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ANCILLARY BENEFITS OF GHG ABATEMENT POLICIES IN DEVELOPING COUNTRIES: A LITERATURE SURVEY

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Ancillary benefits of GHG abatement policies in developing countries: a literature survey

Abstract

In this paper we survey the literature that estimates the ancillary benefits of greenhouse gas (GHG) abatement in developing countries, and the extent to which its findings can be transferred across countries. Specifically, we focus upon the *health* benefits from emission reduction in developing nations. In order to evaluate the spillovers and indirect benefits that a country could reap from GHG mitigation policies, it is crucial to account for the differences that exist among nations in the valuation of such benefits. In fact, the monetary loss attached to an illness and the value of a human life may vary across cultures, economies and over time, depending on income, demographics, socio-economic and political characteristics of a country. There is a rich literature on valuation techniques that spans much of the developed world, whereas there has been far less analysis of developing countries. The goal of this research is to examine the still relatively scarce literature on the developing world and its specific findings. Particular attention will be dedicated to case studies of China.

Introduction

The debate about ancillary benefits[1] of climate change policies aimed at reducing greenhouse gas (GHG) emissions has in recent years paid more and more attention to developing countries. Numerous studies have examined how different countries evaluate the side-effects, externalities and spillovers that derive from climate change policies, considering the impact of differences in per capita income. Ancillary benefits of climate change mitigation policies, such as reduced local air pollution, can indeed be beneficial for developing countries committed to reduce GHG, even though for them the opportunity cost of allocating resources to this task is high. Ancillary benefits can provide in the short run and with less uncertainty specific benefits to the current generations and therefore create an incentive for poorer nations to participate

[1] Sometimes termed "co-benefits", for instance in OECD reports (OECD > benefits of climate change policies, http://www.oecd.org/env/cc/benefitsofclimatechangepolicies.htm)

in international climate change mitigation. Nonetheless, demographic, social and economic conditions are significantly different in developing countries, hence the exact monetary value attached to any ancillary benefit - for example to better air quality and health spillovers – can be quite different for people in developing countries compared to those in developed ones.

In this paper we review the most important studies conducted in developing countries that quantify the ancillary benefits of reducing GHG emissions. Specifically, we focus on the health benefits achieved through lower levels of domestic air pollution. Fig. 1 summarizes the parallel improvements deriving from climate change mitigation policy, with reduction in GHG emissions on one side and improvements in local air quality and health benefits on the other.

