are willing to pay to reduce the risk of death, and includes the measurement of prevented deaths. Morbidity risk valuation captures the value of the pain and suffering avoided and the value of time lost due to illness. Morbidity risk valuation is defined by respiratory and cardiovascular hospital admission, and the incidence of chronic bronchitis (from exposure to air pollution).

Willingness-to-Pay Example

In Europe, the European Commission calculated the co-benefits from avoided emissions (SO_2, NO_X and PM) associated with a 30 percent reduction of carbon emissions by 2020 relative to 1990. SO_2, NO_X and PM were studied since these pollutants are released by some of the major sources of CO_2, and their emissions can be reduced by CO_2 control measures such as a carbon intensity target and an ETS.

The Clean Air for Europe (CAFE) Program of the European Commission's Directorate General for Environment developed a methodology to quantify health co-benefits valued based on the impacts linked to health, such as, higher rates of death and respiratory illnesses, including bronchitis and the exacerbation of asthma symptoms, and respiratory and cardiac hospital admissions.[5]

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[3] The values were calculated using 2008-2010 data in China. If a different set of technology is used, the numbers should be updated accordingly.

[4] *Quantifying the Human Health Benefits of Curbing Air Pollution in Shanghai*
J. Li, Center for Clean Air Policy, S. Guttikunda, G. Carmichael, Center for Global and Regional Environmental Research, Global Greenlife Institute, Argonne National Laboratory (2001)

[5] The Co-benefits to Health of a Strong EU Climate Change Policy. M. Holland, EMRC - Ecometrics Research and Consulting, UK. 2008.

The study estimated that the economic benefits of a 30 percent reduction in CO_2 emissions, gained through improved health impacts is valued between USD 10 and USD 23 billion per year, and correspondingly, SO_2 emissions are estimated to decrease by 424 kilotons, NO_X emissions by 350 kilotons, and $PM_{2.5}$ emissions by 54 kilotons.[6]

Part B: Updating Marginal Abatement Cost Curves

LEAP is used to forecast the marginal change in emissions, energy consumption and production with the inclusion of an ETS policy and technology changes. The forecasted data points are then imported into the Hubei ETS environmental directional distance function model to produce an updated production frontier curve, with new production and emissions output levels.

An environmental directional distance function model computes the optimal point of production for a given firm.

With the inclusion of the social cost of carbon, the Hubei ETS environmental directional distance function model produces an updated marginal abatement cost curve with the internalization of the cost of pollution.

Sensitivity Analysis

When calculating the economic outcome of various climate change mitigation policies and measures, a sensitivity analysis can be performed to test a range of discount rates. At the moment, there is no consensus on a suggested discount rate for climate change policies; however the international climate change community agrees that in the face of uncertainty, a range of discount rates should be considered.[7] This study proposes three discount rates: a close to the market discount rate, a high discount rate (10-12 percent), and a low discount rate (2-4 percent).

Climate change impacts and mitigation policies have long-term characteristics, and the cost analysis of climate change policies involve a comparison of economic flows that occur at different points in time.[8] The choice of a discount rate has a large influence on the result of any climate change cost analysis. A high discount rate implies that the value of a project in the current terms is less valued then in the future, and a low discount rate implies that a project in current terms is valued similarly to one in the future.[9]

When a discount rate is applied to the Hubei ETS, a smaller discount rate should be applied if it is assumed that the impact of this policy will play a positive role in mitigating future climate change impacts.

[6] Acting Now for Better Health: A 30% Reduction Target For EU Climate Policy. P. Maro, HCWH/HEAL; D. Smith, HEAL; and A. Acquarone, HEAL. September 2010.
[7] Cunningham, R. Discount Rates for Environmental Benefits Occurring in the Far-Distant Future. Independent Economic Advisers Research. 2009.
[8] Intergovernmental Panel on Climate Change. Climate Change 2007: Working Group III: Mitigation of Climate Change
[9] Cunningham, R. Discount Rates for Environmental Benefits Occurring in the Far-Distant Future. Independent Economic Advisers Research. 2009.

Discount Rates in LEAP

Table 7 is an example from LEAP that demonstrates the result of a range of discount rates applied to a hypothetical mitigation scenario. The table compares the cumulative costs and benefits of a mitigation scenario using a 2 percent and 12 percent discount rate.

The output shows that a 2 percent discount rate applied to the mitigation scenario investments incurs a net present value of about USD 300 million, while a 12 percent discount rate incurs a net present value of the USD 48 million. This exercise demonstrates that the choice in discount rate will have a significant impact on the value of a given project or policy, and a lower discount rate places a higher value on the mitigation scenario investments.

Table 7. LEAP Cost Benefits Analysis Comparison of Discount Rates

Total costs	Discounted at 2% to year 2010	Discounted at 12% to year 2010
Industry sector	$ 472,264,592.68	$ 76,019,137.07
Environmental Externalities	$ (18,305,252.15)	$ (3,102,941.50)
Net Present Value	**$ 299,696,358.93**	**$ 48,028,930.74**
Total benefits		
GHG Savings (Tons CO2 Eq.)	1,894,775,501,303	1,894,775,501,303
Cost of Avoided CO2 (U.S. Dollar/Tonne CO2 Eq.)	$ 158.17	$ 25.35

Conclusion

Hubei is a leader in China's climate change efforts and is one of five nationally recognized pilot low carbon provinces. The first phase of the Hubei ETS is an opportunity for the government to determine the underlying costs of mitigation abatement, uncover the inefficiencies in energy consumption, and the gains to participating in an ETS, all of which will be advantageous for long-term low carbon development planning and can produce a uniform system to monitor, report, and verify emissions. During this phase, it will be critical to determine what positive outcomes can come of an ETS program based on provincial circumstances and what lessons can be passed on to inform the national plan.

