Policy Modelling for Reducing GHG emissions: A Global Review

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Abstract

This paper provides a comparative review of the modelling/analyses undertaken by various countries to develop climate change policies. The review suggests that there is a commonality in such modelling approaches at the macro levels. The results of these modelling/analyses however differ considerably at micro-levels. This is largely due to the differences in baseline assumptions which are a reflection of country-specific social-political. This limits the usefulness of the existing models to facilitate the development of a broader consensus on policy responses to address the climate change challenge. This limitation appears pronounced if one takes note of the fact that several other influencing factors are not even considered in these modelling approaches. These factors include uncertainty associated with the availability of low-carbon technologies; implications of non-pricing approaches; market failures due to asymmetric information; culture and social factors. The conceptual bases of the existing modelling approaches therefore need to evolve.

1. Introduction

Global warming and its potential consequences for humanity have lately emerged as issues of significant public policy interest. Countries across the world are considering a range of policy measures to redress the climate change challenge. These measures can be broadly classified into two broad categories, namely, a market-based and regulatory. Most of these measures focus on reducing the growth of greenhouse gases (GHG), principally carbon dioxide (CO2) – the dominant GHG.

Further, these measures have been designed on the basis of modelling of energy systems and analysis of energy-economy interactions. A review of such modelling/analyses reveals that there are considerable contrasts across countries and regions. This raises the questions: Do such contrasts preclude the development of a common platform for developing a global policy discourse on this topic and hence a global consensus on policies to achieve CO2 reductions? Against this background, this paper develops a comparative assessment of the salient features of modelling and analyses undertaken by select major countries. The emphasis in this assessment is on identifying the similarities and differences in the approaches adopted by different countries to develop their climate change policies.

Countries/regions included in this review include: Australia, Canada, European Union (EU), Japan, United States, Brazil, India, China and Russia. This country grouping is fairly representative. It includes developed and developing economies, countries with effective climate change policies and countries which have decided to play a wait-and-see game.

The main methodology followed in this paper for developing comparative assessment (as noted above) is to review policy modelling and analyses undertaken by various countries in terms of the following features: model structure, model methodology, time horizon, geographical scope, baseline assumptions and mitigation options. Baseline assumptions include: negative cost measures, technological representation, discount factors and underlying data assumptions for economic growth, population growth and energy use.

The paper is organised as follows: Section 2 provides an overview of climate change policies and underlying modelling undertaken by various countries included in this paper. Section 3 presents some observations made on a basis of a review of various models in terms of the features as noted above. Section 4 highlights some limitations of these models in facilitating the development of a common platform for achieving a global consensus to readdress the climate change challenge. Section 5 draws some major conclusion of this analysis.

2. Climate Change Policies and Underlying Models

Table 1 provides a general overview of the various polices considered by various countries and the models employed by them to formulate such policies. Policy analysis in the developing countries seems not to be based on any rigorous modelling effort at national levels; hence for the purpose of this analysis, results obtained from international studies are considered.