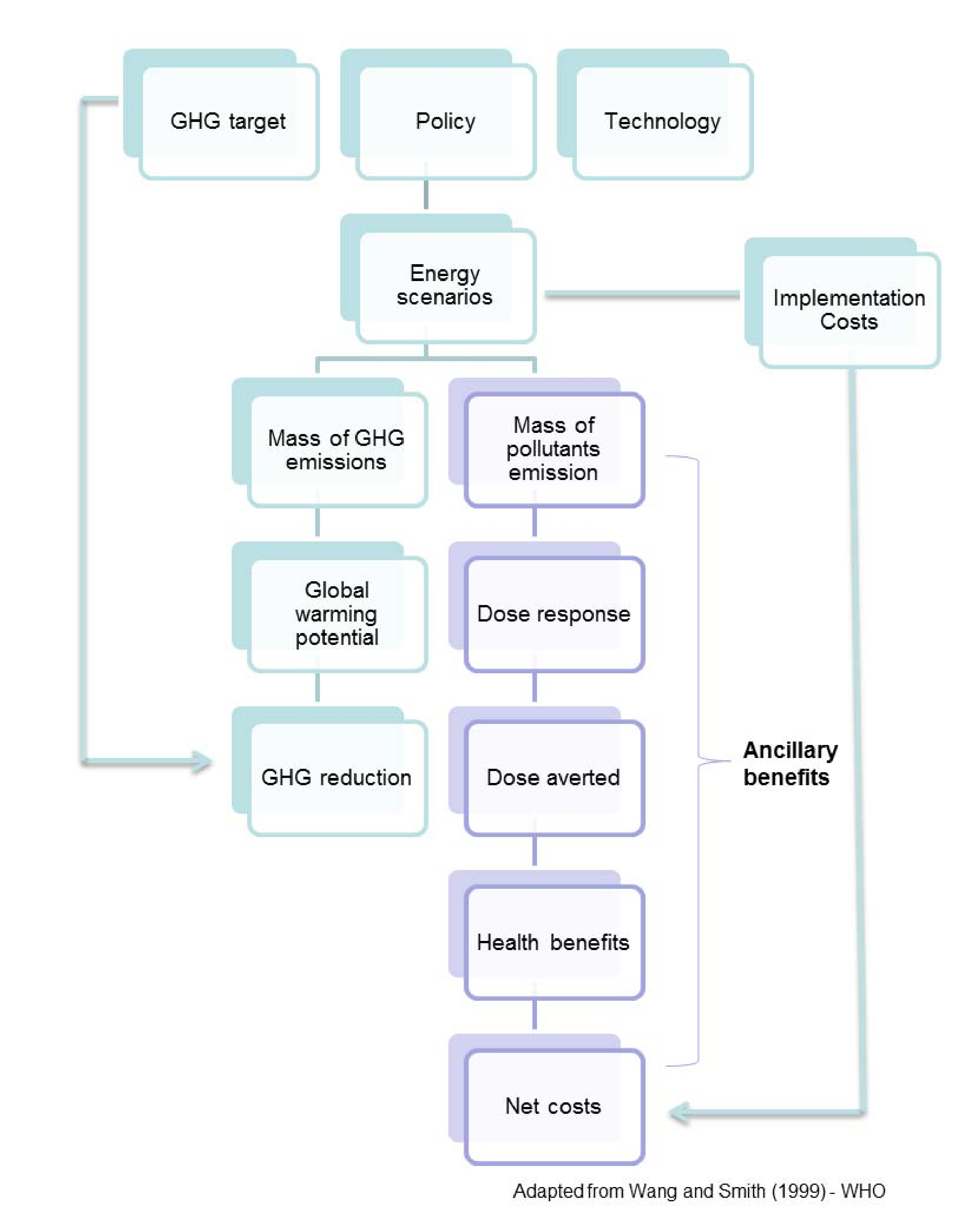

Fig. 1 – Ancillary benefits on the side of GHG emission reduction policy

This literature review is organized as follows: first, it presents some theoretical models that have been used for framing the analysis of ancillary benefits. This literature is still relatively limited regarding developing countries, hence a greater part of the literature review will be dedicated to empirical studies in developing countries. Methodologies for empirical research have consolidated over time and consist, broadly speaking, of two different types of approaches: *top-down* studies, which use general equilibrium models of the socio-economic sphere and of various natural systems, and *bottom-up* approaches, which study from a micro-perspective some specific relationships between policies, specific co-benefits and their valuation.

I - Theoretical Approaches

Looking at the theoretical background before reviewing the empirical works on ancillary benefits in developing countries, it is possible to understand how the economic literature usually frames the issue of domestic spillovers of global climate change policies. Not much has been modelled specifically for developing countries in terms of these externalities, but often classical models of climate change or local pollution incorporate them as part of the overall strategic bargaining or optimization done by a country.

1. International models

Ancillary benefits can be included within a strategic framework of countries bargaining to achieve a cooperative agreement on climate policy as a global public good. The presence of ancillary benefits that accrue directly to the implementing country should reduce the incentives for free-riding in an international agreement. Rübbelke (2003) models these new abatement incentives with an impure public good model with different abatement technologies and finds that indeed ancillary benefits affect the chosen provision of climate policy. Furthermore, when framing the problem of ancillary benefits within a game-theoretical analysis, ancillary benefits provide a significant incentive for developing countries to participate in international agreements (Pittel and Rübbelke 2008).

2. Domestic models

Alternatively, ancillary benefits can be considered as positive domestic externalities. Burtraw et al. (2000) engage in a thorough discussion about what types of ancillary benefits can be considered true externalities, how they can vary under different climate change policies, and also what difference should be considered when studying them in developing countries. In particular, they highlight the difficulty in performing exact measurements of the value of ancillary benefits in economies where markets are incomplete, institutional capacity is limited, and many socio-economic processes are quite different from developed nations (gender issues, living standards of the poorest, unemployment levels, equity, etc.). O'Connor (2001) also theorizes the effect of ancillary benefits simply as a domestic problem for developing countries, abstracting from other primary benefits of averted climate change damage, “*not because they are considered insignificant, but because they are judged to be too uncertain and distant in time to influence substantially policy making in most developing countries*” (Bussolo and O'Connor 2001:3). Fig.2 below shows graphically their optimal level of CO_2 abatement and the “no regrets” (zero net costs) options, given ancillary benefits.

