An overview of **Mitigation Scenario Modelling Tools for the Energy Sector**

UNEP DTU Partnership

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Author

Jyoti Prasad Painuly
With coordination of : Fatima-Zahra Taibi

Reviewers

Fatima Zahra Taibi
Gordon A. Mackenzie
Govinda R. Timilsina
Jay Sterling Gregg
Marlan Pillay
Pallav Purohit
Subash Dhar
Vintura a Silva

Design and layout: bounford.com

Cover design: Monna Hammershøy Blegvad

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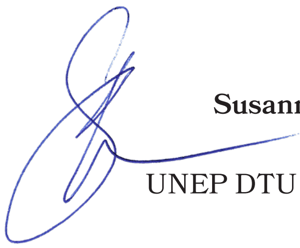
Foreword

Countries have been submitting National Communications (NCs) and Biennial Update Reports (BURs) to the UNFCCC. Following the Paris Climate Change Agreement, countries also need to identify priority areas for implementing the Nationally Determined Contributions (NDCs), report their implementation progress and update them periodically. Funded by Global Environmental Facility, the Global Support Programme provides support to non-Annex I Parties in preparation of NCs, BURs, and NDCs by identifying priority actions in Greenhouse gases inventory, mitigation assessment and vulnerability and adaptation assessment areas. The Programme is jointly implemented by the United Nations Development Program (UNDP) and by the United Nations Environment Program (UNEP).

Countries need suitable tools and approaches to analyse the development and greenhouse gas emissions pathways under existing and new mitigation policies and actions. Assessment of mitigation policies and actions requires scenario building with a view to identifying priority mitigation actions. The GSP identified the need for "Mitigation Scenario Modelling Tools" to support non-Annex I countries for this purpose. The UNEP DTU Partnership (UDP) is implementing partner of the UNEP and is happy to contribute to GSP efforts through this document "Mitigation Scenario Modelling Tools for the Energy Sector". I hope this will help countries identify suitable mitigation action and policies for their energy sector in line with their committed development pathway.



Susanne Pedersen
Director
UNEP DTU Partnership

Preface

The GSP identified the need for "Mitigation Scenario Modelling Tools" to help non-Annex 1 countries assess their mitigation action and policies. The current document covers the modelling tools for the energy sector, which contributed more than 78% of CO_2 emissions in 2020.

The modelling tools can help countries assess national emissions trajectories for the energy sector under existing (business as usual) policies and mitigation actions and policies.

The document covers a wide variety of modelling tools, and countries can select suitable models depending on their objectives, capacity and other constraints. A section on selection criteria can help countries select a suitable model. For example, an optimisation model such as TIMES can be used if the objective is to minimise the cost of the mitigation trajectory. Other bottom-up models such as LEAP and GACMO are easy to use with several mitigation technologies in their databases. The document also includes models for sub-national/sectoral levels such as for buildings, transport and others. Policymakers and practitioners in developing countries interested in GHG mitigation assessment are the primary audiences of the document, and the information presented here can help them select appropriate models /tools to assess mitigation opportunities in their countries. We hope they find it useful.

The author would especially like to thank the report's reviewers for taking the time to review the document. Errors remaining, if any, are his own.

Fatima-Zahra Taibi
Project Manager
UNEP DTU Partnership

Jyoti Prasad Painuly
Senior Researcher
UNEP DTU Partnership

Abbreviations

BAU	'business as usual'
CGE	computable general equilibrium (a type of model)
CO_2	carbon dioxide
GDP	gross domestic product
GHG	greenhouse gas
GSP	Global Support Programme
IAM	integrated assessment model
IEA	International Energy Agency
IO	input-output (a type of model)
IPCC	Intergovernmental Panel on Climate Change
NDC	nationally determined contributions
UNEP	United Nations Environment Programme
UDP	UNEP DTU Partnership
UNFCCC	United Nations Framework Convention on Climate Change

1 Introduction

This publication is a part of the Global Support Programme (GSP; https://www.un-gsp.org/), which supports non-Annex I Parties in preparing their National Communications and Biennial Update Reports that are submitted to the United Nations Framework Convention on Climate Change (UNFCCC). The GSP provides support to the developing countries that includes technical backstopping, tools and targeted guidance, and training to carry out the preparation of these reports. The GSP also assists developing countries in strengthening national institutional arrangements to support the new reporting requirements and ensure alignment with national development priorities.