Annex I

Table A. CO_2 Emission Factors for Primary Fuel Sources[10]

Fuel Type	Calorific value of carbon units (kgC/GJ)	Carbon oxidation rate (%)	Low calorific value (kcal/kg or kcal/m3)	Emission Factor (kgCO2/kg or kgCO2/m3)
Raw coal	26.4	94	5000	1.9027
Washed coal	25.4	93	6300	2.2855
Other coal	25.4	93	2497	0.9059
Briquette	33.6	90	4200	1.9498
Hard coke	29.5	93	6800	2.8640
Other coking products	29.5	93	9100*	3.8327
coke oven gas	12.1	99	4145	0.7623
blast furnace gas	70.8	99	900	0.9684
Other gas	12.1	99	4830	0.8882
Natural gas	15.3	99	9310	2.1649
crude	20.1	98	10000	3.0240
Gasoline	18.9	98	10300	2.9827
Kerosene	19.6	98	10300	3.0372

[10] Data sources:"provincial guidelines for the preparation of greenhouse gas inventories (Trial)","2006 IPCC Guidelines for National Greenhouse Gas Inventories"and "China Energy Statistical Yearbook".* Indicates low calorific value of other coking products derived from the "energy consumption caused by greenhouse gas emissions calculation tool Guide" (World Resources Institute).

Diesel fuel	20.2	98	10200	3.0998
Fuel oil	21.1	98	10000	3.1744
LPG	17.2	98	12000	3.1052
Refinery gas	18.2	98	11000	3.0119
Other petroleum products	20.0	98	8400	2.5275

Table B. CO_2 Emission Factors for Secondary Fuel Sources

Year	Electricity carbon emission factor （$tCO_2/10^4kW·h$）	Heat carbon emission factor（$tCO_2/10^6kJ$）
2006	2.0698	0.0694
2007	2.1128	0.0695
2008	1.6559	0.0703
2009	1.7043	0.0672
2010	1.9911	0.0674

Table C. Cement Sector Technologies: Electricity-Efficiency Measures for 16 Studied Cement Plants in Shandon Province Ranked by Cost of Conserved Electricity (CCE)[11]

CCE Rank	Efficiency Measure	Measure No.	Electricity Saving (GWh)	Cost of Conserved Electricity	CO_2 Emission Reduction (kton CO_2)
1	Efficient roller mills for coal	2	17.18	67	17.66
2	Adjustable speed drive for kiln	14	26.68	83	27.43
3	New efficient coal separator for fuel	1	2.20	88	2.26

[11] Analysis of Energy-Efficiency Opportunities for the Cement Industry in Shandong Province, China, Lawrence Berkeley National Laboratory, China Buildings Materials Academy, L.Price, A.Hasanbeigi, H.Lu, L.Wang (2009)

4	Replacement of Cement Mill vent fan with high efficiency fan	29	1.37	144 .89	1.41
5	High efficiency motors	31	52.97	157	54.45
6	Variable Frequency Drive (VFD) in raw	9	6.12	158	6.29
7	High efficiency fan for raw mill vent fan with inverter	11	7.23	191	7.44
8	Replacement of Preheater fan with	23	4.97	203	5.11
9	Variable Frequency Drive in cooler fan of grate cooler	21	1.83	230 .41	1.88
10	Energy management & process control in grinding	24	34.98	245	35.96
11	Adjustable Speed Drives	32	147.85	321	151.99
12	Installation of Variable Frequency Drive & replacement of coal mill bag	3	1.53	353 .17	1.57
13	Improved grinding media for ball	27	11.72	375	12.04
14	Low temperature Waste Heat Recovery power generation	16	56.06	539.77[12]	57.63
15	Replacing a ball mill with vertical roller mill	25	68.46	622	70.38
16	High pressure roller press as pre-grinding to ball mill	26	181.20	661	186.27
17	Raw meal process control for Vertical	4	2.18	764	2.24
18	Efficient kiln drives	17	6.38	883	6.56
19	High-Efficiency classifiers for finish	28	51.10	1057.75	52.53
20	High Efficiency classifiers/separators	5	24.40	1416.72	25.09
21	High Efficiency roller mill for raw materials grinding	6	160.54	1770.91	165.04
22	Low pressure drop cyclones for suspension preheater	20	39.32	2380.22	40.42
23	Efficient (mechanical) transport system for raw materials	23	8.51	3139.33	8.75

[12] In the calculation of the CCE for low temperature waste heat recovery power generation, the revenue from CERs of the CDM project is not taken into account. If taken into account the value of CERs, CCE will be equal to 500.45 RMB/MWh-saved.

SUPPORTED BY:

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