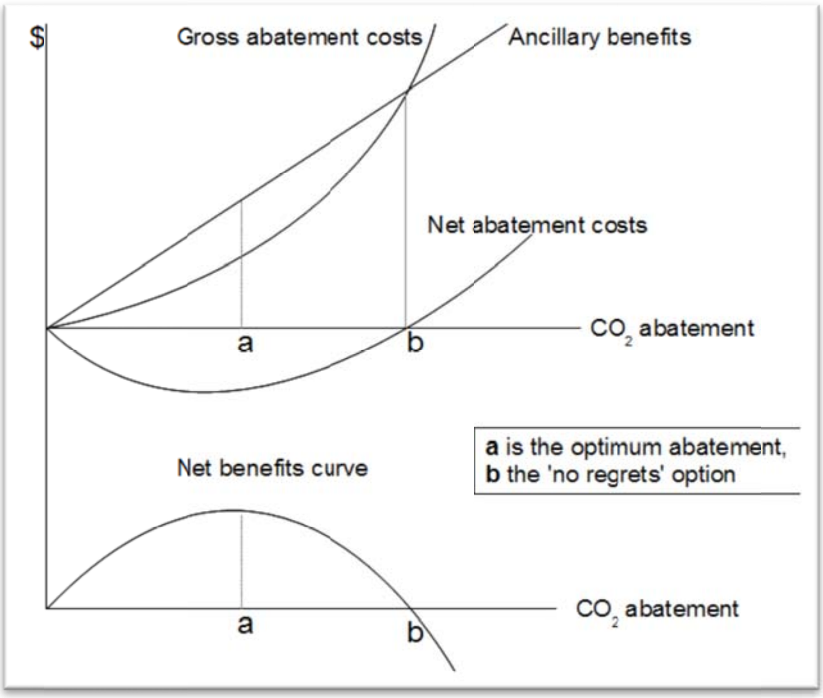

Fig. 2 – optimal abatement with ancillary benefits (Bussolo and O’Connor 2001)

II - Empirical Approaches

Most of the literature on ancillary benefits, however, consists of empirical analyses, both for developed and developing countries. Different research strands used either Computable General Equilibrium (CGE) models to simulate the economic and natural processes that induce some ancillary benefits, or alternatively econometric analyses to estimate various key parameters (dose responses, willingness to pay, cost of illness) that can be themselves inputs for CGE models. This section presents the most important empirical researches conducted in developing countries, with particular attention for studies performed in China, both taking a bottom-up and a top-down perspective. Fig. 3 below shows the causal linkages that this literature has been focusing on, starting from the policy and arriving to the endpoint welfare gains. Generally, bottom-up approaches try to estimate specifically one or two of these links, while top-down, economy-wide models analyse the entire chain of causality.

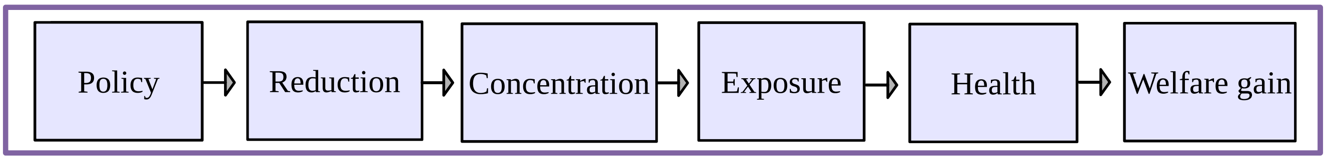

Fig. 3 – The chain of impacts from climate change policy to ancillary welfare gains

1. BOTTOM-UP STUDIES

There are a number of bottom-up studies that analyse more than one part of the aforementioned sequence of causalities. For simplicity, however, here they are categorized following the order of the linkages displayed above, considering where the paper gave the greatest contribution in testing one of such linkages.

1.1 From policy to pollutants' reduction

A first type of empirical analysis shows how different policies (actually implemented ones or simply simulated) can produce ancillary benefits for a country. Rigorous policy evaluation poses several problems in developing countries, from lack of data to non-random design of the policy intervention just to mention a few, so usually these type of studies tend to propose alternative scenarios rather than looking in retrospect at actual policies implemented.

A seminal paper from the World Health Organization (WHO) laid down a complete methodology for comparing different policies in their effectiveness to improve air quality (Wang and Smith 1999). They contrast a business-as-usual scenario with interventions in the household and energy sector. Then they consider exogenous emission targets plausible for China and how these could translate into a reduction in GHG emission. They estimate how much human exposure to such pollutants would change, and applying dose-response functions estimated in the epidemiological literature they calculate the final impact on human health. Finally, they adopt the results of a World Bank study in China of some years before to measure the exact monetary value of these economic benefits. They apply the estimated willingness to pay (WTP) for reduced risk of premature deaths (mortality), and wages and medical expenses to the reduced illnesses (morbidity). This is a standard estimation of ancillary benefits starting at the policy level.