Mitigation of greenhouse gases (GHGs) is an important measure to address climate change. All the Parties (i.e. countries, signatories to the UNFCCC) have agreed to address and cooperate under the framework of UNFCCC. After the Paris Agreement of 2015, the countries submitted their Nationally Determined Contributions (NDCs), which indicate the actions that countries commit to take for mitigation and adaptation. The identified mitigation actions need to be appropriately assessed, and their expected contribution to mitigation reported to UNFCCC. The GSP support for mitigation assessment includes providing guidance on cost-benefit analysis of mitigation options and socio-economic implications, suitable models for national level mitigation analysis, calculations of mitigation potentials and others.

Why this publication?

This publication has been prepared with the following audience in developing countries in view; (i) current and potential users, who have little knowledge of mitigation modelling and are interested in starting from scratch to build and apply the knowledge in this area, (Ii) policymakers, who want to get an overview of mitigation modelling so that they can initiate and facilitate work of experts working on national communication and similar documents, (iii) experts in developing countries already working on some models in this area but needing a handy document to widen their knowledge base and looking for information on available resources. Many reports and journal articles cover mitigation modelling tools; many reports and similar publications have been listed in section 7, and journal articles are listed in the references section of this document. However, most publications that cover mitigation modelling tools assume users have a good background in using models and list basic features of models with links to the resources: for example, LEDs Energy Toolkit 2.0. Most of such publications either do not cover selection criteria for models, or the coverage is not comprehensive and user friendly. On the other hand, publications that start with the basics of the mitigation modelling tools (some also cover selection criteria) cover only a few modelling tools. Similarly, though covering a specific aspect in details, journal articles are also not comprehensive in coverage as needed by a developing country audience. Journal articles are generally meant for professionals, and another drawback is restricted availability to most users (very few are open access). Also, publications that cover mitigation models, in general, do not cover models for sub-national or sectoral levels such as for buildings, transport etc. Finally, there are continual new developments due to the dynamic nature of this discipline, which are seldom covered by publications. This publication attempts to fill some of these gaps. While not the prime target audience, expert modellers in developing countries can use it as a resource to find publications and platforms that may contain models of interest.

This publication is focussed on the use of models for mitigation analysis at the national level. It lists some models, their applicability requirements, and the benefits of using them and their constraints in terms of complexity, availability, and applicability. Policymakers and practitioners interested in GHG mitigation assessment in developing countries are the primary audiences of the document, and the information presented here can help them select appropriate models /tools to assess mitigation opportunities in their countries. Integrated Assessment Models (IAMs) are primarily used to assess climate change impacts at the global level, and hence they are not discussed here. IAMs have also been used to identify GHG mitigation opportunities at the global level: for example, WITCH and MERGE-ETL 6.0 (hybrid version of MERGE) (IPCC, 2SM).

2 Baselines and mitigation scenarios

A scenario is defined as a possible future pathway with the ability to "capture key factors of human development that influence GHG emissions and our ability to respond to climate change. Scenarios cover a range of plausible futures, because human development is determined by a myriad of factors including human decision making" (IPCC, 2014).

A scenario, when generated with existing policies, is termed a baseline scenario. It is also referred to as the business as usual (BAU) scenario since it assumes non-intervention in terms of policies for mitigation. Therefore, a baseline scenario becomes a "reference scenario" to measure alternate outcomes from an intervention. According to the IPCC, "Baseline scenarios are projections of GHG emissions and their key drivers as they might evolve in a future in which no explicit actions are taken to reduce GHG emissions. Baseline scenarios play the important role of establishing the projected scale and composition of the future energy, economic, and land-use systems as a reference point for measuring the extent and nature of required mitigation for a given climate goal. Accordingly, the resulting estimates of mitigation effort and costs in a particular mitigation scenario are always conditional upon the associated baseline".