Table 1: Climate Change Policies and Underlying Models

	Key Policies	Models	Model Description
Australia	Carbon Price (ETS from 2015), RE, EE, Land use	MMRF, GTEM, G-Cubed	These CGE models are whole-of-economy models they capture the supply and demand interactions between different sectors of the economy (IEA, 2009).
Canada	RE, EE, Invest in clean energy technologies	E3MC, EC_IDYGE	E3MC consists of a combination of Energy 2020 model and the Informetrica Model (TIM) (IEA, 2009). EC_IDYGE is CGE model of global trade and energy use.
EU	ETS, EE, CCS, RE (20% from 2020)	POLES, GEM-E3	POLES is a world energy sector simulation model, providing a detailed analysis of technologies of the energy sector (IEA, 2009). GEM-E3 provides a broad evaluation of the economic consequences in the whole economy (Capros *et. al*, 1997).
Japan	EE, RE, Domestic ETS, CDM	DNE21+, AIM/Enduse	DNE21+ determines the most cost-effective measures to reduce emissions (IEA, 2009). AIM/Enduse estimates GHG mitigation potential using a marginal abatement cost tool with a detailed mitigation options database (IEA, 2009).
US	Carbon Tax (limited regions), ETS, CCS, RE (20% from 2020)	ADAGE, SGM, EPPA, MERGE	ADAGE and SGM models are more focused on long-term (2050-2100) policy analysis (IEA, 2009). EPPA and MERGE models play a key role in providing insight for Congressional testimony, and (IEA, 2009).
Brazil	EE, RE, Reduce Deforestation, Increase use of Bio-fuels		
India	EE, RE, Reduce Deforestation, Increase use of Bio-fuels	Global GHG Abatement Model v2.0 (McKinsey)	McKinsey model is mainly based on external baseline sources IEA WEO, US EPA and Houghton and assesses the abatement potential and cost of over 200 abatement levers in 21 world regions (IIASA, 2009).
China	EE, RE, Expand Nuclear Reserves, Reduce Deforestation		
Russia	EE, RE, Expand Nuclear Reserves, Carbon Tax & ETS (under consideration)	GAINS	GAINS quantifies GHG mitigation potentials and costs for the major Annex I countries (includes Russia), and estimates co-benefits on air pollution (IIASA, 2009).

Source: Garnaut, 2011b; IEA, 2009

3. Comparative Assessment

Table 2 provides an overview of GHG modelling undertaken by various countries as noted in Section 1. Key observations are discussed as follows:

Model Structure: It appears that some of the countries such as Australia and United States employed general equilibrium top-down models, whereas Japan and other international institutions have relied on bottom-up models. EU and Canada have employed both bottom-up and top-down models. Also, some of the models employed by Australia and United States consist of hybrid features.

A key distinguishing feature of these approaches is how they characterise technology, emissions, energy and the economy. In general, top-down models emphasize economy-wide impacts of environmental policies, but have less detail on specific emissions abatement technologies (IEA, 2009). In contrast, bottom-up models assume a rather narrowly defined system boundary and focus on technical mitigation measures; that do not consider feedback effects associated with the adjustment in market mechanism or prices (IIASA, 2009). Hybrid models on the other hand, incorporate technological detail into a macroeconomic context (IEA, 2009).

Such differences could therefore produce different results and, as a consequence, lead to significantly different investment and costs decisions. Computable general equilibrium (CGE), top-down models, measure total cost of a policy for the whole economy, not just the costs for the affected sectors (IEA, 2009). In contrast, bottom-up models are generally built upon an engineering cost basis of emitting processes and technologies, and measure only direct costs (IEA, 2009). Also, bottom-up models with higher interest rates or relatively short payback periods assess long-lived capital investment with higher costs (IEA, 2009).

Thus, on the basis of modelling structures it can be argued that better insights into policy questions can be gained only by employing models that integrate top-down and bottom-up approaches.

Model Methodology: As can be seen from Table 2, models differ in the underlying methodology and can be broadly grouped into recursive-dynamic and forward-looking models.

In general, recursive-dynamic and forward-looking models differ in their assumptions of future changes. For example, in a recursive structure agents cannot look ahead to see resource depletion and hence would, if allowed, produce and consume these resources at marginal cost of production until they suddenly ran out of them (IEA, 2009). Forward-looking agents look ahead and see the implications of over-consuming depletable resources and hence allocate these scarce resources optimally over time (Babiker *et al.* 2008). Forward-looking models tend to bring forward some substitution between technologies, lowering the transition costs and thus reducing the carbon price for a given level of mitigation (IEA, 2009). Thus, forward-looking models, such as G-cubed, EC-IDYGE, DNE21+, EPPA, ADAGE, MERGE and McKinsey examined here tend to show greater emission reduction potential in earlier years as compared to others as they recognise the carbon price signals in later years (IEA, 2009).

