MAPS
Mitigation Action Plans & Scenarios

THE CHALLENGES OF LINKING
sectoral and economy-wide models

TECHNICAL // Linking Models

October 2012

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Purpose

The purpose of this brief is to highlight some of the issues arising in linking models for use in policy analysis and to share some of the approaches that have been explored by researchers in MAPS to address these challenges. It aims to provide other researchers working on establishing similar linkages with a better understanding of the challenges involved and to raise awareness among other stakeholders of the complexities of linking models.

Introduction

Policy makers and researchers in the MAPS countries, namely Brazil, Chile, Colombia, Peru and South Africa are interested in knowing what the socio-economic implications of proposed mitigation actions in their countries will be. Understanding the developmental benefits of acting on mitigation can provide a strong case for more ambitious mitigation action. Where costs of mitigation actions outweigh benefits, it is important to understand clearly who might bear the burden of such costs, to be able to manage them effectively. To carry out such analysis to provide good information, researchers would have to link sectoral models that project the impact of mitigation actions within sectors, with economy-wide models. This is because these sectoral models cannot provide us with the complete set of answers we are looking for, on their own. Sectoral models such as those for energy and those for land-use often do not include variables like employment and poverty and when they do, represent only the direct impacts in the sector, not the ripple effects throughout the economy and society. On the other hand, we cannot use economy-wide models to simulate the necessary shocks brought about by mitigation actions in the various sectors. It is therefore necessary to link sectoral and economy-wide models to provide rigorous information on the socio-economic implications of mitigation actions.

The linking of these models is however complex and has not been perfected by anyone, despite efforts to address the challenges of providing socio-economic analysis of mitigation (Dubash 2009; Halsnæs & Shukla 2008; La Rovere et al. 2011; Pan 2003; Urban 2010; Winkler & Marquard 2009). It is therefore important that researchers consider the challenges that they are likely to encounter as they attempt to link these models. This will inform them of the feasibility of achieving the desired linkages. Identifying these challenges will also help researchers to think about possible solutions.

Climate policy questions in a national context

Models are tools to explore policy questions. In considering the challenges of linking, the MAPS researchers examined key drivers and related policy questions in their respective countries.

In Brazil, the deforestation of the Amazon is the biggest contributor to greenhouse gas (GHG) emissions. Emissions from deforestation accounted for 57.5% of total emissions of 2,203Mt CO_2eq/annum in 2005 (MCT 2009). This was followed by emissions from agriculture and animal husbandry at 22.1%. The energy sector came third at 16.4%, largely due to the contribution of hydropower and renewable biomass which accounted for a 45% share of renewables in the country´s total energy supply. At COP 15 the Brazilian government volunteered to reduce emissions by between 36.1% and 38.9% by 2020, compared to the business-as-usual (BAU) projection. In information submitted to the UNFCCC, Brazil also identified specific mitigation actions to achieve this level of relative emissions reduction, most notably an 80% reduction in rates of deforestation in the Amazon and 40% in the Cerrado (La Rovere 2011). Additional measures include the agricultural sector as well as mitigation in the energy sector. The focus in Brazil's mitigation policy has been on reducing emissions from deforestation. As the Brazilian economy grows and deforestation is reduced, emissions from the energy sector are expected to overtake those from deforestation around 2020. Mitigation actions in the energy sector as well as their socio-economic impacts are therefore important for MAPS Brazil. The key policy questions in the short term (up to 2020) focus on how to implement reductions in the LULUCF sector, but in the longer term focus on how to avoid increases in energy-related emissions.