There are several other examples of analyses of policy interventions that led to air quality improvements, including, among others: Xianqiang et al. (2005), who perform a study of Chinese energy policy for substitution of coal with natural gas; Seunghun et al (2004) who compare different GHG targets for Korea; Wang et al. (2004) who analyse regulatory standards on energy-saving and indoor-air-quality. It is also possible to evaluate the policy options that generate ancillary benefits using CGE models (see section 2), or a combination of top-down and bottom-up studies, such as the study by Jing et al. (2008) of different environmental taxes, or by Aunan et al. (2003).

From policy to ancillary benefits			
AUTHORS	LOCATION	MODEL & CONTROLS	CONCLUSIONS
Wang and Smith (1999)	China	Bottom-up methodology for two sectors: energy and household. Policy reduction targets: 10% below business-as-usual (BAU) by 2010 and 15% below by 2020.	Some scenarios estimate a reduction in total mortality of 4% - with sectoral variations: for example, the benefits of one ton reduction in particulates emissions from household stoves are at least 40 times larger than those from coal-fired power plants.
Xianqiang et al. (2005)	Beijing and Chongqing (China)	Cost–benefit analysis of natural gas substitution policies.	Substituting natural gas for coal makes the most sense from a cost–benefit point of view in large cities, where there is dense population and intensive economic activity. In fact, usually, clean-coal technology is superior to natural gas substitution in terms of pollutant emission reduction per unit of money spent.
Jing (2004)	Guiyang City, China	Compare GHG mitigation technology options related to coal consumption[2]. Also other mitigation options such as coal pretreatment, the renovation of existing old boiler systems and the application of new, efficient boiler systems in the industrial sector of Guiyang, China.	Both industrial and electricity sectors might produce significant ancillary health benefits. Technology transfer should be encouraged, as well. Estimated benefit of 89-278 $/tC (dollars per ton carbon reduced). They also rank the technology options in terms of welfare benefits (results are sensitive to the choice of discount rates).
Seunghun et al. (2004)	Korea	Predict ancillary benefits for specific GHG targets.	A 5–15% reductions in GHG by 2020 would reduce by 40 to 120 premature deaths per year and 2800 to 8300 cases per year of asthma and other respiratory diseases in Seoul Metropolitan Area. The annual cumulative value of these avoided health effects is 17 to 21 million US (in 1999 dollars). Or, 6.8 to $7.5 per ton of carbon emissions reduced for the climate change scenarios.
Wang et al. (2004	China	Review building energy-saving and indoor-air-quality (IAQ) related standards in China, in comparison	In comparison to other countries, some regulations are similar even to developed nations.

[2]Such as the advanced electricity generation technologies of Integrated Gasification Combined Cycle (IGCC), Atmospheric Fluidized Bed Combustion (AFBC), Pressurized Fluidized Bed Combustion (PFBC), Oil Fired Combined Cycle (OILCC) and Gas Turbine Combined Cycle (GASCC)

		to other developing countries.	
Jing et al. (2008)	China	Combination of a top-down recursive dynamic CGE model with a bottom-up electricity sector model, to simulate policies: an output tax, fuel tax, and carbon tax, as well as combinations.	The preferred policy for China is either a national level fuel tax or carbon tax imposed at the national level with carbon emission caps in the electricity sector.
Aunan et al. (2003)	China	A bottom up study (in Taiyuan), a semi-bottom-up study in Shanxi province, and top-down study using a CGE model for China. Policy: carbon tax on energy.	Maximum 'no-regrets abatement' of CO_2 estimated at 15-20% (including agricultural benefits). Top-down analysis estimats benefit of abatement at 4-5 USD/ton CO_2.
Garg et al. (2003)	India	Estimates the future GHG and local pollutant emissions for India under various scenarios: high and low growth, carbon or sulphur mitigation, frozen development scenario.	GHG and local pollutant emissions do not move in synchronization and are disjoint under various scenarios. Kuznet curve estimate: SO_2emissions peak around per capita GDP of US$ 5,300–5,400 (PPP basis).

Note that such studies can comprehend other ancillary benefits beyond health. The World Bank and China SEPA (2007), for instance, prepared a study of ancillary benefits that considers in the policy cost-benefit analysis also crop loss and corrosion of materials. In developing countries, however, it is still quite rare to find estimates of the ancillary benefits of a policy which include a variety of ancillary benefits beyond air pollution and health related ones.