Policy analysis in Australia and the United States is based on the application of both methodologies, whereas EU employs only recursive-dynamic models. Canada and Japan, on the contrary, employ forward-looking models, along with casual simulation and

Table 2: Key features of the Models undertaken by selected countries

Model	Model Structure	Model Methodology	Time Horizon	Geographical Scope	Baseline Assumptions			Mitigation Options			
					Negative cost Measures	Technological Representation	Discount Factor	CCS	Nuclear Power (Additional to Baseline)	Hybrid Vehicles	Bio-fuels
MMRF	Hybrid	Recursive-Dynamic	2050	Australia	No	Exogenous	4% for exogenous assumptions otherwise none	Yes (from 2020)	No	Yes	Yes
GTEM	Hybrid	Recursive-Dynamic	2050	Global	No	Exogenous		Yes (from 2020)	Yes, but not for Australia	Yes	Yes
G-Cubed	Top-down	Forward-looking	2050	Global	No	Yes	4%	No	No	No	No
E3MC	Bottom-up	Casual Simulation	2020 (2050 possible)	Canada	No	Exogenous	7%	Yes (from 2020)	Yes	Yes	Yes
EC-IDYGE	Top-down	Forward-looking	2050	Global	No	Exogenous (Labour only)	5% benchmark interest rate	No	No	No	No
POLES	Bottom-up	Recursive-Dynamic	2050 (2100 optional)	Global	No	Information not available	N/A	Information not available			
GEM-E3	Top-down	Recursive-Dynamic	2050 (infinite optional)	Global	No	Exogenous	Determined endogenously	No	No	No	No
AIM/ Enduse	Bottom-up	Linear Optimization	2050	Global	Yes	No	5%	No	No	Yes	Yes
DNE21+	Bottom-up	Forward-looking	2050	Global	Yes	Exogenous	5%	After 2021	No	Yes	Yes
EPPA	Top-down	Forward-looking	2100	Global	No	Exogenous	4%	Yes	Yes	No information available	Yes
SGM	Top-down	Recursive-Dynamic	2100	Global	No	Exogenous	3%	Yes after 2025; no retrofits	Yes	No	No
ADAGE	Top-down	Forward-looking	2050	Global	No	Exogenous	5%	Yes	Yes	No	Yes
MERGE	Hybrid	Forward-looking	2100	Global	No	Exogenous	5%- real interest rate, 4%-by 2050	Yes	Yes	Yes	Yes
GAINS	Bottom-up	Static(single year) cost optimization	2030	Annex 1	Yes	Exogenous	4%	Yes	No	Yes	Yes
Mckinsey	Bottom-up	Forward-looking	2030	Global	Yes	Exogenous	4%	Yes	Yes	Yes	Yes

Source: IEA, 2009

linear optimization models. International models, such as GAINS and McKinsey, typically employ cost optimization and forward-looking approaches, respectively.

Time Horizon: Time horizon varies across the models, for example, models such as AIM, McKinsey and GAINS focus on short-term issues only, whereas other models such as MERGE, SGM and EPPA extend analyses to 2100; remaining models project out to 2050. A longer time horizon gives a longer planning horizon allowing for more capital turnover and technological progress (IEA, 2009). However, comparing models with different time horizons shows difference in results, especially in the later years (i.e. beyond 2050), because the uncertainties become large the farther models project into the future.

Geographic Scope: Some of the national models such as MMRF and E3MC and international models such as GAINS have limited geographic scope whereas other models have a global coverage. In general, models that are geographically limited in scope do not capture all of the international trade effects of a carbon price scenario, but are better suited to capture detailed existing capital (IEA, 2009). For example, in E3MC which is a national model of Canada, the electricity sector is highly disaggregated (i.e. unit by unit) and is fully aligned to provincial circumstances and operating conditions of existing electricity-generating capital stock, whereas the other model, EC-IDYGE, which is global in scope has a more aggregate treatment of electricity, does not necessarily reflect provincial circumstances (IEA, 2009b).