The energy sector is the largest contributor to national emissions of GHG in Chile. The country's energy mix is based primarily on fossil fuels, with oil accounting for 56%, and both natural gas and coal accounting for 11% in 2007 (IEA 2009). At COP 16, the government of Chile pledged to reduce the growth of CO_2 emissions by 20% of the BAU scenario by 2020, using 2007 as a base year. To meet this target, government initially pledged to increase the contribution of Non-conventional Renewable Energy (NCRE) from 3% in 2010 to 20% by 2020. The NCRE target has since been reduced to 10% by 2024 for technical and economic reasons (Ministry of Energy 2012). Under Chilean law, NCREs are small hydroelectric centers (with a capacity of less than 20 MW) and projects that utilize energy from biomass, hydraulics, geothermal, solar, wind, tidal, and others (IEA 2009). Voluntary mitigation actions by about 4000 companies under the Clean Production Agreements (APL) are now expected to help Chile to meet its target (CPL 2012) by reducing 18.4 million tons by 2020. Other potential mitigation actions for Chile identified in Sanhueza (2011) include energy efficiency in copper mining and the the sustainable management of and recuperation of native forests, with the latter having the potential to reduce emissions by 234 million tons by between 2011 and 2050. In the transport sector, an energy efficiency programme and a programme to promote a sustainable modal shift from private to public and from motorized to non-motorized could also contribute to reduced emissions (Sanhueza 2011). Key policy questions addressed by the MAPS Chile team focus on the most efficient and effective mitigation options to achieve its international pledge, associated opportunities and trade-offs including addressing poverty impact on the economy; Chile's international competitiveness; links between adaptation and mitigation options; and key public policy measures and private sector initiatives that can help achieve this (Rudnick et al. 2011).

The three main sources of GHG emissions in Colombia are the energy and agricultural sectors, as well as deforestation. According to the national emissions inventories, the energy sector contributed 36.6%, livestock and agriculture 38.1% and the deforestation of natural forests 14.5% in 2004 (IDEAM 2009). In 2010 the Colombian government sent a letter to the UNFCCC pledging to have at least 77% of installed capacity for power generation being renewable technology by 2020 (Cadena et al. 2011). Colombia would aim to have zero deforestation of the Colombian Amazon by 2020 as well as to increase biofuel production to at least 20% of the total fuel by 2020. As part of MAPS, Colombia is undertaking a comprehensive analysis of the growth perspective for the sectors in the short, medium and long term and the technologies that are expected to lead to the development of these sectors (MAPS Colombia 2012), as well as the implications for the national GHG profile. Key policy questions include the identification of the options with the greatest potential for reduction of emissions in each of the sectors; the costs and co-benefits of these options and the impact they would have on economic growth, employment, competitiveness, poverty reduction and the wellbeing of the Colombian people. Added to that, MAPS Colombia team would also like to identify the sectors that would be most affected by a consumer shift away from carbon-intensive products internationally.

According to recent estimates, total emissions in Peru were 146,783 Gg CO_2eq in 2009 (Gutiérrez et al. 2012). Land use change was the main source of emissions, accounting for 38% in that year. This was followed by energy at 27% and agriculture at 25%. To mitigate climate change, the Peruvian government made 3 voluntary commitments to the UNFCCC in 2010. The first is to work towards acheiving zero net deforestation of natural forests by 2021 (Postigo et al. 2011; MINAM 2011). The second is to have renewable energy contributing at least 40% of all energy in Peru by 2020 and the third is to reduce emissons from urban solid waste disposal, with potential emissions reduction estimated to be 7 Mt CO_2eq for the latter (MINAM 2011). For Peru, adaption has a high priority because of decreasing water availability and the loss of tropical areas. Mitigation is however important in terms of the co-benefits it might have on the Peruvian economy. The MAPS programme is aiming to contribute the mitigation part of a PlanCC, and has recently been identified as one of three activities on climate change by the Peruvian Ministry of Environment. Some of the key policy questions for Peru include the identification of mitigation options available over the short, medium and long term and its impact on GDP, employment, productivity, competitiveness (including exports), public finance, inflation, income distribution and poverty reduction (PlanCC 2011). PlanCC would also investigate other impacts and/or co-benefits (including their contribution to adaptation) of each of the mitigation actions. Doing so, PlanCC would assess the risks and opportunities presented by a shift to a low-carbon economy and determine whether doing so would be in Peru's best interest.