1.2 From reduction to concentration and exposure

Part of the empirical research focuses on the physical mechanism that translates a reduction in air pollutants from given sources into average concentration levels in a given space. These can either be numerical models, such as PHOENICS, FLUENT, MERCURE, MEMO, CALGRID, etc. (more computationally intensive) or parametric models, such as STREET, CPBM, OSPM, etc. (harder to test) (Murena et al. 2009). The most used models are:

i. Dispersion models - atmospheric simulations that estimate the ground-level concentration of pollutants at various distances from their sources;

ii. Computational fluid dynamics (Karim and Nolan 2011);

iii. Land use regression models, which combine monitoring of air pollution at various locations and development of stochastic models using predictor variables (traffic representations, population density, land use, physical geography), usually obtained through geographic information systems (GIS) (see Hoek et al. 2010 for a review).

Unfortunately applications of such models in developing countries are scarce: see for instance Briggs et al. (1997) for Prague, Czech Republic, or specific case studies in the yearly NATO report on Air Pollution Modelling and its applications (the XIX edition included for instance case studies for Sofia, Bulgaria and Istanbul, Turkey). From an economic perspective, the estimates of these models are often borrowed from the natural science literature as an input to obtain the final social benefits..

1.3 From exposure to health

Moving from concentration to actual health impacts requires an understanding of the epidemiological response of individuals to a given dose of pollutants, controlling for the characteristics and behaviours of these individuals. This issue has spurred an ample medical literature on dose-response functions and health effects of air pollutants. Some years ago this was an extremely popular field of research - consider for instance that that between 1980 and 1993 Zmirou et al. (1997) identified and reviewed 107 original dose-response function studies. Recently this type of research has also become quite common in developing countries, despite the difficulties in accessing long time series on air pollution and health data. A special report of the Health Effects Institute found 138 papers published in the peer-reviewed journals with original estimates of health effects of outdoor air pollution in Asia, between 1980 and June 2003 (HEI 2004).

The methodology for such studies has become quite standardized, although the accuracy of specific results depends on the quality of collected data. Differences in dose-response functions in developed and developing countries should not be too large, once all possible confounding factors for socio-economic, demographic and institutional conditions are controlled for. The population of a developing country is likely to have on average worse health conditions due to poverty and scarce access to medical infrastructures, therefore being more sensitive to air pollution, however in terms of dose responses, after controlling for the baseline health conditions of individuals, differences are not too large (Wong et al. 2002).

The general methodology for obtaining dose-response functions (as illustrated, for instance, in Yanjun et al. 2011) consists of an empirical model for either mortality or morbidity outcomes as a function of a time-stratified (e.g. moving average of past 3 days) measure of air pollution, plus a large number of environmental and individual controls. The exact model specification is usually non-linear and depends on the nature of the pollutant. Often it is assumed a Poisson distribution for the dependent variable, since death and illnesses are rare events. Case-crossover design can be applied to study the effect of transient exposure onto acute events such as death (Carracedo-Martinez et al. 2010).

Below are summarized the results of a number of dose-response function studies conducted in developing countries and especially in China since the end of the 1990s. Note that cohort studies on long term health impacts are still very rare in China (Zhang et al. 2007)

Dose-response functions estimations			
AUTHORS	LOCATION	MODEL & CONTROLS	RESULTS - Coefficients of pollutant on health outcome
Alberini et al. (1997)	Delhi, India	Time series study on the impact of TSP on mortality.	An increase of 100 micrograms in TSP 2.3 % increase in deaths, lower than average in other countries.
Jin et al. (1999)	China	Total Suspended Particulate (TSP) and PM_{10} effect on mortality and morbidity.	All-cause mortality DRF of 0.046% change, with standard error of 0.017. Mortality due to respiratory diseases 0.359% (s.e. 0.127). Mortality for cardiovascular disease 0.128 (0.053).
Xu et al. (2000)	China	PM_{10} (TSP), SO_2.	All-cause mortality DRF of 0.028% change, with standard error of 0.009 for TSP, 0.029% (s.e. 0.009) for SO_2 . Mortality due to cardiovascular diseases 0.036% (s.e. 0.013) for from TSP, 0.018 (0.012) for SO_2. Mortality from respiratory disease 0.043 (0.027) from TSP , 0.074 (0.025) for SO_2.
Kan and Chen (2003)	China	PM_{10}, SO_2	All-cause mortality DRF of 0.030% change, with standard error of 0.010 for PM10, 0.159 (0.025) for SO2. Mortality due to cardiovascular diseases 0.040% (s.e. 0.015) for PM10, 0.169 (s.e. 0.045) for SO2. Mortality from respiratory disease 0.060 (0.035) from PM10, 0.325 (0.078) for SO2.
Venners et al. (2003)	Chongqing, China	SO_2	All-cause mortality 0.039 (s.e. 0.024). Mortality due to cardiovascular diseases 0.182% (s.e. 0.041). Mortality from respiratory disease 0.104 (s.e. 0.048).
Wong et al. (2001)	China	PM_{10}, SO_2	All-cause mortality 0.161 (s.e. 0.059) from SO_2. Mortality from respiratory disease 0.094 (s.e. 0.053) from PM_{10}.
Cropper et al. (1997)	Delhi, India	PM_{10}(TSP)	All-cause mortality 0.038 (s.e. 0.017). Mortality due to cardiovascular diseases 0.072% (s.e. 0.055). Mortality from respiratory disease 0.052 (s.e. 0.143).
Wong et al. (2002)	China	PM_{10}, SO_2	Hospital admissions for respiratory diseases 0.1 (s.e. 0.025) for PM_{10}, 0.178 (s.e. 0.04) for SO_2. Hospital admissions for cardiovascular diseases 0.07 (s.e.