Similarly, in the case of MMRF model: it is the only model that covers Australian economy in detail, i.e. various sectors of the economy such as electricity, transport, agriculture and forestry are linked with each other. The GTEM and G-Cubed are models of global economy (Australian Government, 2011). This can result in lower emission reduction potential from national models, although it largely depends on the magnitude of trade effects (IEA, 2009).

Baseline Assumptions:

Negative Cost Measures: It appears that models differ considerably in their approaches to the treatment of negative-cost measures. These measures are so-called “no regret” policies, or mitigation options that imply net benefits, although they may often require substantial up-front investments and the treatment of such measures varies across models (IEA, 2009b). In general, only bottom-up models tend to include this feature; however E3MC and POLES models tend to ignore it.

The DNE21+ baseline assumes that all of the negative cost measures for energy-related CO2, and low cost measures for other GHGs which are already utilised, are adopted, thus leading to the situation that marginal cost curves start at zero costs (IEA, 2009). Similarly, other models such as E3MC and POLES calibrate costs of mitigation measures in such away that the baseline simulation reproduces observed behaviour by specifying transaction costs that explain why consumers do not exploit this so-called no-cost energy saving potential (IIASA, 2009). As a consequence, marginal cost curves produced by these models contain only positive costs (IIASA, 2009).

On the contrary, AIM, GAINS and McKinsey do not calibrate transaction costs in the most effective manner. As a consequence, the marginal cost curves in these models start with negative marginal costs (IIASA, 2009). This difference in treatment of cost measures in the baseline explains much of the difference obtained in marginal cost curves. In general, models that include negative cost measures will project higher emission reduction potential for a lower price of carbon.

Technological Improvements: It appears that technologies are generally exogenously specified in most models, and they are assumed to become cheaper over time. While some models assume a continuation of historically observed trends and thus consider some of these measures in their baseline, others include these measures in their mitigation portfolios (IIASA, 2009). The AIMS model adopts a ‘frozen technology’ concept, where the future share and energy efficiency of standard technologies are fixed at the same level as in the base year, thus giving different results (IEA, 2009). As a consequence of such different baseline definitions, estimated mitigation potentials can differ, although in reality the same measures might be applied (IIASA, 2009).

Discount Factor: As seen from Table 2 majority of the models have used low discount rates, ranging from 3% to 7%. The discount rate can significantly influence the results. For example, a low (approx zero) discount rate means that future generations are treated at par with present generations and the use of high discount rate results in burdening the future generations with higher costs of mitigations (Scott, 2007). It is argued that Annex I countries should use a low discount rate when assessing optimal mitigation strategies as postponing action now would put a larger burden on future populations of developing countries who would be poorer than what the citizens of Annex I countries are today (OECD, 2002).

Underlying Data: The assumed growth in emission generating activities such as population growth, general economic development and energy use has a critical impact on costs for lowering GHG emissions in the future.

The use of different data sources will impact modelling estimates. For some parameters, such as population projections, majority of the models have used one particular source (i.e. UN data sets). The sources of other key parameters, such as economic growth, energy use/energy intensities and GHG emissions, tend to vary. This could hamper a cross-comparison of models as some models express GDP in terms of purchasing power parity (PPP), while other models use market exchange rates (MER) concept for quantifying GDP, thus producing different assumptions on economic growth (IIASA, 2009). Different assumptions on GDP growth could also imply different quantifications of GHG emissions in future to which mitigation measures are employed. These factors have direct impact on the starting points and shapes of mitigation cost curves, as they determine baseline emissions levels and the potential for mitigation measures (IIASA, 2009).

Another important driver of baseline differences is the year of the data set used, or how recent the estimates are. For example, the energy price projections are higher in IEA’s World Energy Outlook (WEO) 2008 than in the WEO 2007 (IEA, 2009). Similarly, some of the models such as E3MC, EC_IDYGE, ADAGE, EPPA, MERGE, GEM-E3 and POLES incorporate the impact of global recession of 2008 in their modelling analysis, thus lowering the baseline emissions trends in the short term. It can be suggested that modelling estimates rely a lot on the robustness of the baseline assumptions; variations in the baseline assumptions can cause significant change in the results. Also on comparing the models with similar results, it is difficult to isolate the impact of these assumptions.