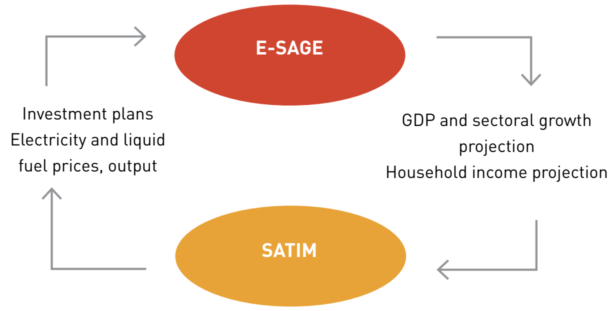
At COP 15 in Copenhagen, the South African government pledged to reduce GHG emissions by 34% and 42% below the BAU emissions growth trajectory for 2020 and 2025 respectively, provided they received the necessary financial, technological and capacity-building support from the international community (DEA 2010). According to the national greenhouse gas inventories, emissions in South Africa are predominantly from the energy sector, which accounted for 78.9% of total emissions in 2000 (DEAT 2009). The largest contributors in the energy sector are the energy industries (electricity generation and refineries), which accounted for 62% of emissions. This is largely due to emissions from the power generation by coal-fired power stations and the conversion of coal to liquid fuels by Sasol. According to the Policy-Adjusted Integrated Resource Plan (IRP) 2010-2030 (DOE 2011), while coal's share of the fuel mix for electricity production would be expected to decrease from 90% in 2010 to 65% in 2030, renewable energy would increase from 0 to 9% and nuclear from 5% to 20%. This would contribute to reduced GHG emissions. In the Long Term Mitigation Scenarios (LTMS), the carbon tax was found to result in the largest reduction in emissions compared to all the other options analysed (Winkler 2007). National Treasury is planning to implement a carbon tax in South Africa in the 2013/2014 financial year, although the tax levels have not been finalised (Business Report 2012). There have however been concerns about the implications a carbon tax would have on jobs and poverty (Pauw 2007; Winkler & Maquard 2011; Devarejan et al. 2011; Van Heerden et al. 2006, Alton et al. 2012). In 2011, the South African government released its National Climate Change Response white paper, presenting their 'vision for an effective climate change response and the long term, just transition to a climate-resilient and lower carbon economy and society' (DEA 2011: 5). A number of flagship programmes meant to assist in climate change mitigation in government departments such as Public Works and Transport were highlighted. Concerns were also raised about the impact of mitigation actions on employment, job creation and living stardards.

What is meant by 'linking models' ?

As mentioned earlier, linking models become necessary when models available are not capable of answering our questions comprehensively. But what does linking involve, and what gets passed from one model to the next? Some researchers in MAPS have already started work on linking models. The approach being used by modellers at the Energy Reseach Centre (ERC) in South Africa and COPPE in Brazil is illustrated below.

The ERC has been working on linking the South African TIMES energy model (SATIM) with an economy-wide model, E-SAGE (Energy extension of the South African Computable General Equilibrium Model). Figure 1 below shows the information that is passed from the SATIM to E-SAGE, and vice versa.