			0.02) for PM_{10}, 0.208 (s.e 0.035) for SO_2.
Zhang et al. (1999)	China	PM_{10}	Chronic respiratory illness in adults 0.299 (s.e 0.014).
Jin et al. (2000)	China	PM_{10}	Chronic respiratory illness in adults 0.461 (s.e 0.05).
Qian et al. (2000)	China	PM_{10}(TSP)	Chronic respiratory illness in children 0.362 (s.e 0.017)
Qian et al. (2004)	China	PM_{10}	Chronic respiratory illness in children 0.969 (s.e 0.045)
Yu et al. (2001)	China	PM_{10}	Chronic respiratory illness in children 4.756 (s.e 0.815)
Zhang et al. (2002)	China	PM_{10}(PM_{10} and TSP)	Chronic respiratory illness in children 0.447 (s.e 0.054)

There exist also interesting meta-analyses of such epidemiological studies (e.g. Aunan and Xiao 2004, Kan and Chen 2005) that were then used them for further studies, for instance of monetary costs of illness (e.g. Zhang et al. 2007, Zou et al. 2010).

1.4 From health to welfare

Finally, health impacts must be converted to monetary values, so to be able to compare different scenarios with different outcomes across countries. The value of a person's life and health, however, can vary a lot across individuals and countries. A number of measures have been developed in the literature: some use indirect estimation techniques based on the average productivity of an individual (Human Capital approach), or the expenses and foregone income due to illness (Cost of Illness); some other ask more directly a stated preference to a sample of individuals, and consist of experiments to elicit the value associated with health outcomes (Willingness to Pay to avoid an airborne disease or the mortality risk associated with pollution). The latter can be sub-divided into Contingent Valuation studies (CV), usually providing just two choices, and Choice Experiments (CE), offering several options. The table below summarizes the main techniques for estimating the economic value of benefits on health[3].

Quantifying the Economic Value of Ancillary Benefits

[3] For an analysis of the criticisms to contingent valuation studies and their biases and reliability in developing countries, see Whittington (1998) and Venkatachalam (2004): for instance, applying "bidding games" in developing countries to estimate the maximum WTP can be problematic since results are very sensitive to the design of the bids and quite costly to implement, since the interviewers must necessarily be present and know well about the survey. Furthermore, there are always issues of benefit revelation (i.e. is the people's behaviour same in both ex-ante and ex-post situations?) and benefit transferability (i.e. is it possible to transfer valuation from one fraction of the population to estimate how a second group of the population would value the same resource?) (Griffin et al. 1995).

Mortality	Human Capital	Based on present value of productivity of an individual, lost in case of premature death.
	WTP	Ask people directly what they are willing to pay for reduced risk of mortality. Captures intangibles.
Morbidity	COI	Consider 1) medical expenses and 2) lost wage and restricted activities while in bed
	WTP	1) Averting method behaviour: time and money spent by an individual to avoid air pollution is the lowest bound value of health 2) Contingent valuation method: willingness to pay to avoid symptoms and lost days of work.

Source: adapted from El-Fadel and Massoud (2000)

A number of studies explored how different these values can be for developing countries: to quote some examples, Alberini et al. (1997) perform a WTP survey for Taiwan, Alberini et al. (2007) study WTP in Delhi, El-Fadel and Massoud (2000) apply both COI and WTP to Beirut, Lebanon, and Citifuentes et al. (2001) analyse the case of Chile. The table below summarizes some of these studies' results. The most significant recent studies for China are listed at the end.