Mitigation Options: Models analysed in this assessment differ in their sectoral definitions and level of disaggregation, however most of them agree on the role of electricity and transport sectors in increasing the GHG emissions of the world. Thus with the availability of mitigation options from 2020 onwards, greater emission reduction potential also lies in these sectors.

It appears that majority of the models include CCS and nuclear options in the electricity sector, with the exception of MMRF and GTEM models, as expansion of nuclear power generation currently appears unlikely in Australia. While the GAINS model does not allow for nuclear growth beyond what is included in the baseline as a mitigation option, DNE21+ model however excludes nuclear power completely. In addition, some of the models such as G-Cubed, GEM-E3 and EC-IDYGE do not include mitigation options as part of their analyses. Similar estimates are drawn for mitigation options in transport sector with the introduction of hybrid vehicles and bio-fuels.

With the introduction of these mitigation options from 2020 onwards, most of the countries can reduce their emissions as, with time, countries undergo structural and technical changes. However, in the early years, the marginal abatement cost curves are flat but in later years cost curves tend to be much steeper, indicating higher costs as most of the least-cost options would have already been implemented.

4. Some Limitations

The above discussion provides an overview of the key features of modelling/analyses undertaken by various countries to develop policies to address the climate change challenge. It appears that, at a macro level, there is a significant commonality in the modelling/analytical approaches followed by various countries. The results however of such modelling differ considerably. This is mainly due to the appreciable differences that exist at the micro-levels, especially in the baseline assumptions. These differences are a reflection of country-specific social-political differences. This should provide some idea about the limits of the usefulness of these models to enable the development of a national or global policy consensus. This limitation will appear even more pronounced if one takes into consideration the following:

1) Most of the models assume that low-carbon emission technologies would be available from 2030 onwards, but as result of technological advancements and marketing, these options could be available much earlier. This could result in increased energy consumptions and higher GHG emissions. Again, it is not possible to anticipate such developments with accuracy in advance, especially as simulations extend further into the future (Murphy, *et. al*, 2007).

2) Most models do not consider the implications of non-price based mechanisms such as voluntary schemes being followed by some countries. Furthermore, models do not capture the risks and impacts of climate change itself and market failures caused by it, as the mitigation policy aims at improving the efficiency of the economy by pricing the ‘externality’ involved, but those emitting do not bear all the costs associated with emissions (Australian Government, 2011).

3) Market failure caused by asymmetric information, strategic interaction between agents and public goods are also excluded from modelling. Also, models do not capture the potential co-benefits of climate change mitigation policy. Some co-benefits occur between mitigation and other environmental objectives, such as the simultaneous reduction in local and regional air pollution, together with carbon reduction from less coal burning (Australian Government, 2011).

4) One of the dominant issues in the economics of climate change is dealing with uncertainty, which is difficult to account for through modelling. Policy-debate world-wide is dominated with the question: "Do we know enough to control the problem now or should we wait until more is known about climate change?" (Kelly, *et. al*, 1998) However, if this uncertainty is not resolved quickly, then the costs associated with waiting will add up to

much higher costs in future. In addition, the uncertainty of investment return is major risk for investors and in the absence of transparent prices underpinning efficient markets, investors will require far higher rates of return to protect themselves from adverse market events.

5) The majority of literature on climate change indicates that the capability of models for enabling a comprehensive policy analysis for developing countries is limited. The development of baseline scenarios for developing countries is very complicated and uncertain due to the unavailability of national statistics and formal macroeconomic models (Kirsten, 1996). Different modelling methodologies exist to analyse energy-economy-environment policies but their methodological features and modelling frameworks need to be developed specifically for developing countries. This appears to be a major challenge for developing countries modellers.