FIGURE 1: SIMPLIFIED REPRESENTATION OF TIMES–CGE LINK FOCUSING ON MAJOR ELEMENTS LINKING THE MODELS



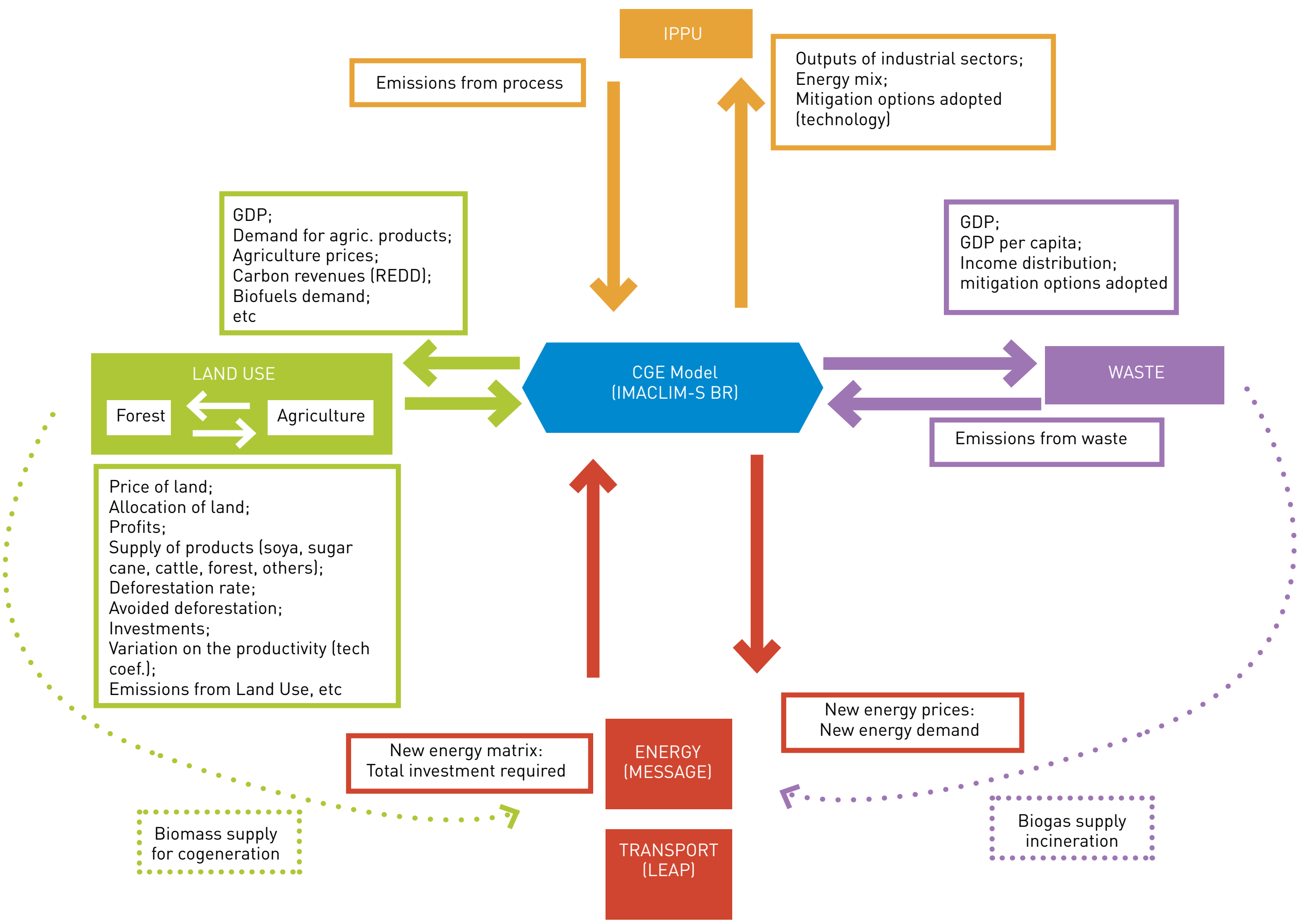
Source: Hughes et al. 2012.

Overall GDP and sectoral growth projections are outputs from the economy-wide model as shown in Figure 1. These projections are used to calculate useful energy demand for the different sectors, with the latter being used as input into the energy model. Household income projections from E-SAGE are also used to calculate useful energy demand particularly for the residential sector. On the other hand, information on investment, as well as the electricity and liquid fuel prices and quantities, are passed from SATIM on to the economic model. E-SAGE, then forces the electricity supply path (an exogenous input) as well as investment into the electricity sector, which reduces the investment available for other sectors.

Researchers at COPPE in Brazil have been working on the link between IMACLIM, a computable general equilibrium (CGE) and MESSAGE, an energy model. In addition, the researchers are planning to link IMACLIM with a land-use model, and other models, as shown in Figure 2. The information that would be passed from one model to the other is shown.

Establishing links between the various modules has also started with energy, and particularly electricity, as in South Africa. The major data passed between MESSAGE and the CGE model are the new energy prices and energy demand from the CGE as well as the new energy mix and the total investment from the energy model.

FIGURE 2: LINKAGES BETWEEN IMACLIM AND SECTORAL MODELS



Source: Wills 2012

The challenges of linking models

Linking sectoral models with economy-wide models is a complex exercise and modellers are faced with an array of challenges with which they have to deal. Some of these challenges are identified and discussed below. It is important to note that this list is meant to raise awareness of some of the challenges that have already been identified by researchers and is therefore not exhaustive.

Understanding/common language

As the models being linked are from different disciplines, one of the biggest challenges is having an understanding of all the models being linked. Running models across disciplines such as economics and engineering, and having full grasp of what is happening can be very difficult. Modellers from different backgrounds use different languages, in the sense of different modelling software, but at times also conceptually (e.g. "demand" may refer to energy demand in GJ for energy modellers, but economic demand in monetary terms for economic modellers). Having to communicate results and explain the modelling can become even more complicated.