From health benefits to welfare gains			
AUTHORS	LOCATION	MODEL & CONTROLS	RESULTS
El Fadel and Massoud (2000)	Lebanon	Hospital data in various parts of Beirut: COPD hospital admissions, Pneumonia hospital admissions, Respiratory and cardiac hospital admissions. Measures COI, WTP and human capital value.	Economic benefit due to 10 μg/m3 reduction in PM10: 11-617 death cases avoided; morbidity (CODP) 31-441. In Millions US$/year ranges between 0.41-15.8 (by COI) and 4.53-172.5 (by WTP).
Cifuentes, Prieto, and Escobari (2001)	Chile	WTP survey	Get also WTP also for later stages of life (70-80 years old)
Alberini et al. (1997)	Taiwan	WTP survey	Median WTP for a typical airborne illness episode is around 40 US$.
Wang and Mullahy (2006)	Chingqing, China	WTP study, sample of 500 residents based on multistage sampling methods. Face-to-face household interview with a series of hypothetical, open-ended scenarios followed by bidding game questions.	Given a mean annual income of $490, WTP for one statistical life is $34,458. Marginal increases are of $240 with 1year age increase, $14,434 with 100 yuan monthly income increase, and $1590 with 1 year education increase. Unlike developed country, clean air is still a “luxury” good in China based on these income elasticity.
Guo et al. (2006)	China	Contingent valuation study to elicit WTP for asthma and	Estimated value of a statistical case of asthma is about US$2300,

		mortality.	median VSL estimated is about US $24,000.
Hammit and Zhou (2006)	China: Beijing, Anqing in Anhui province and rural areas near Anqing.	Contingent valuation study (WTP) on three health endpoints: cold, chronic bronchitis, and fatality.	Median WTP to prevent an episode of cold: US$3-6; to prevent a statistical case of chronic bronchitis: US$500-1,000; value per statistical life: US$4,000-US$17,000 - about 10 and 1,000 times smaller than estimates for the US and Taiwan.
Hoffmann et al. (2010)	Shanghai, Jiujiang and Nanning, China	Stated preference survey for contemporaneous and future mortality risk reductions.	Reduction in annual mortality risk reduction of 5 in 10,000 is about $430,000 in PPP.
Hoffmann et al. (2012)	Mongolia	WTP study for value of a statistical life	VSL of $500,000 (based on a purchasing power parity exchange rate) for a contemporaneous 5-in-10,000 annual risk reduction.
Desheng et al. (2012)	Pearl river Delta, China	Morbidity effect: cost of illness (COI) method. Mortality effects: both the amended human capital (AHC) method and the results of contingent valuation (CV) study.	Economic loss from PM_{10} pollution in PRD is 29.21 billion Chinese yuan by using CV results and COI method, (1.35% of the regional GDP), and is 15.51 billion Chinese yuan by using AHC and COI methods (0.72% of the regional GDP).

These studies in developing countries are also useful to assess the feasibility of benefit-transfer methods, with values from developed countries, adjusting for either income, income elasticity of for a WTP function: Alberini et al. (1997), for instance, find that different benefit transfer strategies from US values yield more or less agreement with their estimates, with more sophisticated benefit transfer techniques (like WTP functions) providing more accurate results. Similarly, Hoffman et al. (2012) administer in Mongolia a survey similar to others done in other countries (USA, Canada, Japan, France, Italy, UK, and China), and find that given income differences, their values are on the lower range of those found in other countries (except for VSL, similar to that of China). For a comprehensive review and a case study of benefit transfer methodologies across countries with large income differences, see Czajkowski and Scasný (2010).

1.5 Linking steps together: Environmental Burden of Disease

Using the concentration of pollutants in the air, the values of dose-response functions and the valuation of health outcomes, it is possible to estimate the overall environmental burden of a disease (EBD) caused by air pollution, therefore predicting how much a reduction in the pollutants' concentration can benefit a society. The World Health Organization (WHO) presents a methodology that is then applied to the case of Bangkok, Thailand? for implementing the overall EBD caused by air pollution (Ostro 2004). The steps are the following:

1. Get the dose-response function for a pollutant in terms of a health endpoint
2. Calculate with it the relative risk, a non-linear function of the DRF and the change in pollution level above a baseline. The functional forms chosen in the literature are summarized in the table below.

Outcome and exposure metric	Source	Relative risk function[a]	Suggested ß coefficient (95% CI)	Subgroup
All-cause mortality and short-term exposure to PM10[b]	Meta-analysis and expert judgment (see text)	RR = exp[ß (X -Xo)]	0.0008 (0.0006 - 0.0010)[c]	All ages
Respiratory mortality and short-term exposure to PM10 (all-cause mortality for upper bound where applicable)	Meta-analysis (Table 2)	RR = exp[ß (X-Xo)]	0.00166 (0.00034, 0.0030)	Age <5 years
Cardiopulmonary mortality and long-term exposure to PM2.5	Pope et al. (2002); R Burnett[d]	$RR = [(X+1)/(Xo+1)]^{ß}$	0.15515 (0.0562, 0.2541)	Age >30 years
Lung cancer and long-term exposure to PM2.5	Pope et al. (2002); R Burnett[d]	$RR = [(X+1)/(Xo+1)]^{ß}$	0.23218 (0.08563, 0.37873)	Age >30 years