6) Further, these models do not consider country-specific behavioural and cultural aspects. These aspects are critical for achieving policy consensus. For example, it is argued that humans are driven by their unconscious minds, that we are not rational individuals but emotional social beings who need to be liked and admired by their kin who are very important to us. Culture cognition can be explained as the need to "filter the information we hear to reinforce our personal beliefs in ways that make us liked by those we admire. In other words, we feel kinship to a team, then listen to information and unconsciously filter it so the information confirms our belonging that that team" (TIF, 2010). This drives the tendency of individuals to listen or believe only what confirms their personal cultural perspectives. Cultural perspectives can "be explained as a complex set of ideas, meanings, attitudes and ideas belonging to a group" (TIF, 2010).

   The different cultural perspectives of eastern and western civilizations have impacted the environment tremendously. Western world has done a lot of damage to the environment in the past in its attempt to modernize and the eastern countries are quite influenced by their practices and are trying to match the western lifestyle and match their technical and economic growth, thus damaging the environment even more. Making a policy addressing climatic change is largely influenced by formal organizations and the relations among them, both informal and formal, as the members of these organizations can be from different countries, with different cultural backgrounds. Political issues, policy proposals, legislation, administrative regulations, judicial decisions, and their interpretation are all socially constructed. Culture shapes both how the goals of public policy are defined and the course of action taken to implement them.

Thus, ignoring such dimensions from modelling analysis will not facilitate a common dialogue within a country or at a global level. Hence the conceptual methodology of these models needs to evolve; models should move away from basic fundamentals of computable general equilibrium or neo-classical approaches and incorporate other variables that can monitor the impact of socio-political changes, cultural attributes and many others.

5. Conclusions

- There are significant contrasts between the policy modelling foci of developed and developing countries. Much of the developed countries appear to favour market based approaches for example Emissions Trading Scheme (ETS) and market mediated carbon pricing regimes. Developing world on the other hand appears to favour approaches underpinned by energy efficiency improvements and technology standard based schemes, giving more emphasis to regulatory and subsidy based mechanisms.

- Policy analysis in the developing countries seems to be not based on any modelling effort whereas in the developed world there are examples of the application of detailed modelling including analysis of economy wide impacts. Most of these models are based on the application of CGE.

- The macro-level models focus is primarily on the economic dimensions and generally lack in technological detail; they are completely neglectful of the significance of institutions and political considerations. Also, these models appear to focus on immediate issues, and tend to discount long-term issues.

- There appears to be a considerable contrast in the drivers that define alternative future scenarios. In addition, baseline assumptions play an important role in determining the modelling results. Also, critical are cultural and social factors.

- Despite apparent commonality at macro-level, there is no distinctive coherence in the modelling and analyses approaches followed by various countries. This clearly militates against the development of common approach and global consensus on redressing the climate change challenge.

- This limitation gets further pronounced if one takes note of the fact that several factors are not at all considered in the dominant modelling practices. These factors include, for example, the uncertainty associated with the availability of low-carbon technologies; implications of non-pricing approaches; market failures due to asymmetric information and cultural and social factors.

Acronyms Used:

ADAGE – Applied Dynamic Analysis of the Global Economy
AIM – Asia-Pacific Integrated Assessment Models
CDM - Clean Development Mechanism
E3MC – Energy-Economy-Environment Model for Canada
EC_IDYGE – Environment-Canada Intertemporal Dynamic CGE
EE - Energy Efficiency
EPPA – Emissions Predictions and Policy Analysis
ETS - Emission Trading Scheme
GAINS – Greenhouse gas Air Pollution Interactions and Synergies
GEM-EC – General Equilibrium Model for Energy-Economy- Environment Interactions
GTEM - Global Trade and Environmental Model
MERGE- Model for Evaluating Regional and Global Effects of Greenhouse gas Reduction
MMRF - Multi Regional Forecasting
POLES – Prospective Outlook for the Longer term Energy System
RE- Renewable Energy
SGM – Second Generation Model

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