Energy modellers at the ERC have been working with economists at the ERC and United Nations University World Institute for Development Economics and Research (UNU-WIDER) on linking the models and this has helped everyone involved to have a better understanding of what is happening in both the energy and economy-wide models.

Consistency

Researchers will also be faced with the challenge of ensuring that there is consistency between the models that they are linking. As sectoral models and economic models are developed independently, it is possible that similar or common sectors in the models to be linked could be defined differently. This was the case for modellers at the ERC as they worked on linking SATIM with E-SAGE. Although both models used standard industry codes (SIC) to define the different sectors, there was a mismatch between the sectors in the models. It was therefore necessary for the modellers to make sure the sectors in the two models were defined consistently, and dealt with any differences systematically. To address the mismatch of sectors in the models, researchers at the ERC used the same SIC digit codes for both SATIM and E-SAGE, thereby ensuring that sectoral definitions were the same.

Consistency between the two models could also refer to the data used by the models, the use of common assumptions and matching the time periods in the two or more models being linked. Researchers from COPPE found it difficult to have consistent energy price levels between the CGE and the energy model. The problem is that market adjustments on the CGE model may lead to a vector of prices that is very different from what was expected by the energy model. Therefore, to have a coherent and realistic framework, price consistency is essential and might have a strong influence on the final results.

Disaggregation

Another important challenge is making sure that we have adequate disaggregation in our models to enable us to carry out the required analysis of mitigation actions. Most economic models have highly aggregated sectors which limit the ability of researchers to get a deep understanding of what is happening within the sectors. If policy questions in the electricity sectors are important, SAMs need to be disaggregated into different fuels providing electricity. If modellers or researchers are interested in linking these economic models with sectoral ones, it could become necessary to disaggregate the sector of interest in the economic model in order to link the models. Researchers could also disaggregate sectors that are of interest in terms of analysing the impacts of mitigation actions. Disaggregation into different household types can provide rich information on implications for poverty and inequality. Impacts on different industry sectors can show winners and losers from a particular mitigation action, which would be important for decision makers to understand – even if there is a net benefit from the national perspective, and even more so if additional costs have to be borne. This could include sectors that are not relevant in terms of emissions but are affected significantly by the impacts, such as fisheries as suggested by researchers from the Energy Centre in Chile.

Compatibility

As researchers link models it is essential that they determine whether the models they are interested in are compatible with each other. Compatibility could be at two levels, that is, the type of models that are being used and the type of platform or software that these models are built on.

Type of model

There are a number of sectoral models that could potentially be linked with an economy-wide model. Sectoral models include those for the energy sector as well as agriculture, forestry and land-use. Differences between these sectoral models mean that we would not be able to apply a standard methodology of linking all the models. The way we would link an energy model to a CGE model would differ technically from the way we would link a land use such as BLUM to a CGE model. It is also difficult to assign monetary values on aspects such as biodiversity and ecosystems for forestry and land-use models and this presents challenges on how they can be linked with economic models that rely heavily on monetary values.

Modeling platforms or software

The different models also use a variety of platforms or software such as GAMS and Matlab and this could affect the ability of modellers to link the models. Modellers must be aware of the platforms on which each of the models they are interested in linking are constructed. They might have to learn how to use new software in order to perform the desired linkages, which would be a challenge on its own. Even for those using the same platform, it is possible that the models use different functions or coding within that platform and linking the two could require significant changes or an additional module.

Time horizon

When assessing compatibility, another consideration could be the time horizon of each of the models being linked. Even when we have consistency in terms of the time periods covered by the models that will be linked up, it could be that within those models results are not produced on a yearly basis or over time periods that conform. This could be related to the platform used and could affect the feedback between the models and how the whole system works.

Hard-linking or soft-linking

Modellers will also have to make a decision about whether or not to have a hard link or soft link between the models. A hard link would be one that is automated, with the two models becoming and acting like one, while a soft link would involve passing information between the models manually. Although a hard link would be more convenient and less time-consuming, one of the cons is that the models become 'black boxes', making them difficult to use and understand by those not involved in coupling them. Once the hard link has been established, it could also be difficult to make any changes to the individual models should it become necessary.

A semi-hard link is being developed between SATIM and E-SAGE. Although the informaton being passed from one model to the other is automated through an additional module, the models still remain independent and can be assessed and reviewed separately.