3. Calculate than the attributable fraction (AF) for that illness, as the sum over all groups I for the product of P_i, the population subgroup (for instance an age group) and RR_i, the relative risk for that subgroup. Subtract 1 from the numerator to eliminate the control group, untreated.
4. Calculate the expected population damage, E, as the product of the AF, the death rate for that population and size of the total population.
5. Finally multiply the number of people affected by the disease by the value of that health outcome, to see how much monetary benefit would derive from a reduction in air pollution could reduce the burden of disease.

Baseline

One fundamental issue to consider when doing bottom-up studies of health benefits of air quality is the baseline to compare with. In the aforementioned methodology, this is needed for the X_0 in the RR calculation. This means having an estimate of the death rate and number of people "normally" affected by airborne diseases – for instance before the implementation of a policy, or before a city became polluted – with as much detail as possible (for instance breakdown by age group, gender, etc.). A well-constructed example of baseline is presented in El-Fadel and Massoud (2000) for their Lebanese case-study.

Morgenstern (2000) identifies 5 categories for baseline control:

1. Policy baseline, including laws and regulations, together with their degree of compliance.
2. Technology and efficiency levels
3. Demographics, such as population trends, health status improvements, income changes, urbanization, etc.
4. Economic activity, possibly disaggregated at industry level
5. Natural activities and assimilation capacity of the environment for pollutants.

In developing countries collecting detailed baseline data might be a problem, since historical trends may not be available for long time periods. This is one reason why many researches consider time series only within the range of observation for the study itself (Burtraw et al. 2000).

2. TOP-DOWN APPROACHES

The previous section reviewed all individual steps needed to estimate what sizeable economic benefits a country could get as an ancillary benefit from GHG mitigation policy. For completeness, however, it is important to mention also how all these individual parameters, which are interesting per se, can also be used as inputs in general equilibrium models, a more powerful tool to simulate different scenarios, controlling for various conditions and extending the analysis to many countries or sometimes the entire globe. The table below summarizes some important CGE models, which use a top-down approach that includes the monetary gains of policy spillovers on local air pollution.

Computable general equilibrium models			
AUTHORS	LOCATION	MODEL & CONTROLS	RESULTS
Dessus and	Santiago	GE model, elasticity of	Including benefits, no welfare loss from

O'Connor (2001)- 1st in LDCs	del Chile, Chile	substitution between different types of energy sources and between energy and other inputs.	10% emission reduction by 2010 or carbon tax of $75/tC, even with conservative controls.
Bussolo and O'Connor (2001)	India	CGE	On conservative assumptions emissions could be reduced by somewhat more than 10 per cent from their 2010 baseline level without incurring net costs.
Aunan et al. (2007)	China	CGE model, ancillary benefits of NOx abatement. Also models impact on agricultural yields.	China may reduce its CO2-emissions by 17.5 per cent without suffering a welfare loss. Half of the benefit originates in the agricultural model.
Garbaccio and Jorgenson (2000)	China	Multi-sector Solow growth (dynamic recursive) model.	Reducing carbon emissions by 5% every year from base case will reduce premature deaths by some 3.5 to 4.5%. The health damage caused by air pollution in the first year is about 5% of GDP. A policy to modestly reduce carbon emissions would reduce local health losses by 0.2% of GDP annually.
Gielen, and Changhong (2001)	Shanghai, China	Linear programming MARKAL model for the Shanghai energy system. optimal set of policies for reduction of SO2, NOx and CO2 in Shanghai for the period of 2000–2020.	The results show that no-regret options are not so advantageous because Shanghai has improved its energy efficiency significantly in recent years.
Songsak et al. (2011)	Thailand	Impact Pathway Approach (IPA). SO2, NOX, and PM10 including secondary particulates (sulfate and nitrate aerosols) –simulated using the CALMET/CALPUFF modelling system. Then exposure-response functions are used to quantify the marginal damage to public health.	The average damage cost was totally about 600 million 2005 US$ annually which ranged between 0.05 and 4.17 US$ cent kWh−1 depending on fuel types.
Van Vuuren et al. (2003)	China	Using IMAGE/TIMER model, it simulates year-to-year investments decisions based on a combination of bottom-up engineering information and specific rules about investment behaviour, fuel substitution and technology. SO2.	Combining all options considered, it appears to be possible to reduce emissions compared to the baseline scenarios by 50%.

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