Model interface

It is also important to consider the interface of the model. Researchers at COPPE are using MESSAGE as the energy optimizing model (supply model), which has an interface that is made in such a way that the user just needs to type in the energy demand, technological costs, etc. This interface makes the use of MESSAGE much easier than what it would be with a programming interface. On the other hand, this interface makes it more difficult to create a hard link with IMACLIM. Overcoming this challenge is now one of the main focuses of the COPPE team.

In summary, the challenges identified above include having an understanding of all the models being linked as they tend to be cross-disciplinary. Consistent definitions of common sectors as well as prices and quantities of commodities in the models and adequate disaggregation of the sectors is also very important. The models must also be compatible with each other, in terms of the type of models being linked, the platforms that they use, and the time horizon they cover. Modellers must also decide between having a hard or soft link, or having something in between. When linking models modellers must remember to focus on information relevant to key policy questions in their countries.

Conclusion

While linking sectoral and economy-wide models may provide researchers with rigorous results, the actual process of linking can be quite challenging. This brief highlights some the challenges that researchers or modellers will be faced with as they attempt to establish these linkages between the models. It is important that modellers are aware of these challenges so they can assess whether or not it is possible for them to successfully complete their desired linkages. Awareness of these challenges will also assist modellers by providing them with a starting point from which they can begin to explore possible solutions to these challenges. This brief shares the experiences of some researchers within MAPS who are already dealing with these challenges. This provides other modellers with insight into how they may approach these challenges. It might also help them to develop ideas that may improve what has already been done to address these challenges.

References

Alton, T, Arndt, C, Davies, R, Hartley, F, Makrelov, K, Thurlow, J & Ubogu, M 2012. The economic implications of introducing carbon taxes in South Africa. Working paper No. 2012/46. http://www.www.wider.unu.edupublicationsworking-papers 2012wp2012-046h. Accessed 25 October 2012.

Business Report 2012. Carbon tax proposed effective from 2013/14. http://www.iol.co.za/business/business-news/carbon-tax-proposed-effective-from-2013-14-1.1240415. Accessed 2 November 2012.

Cadena, A, Rosales, R, Delgado, R, Espinosa, M, Rojas, A, Salazar, M, Castillo, G & Ovalle, K 2011. Mitigation actions in developing countries country study for Colombia. MAPS. Universidad de los Andes.

CPL [Consejo Nacional de la Producción Limpia].

CPL 2012. Reconocimiento mundial a esfuerzos de Chile para combatir el cambio climático. http://www.produccionlimpia.cl/link.cgi/Noticias/1820. Accessed 8 November 2012.

DEA [Department of Environmental Affairs].

DEA 2010. Letter to the Executive Secretary of the United Nations Framework Convention on Climate Change (UNFCCC) on South Africa's nationally appropriate mitigation action under the Copenhagen Accord.

DEA 2011. National climate change response. White Paper. http://www.info.gov.za/view/DownloadFileAction/id=152834h. Accessed 25 October 2012.

DEAT [Department of Environmental Affairs and Tourism].

DEAT 2009. Greenhouse gas inventory South Africa, 1990-2000. Compilation under the United Nations Framework Convention on Climate Change (UNFCCC).

Devarajan, S, Go, D S, Robinson, S & Thierfelder, K 2011. Tax policy to reduce carbon emissions in a distorted economy: Illustrations from a South Africa CGE model. *The B. E. journal of economic analysis and policy*, 11(1): 1-22.

DOE [Department of Energy].

DOE 2011. Integrated resource plan for electricity 2010-2030 Revision 2. Final Report. www.energy.gov.za/IRP/2010/IRP2010.pdf. Accessed 26 October 2012 .

Dubash, N 2009. Climate change and development: A bottom-up approach to mitigation for developing countries? R B Steward, B Kingsbury and B Rudyk (Eds). Climate finance: Regulatory and funding strategies for climate change and global development. New York: New York University Press: 172–178.

Gutiérrez, M E, García, D, Gonzales, S & Barrios, R 2012. Actualización del Inventario Nacional GEI al 2009 Equipo de Investigación. PLANCC presentation.

Halsnæs, K & Shukla, P 2008. Sustainable development as a framework for developing country participation in international climate change policies. Mitigation and adaptation strategies for global change 13: 105-130. http://ideas.repec.org/a/spr/masfgc/v13y2008i2p105-130.html. Accessed 9 October 2011.

Hughes, A, Merven, B & Caetano, T 2012. Modelling emissions in South Africa: How modelling updates have impacted emissions pathways. International Energy Workshop presentation. Energy Research Centre, University of Cape Town.

IDEAM [Instituto de Hidrología, Meteorología y Estudios Ambientales].

IDEAM 2009. Inventario nacional de emisiones de gases de efecto invernadero. Colombia, 127.

IEA [International Energy Agency].

IEA 2009. Chile Energy Policy Review, IEA/OECD Paris.

La Rovere, E L 2011. Mitigation actions in developing countries country study for Brazil. MAPS. CENTROCLIMA/PPE/COPPE/UFRJ. Brazil.

La Rovere, E L, Dubeux, C, Perira, A & Wills, W 2011. Mitigation actions in Brazil. Research Report, MAPS (Mitigation Action Plans and Scenarios). Rio de Janeiro, Brazil, Institute for Research and Postgraduate Studies of Engineering (COPPE) at the Federal University of Rio de Janeiro. http://www.mapsprogramme.org. Accessed 23 March 2012.

MAPS Colombia (2012) National collective assessment project for low carbon development alternatives and opportunities; Towards the construction of Colombia's strategy for low carbon development. Project document.

MCT Ministerio da Ciencia e Tecnologia].

MCT 2009. Inventário Brasileiro de emissões e remoções antrópicas de gases de efeito estufa. Informações Gerais e Valores Preliminares, Brasília, 24 de novembro de 2009.

MINAM [Ministerio del Ambiente].

MINAM 2011. Peru proposed mitigation actions presentation. Bangkok. http://www.google.co.za/unfccc.filesmeetingsad_hoc_working_groupsperu_ws.pdf. Accessed 31 October 2012.

Ministry of Energy 2012. National energy strategy 2012-2030. Energy for the future. Government of Chile.

Pan, J 2003. Emissions rights and their transferability: Equity concerns over climate change mitigation. International Environmental Agreements: Politics, Law and Economics 3: 1-16.

Pauw, K 2007. Economy-wide modeling: An input into the Long Term Mitigation Scenarios process, LTMS Input Report 4. Cape Town, Energy Research Centre. http://www.erc.uct.ac.za/Research/LTMS/LTMS-intro.htm. Accessed 28 October 2012.

PlanCC (Climate Change into Development Planning) 2011. Project Summary Form. MAPS Peru.

Postigo T, Zevallos P & Tolmos, M P C 2011. Mitigation actions in developing countries country study for Peru. MAPS. Libelula. Lima, Peru.

Rudnick, A, Kleysteuber, A, Palma, R, González, H, O'Ryan, R & Blanco, H 2011. MAPS-Chile Mitigation options for addressing climate change. Project document.

Sanhueza, E 2011. Analysis of the national situation in works on mitigation actions. MAPS. CCYD Consultores. Chile.

Urban, F 2010. Pro-poor low carbon development and the role of growth. *International Journal of Green Economics* 4 (1): 82-93.

Van Heerden, J, Gerlagh, R, Blignaut, J, Horridge, M, Hess, S, Mabugu, R & Mabugu, M 2006. Searching for triple dividends in South Africa: Fighting CO2 pollution and poverty while promoting growth. *The energy journal* 27 (2): 113-141.

Wills, W 2012. The challenge of linking models – A first draft. Working paper. Centro Clima/COPPE. Federal University of Rio de Janeiro, Brazil.

Winkler, H (Ed) 2007. Long Term Mitigation Scenarios : Technical report. Prepared by the Energy Research Centre for Department of Environmental Affairs and Tourism, Pretoria, October 2007. http://www.erc.uct.ac.za/Research/LTMS/LTMS-intro.htm. Accessed 26 October 2012.

Winkler, H & Marquard, A 2009. Changing development paths: From an energy-intensive to low-carbon economy in South Africa. *Climate and development* 1 (1): 47-65. http://www.ingentaconnect.com/earthscan/cdev/2009/.../. Accessed 21 August 2009.

Winkler, H & Marquard, A 2011. Analysis of the economic implications of a carbon tax. *Journal of energy in Southern Africa* 22(1): 55-68.

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