Thus, baselines are defined as scenarios that describe future GHG emissions in the absence of defined mitigation efforts and policies. The term "baseline" is often used interchangeably with "business as usual scenario" and "reference scenario" (UNFCCC, 2016). A baseline can, however, deviate from the BAU. This can happen when BAU has some mitigation policies/actions, and the impact of these needs to be estimated. The mitigation policies/actions are extracted from BAU in such cases to formulate the baseline.

An intervention can be a policy or an action (or a combination) that leads to mitigation of GHG emissions: for example, carbon tax (a policy intervention), building a wind power plant (an action) etc. A scenario resulting from an intervention (a policy or action) that leads to mitigation of GHG emissions is referred to as a "mitigation scenario". Thus, the integration of mitigation drivers/mitigation options with a BAU scenario leads to a mitigation scenario. Therefore, a mitigation scenario represents future GHG emissions due to the introduction of specific policies and measures that lead to a reduction in GHG emissions with respect to some baseline (or reference) scenario.

GHG mitigation requires an understanding of complex interaction among energy, economic, social and environmental variables. This requires a modelling approach in order to capture these relationships. Models can help generate different scenarios, estimate emissions and the associated cost of policies and actions over the model's time horizon. The models can thus help estimate the costs and effectiveness of different policies for reducing GHG emissions.

3 Mitigation models and their classification

GHGs primarily include the following gases; carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulfur hexafluoride (SF_6), and nitrogen trifluoride (NF_3)[1] Ozone-depleting GHGs such as chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HFCs), etc., are covered by the Montreal Protocol and its subsequent agreement Kigali amendment to the Montreal Protocol. Other gases are not covered here.

As the title indicates, mitigation modelling tools for the energy sector only are covered in this publication, and the focus is on CO_2 emissions. The publication does not cover mitigation in the Industrial Processes and Product Use (IPPU), Waste, Agriculture, Forestry and Land use (AFOLU) sectors. AFOLU sector emissions include methane emissions from livestock (enteric fermentation), rice cultivation, manure management and flooded lands, nitrous oxide (N_2O) and CO_2 emissions from sources such as managed soils, managed lands, manure management, etc. The AFOLU sector also acts as a sink as it removes CO_2, for example, through afforestation. However, CO_2 emissions from fuel use in machinery (primarily used for non-transport usage) in the agriculture sector are covered by energy models. CO_2 is primarily emitted during the exploration, conversion, transmission, distribution and use of fossil fuels in stationary and mobile applications. Therefore, energy modelling tools covering emissions from energy production, transmission and distribution, and energy use are prime candidates among mitigation tools. While energy models generally cover various sectors of the economy as energy users, the level of detail varies across models. Sector-specific models can be used for detailed analysis of mitigation at the sectoral level. Similarly, depending on the requirement, models covering a geographical unit (a city, for example) or specific end-use, such as heating and cooling, are also in use.

This document is conceived as a living document given the expanding development and use of mitigation modelling tools. New tools and models may be included as and when inputs are received, and the classification will also be updated when needed.

1 For a complete list, refer to 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Chapter 1, page 5.

3.1 Classification of Models

There are a variety of classifications of energy models used for GHG mitigation analysis in the literature, and following Beeck (1999) and Sathye & Shukla (2013), classification criteria include as follows:

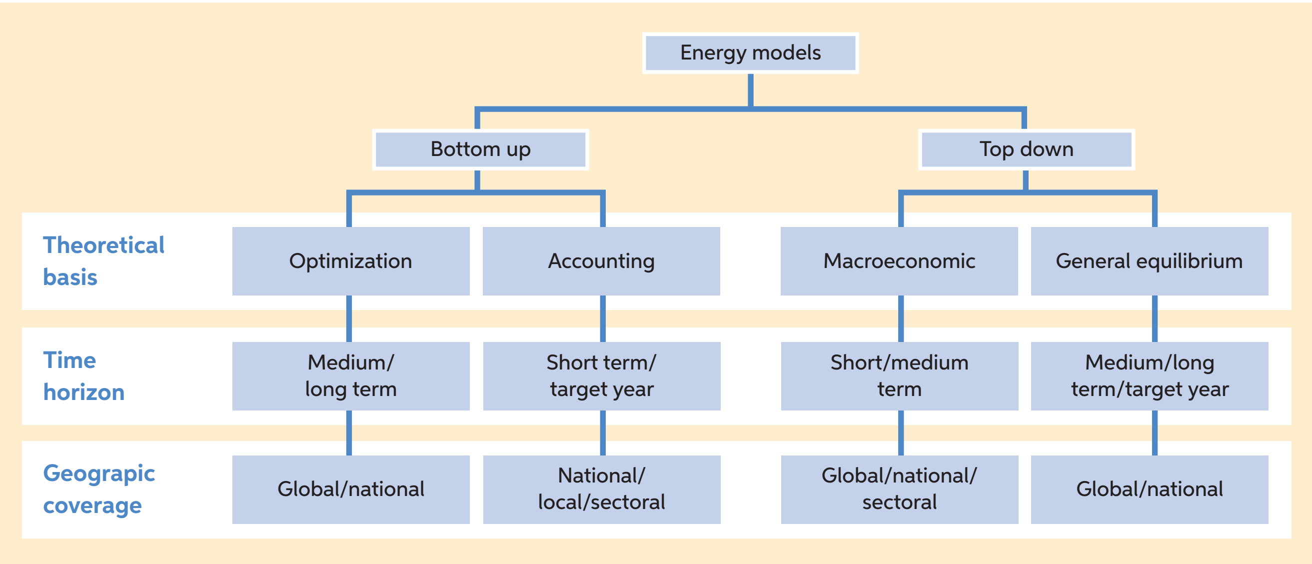
1. General-purpose energy models such as forecasting and backcasting models, and specific purpose energy models such as energy demand models, energy supply models. While forecasting energy models predict the future state of the energy sector under an assumed policy pathway, backcasting refers to a planning method that starts with defining a desirable future and then working backwards to identify policies and programs that would lead to the specified future.[2]
2. The model structure in terms of the degree of endogenisation, coverage of sectors, end uses, technologies etc. Top-down models typically have a high level of endogenisation on account of relationships between different parameters built in the models, whereas, in bottom-up models, many parameters have to be provided exogenously.
3. The analytical approach includes top-down models (economic approach), bottom-up models (engineering approach), and hybrid models that combine these two approaches.
4. The underlying methodologies, which include econometric, general equilibrium, and partial equilibrium models. The partial equilibriums models include optimisation, simulation, and accounting framework models.
5. General equilibrium models encompass the entire economy and all economic agents (such as firms, households and government), and their interactions are fully represented in the models. In these kinds of models, not only the immediate impact of policy but subsequent impacts (referred to as second-order impacts), technological changes or other impacts over time are also considered (Babatunde et al. 2017). On the other hand, partial equilibrium models focus on the representation of a subset of the economic sector and agents. In the case of energy models, partial equilibrium energy models have a more detailed representation of the energy sector, such as technologies, policies etc. Other classification criteria include:
   - Geographical coverage of the models- global, regional, national, and sub-national such as city-level and project level. In global models, coverage of regions (and sometimes even definition in terms of how regions have been clubbed) can vary. In regional models, the number of countries can vary depending on how the region is defined.

2 Backcasting is a planning method that starts with defining a desirable future and then works backwards to identify policies and programs that will connect that specified future to the present (Robinson, 1982). The backcasting responds to the question, "if we want to attain a certain goal, what actions must be taken to get there?" Backcasting is not commonly used - readers interested can refer to page Sathaye and Shukla (2013), page 148, to see the comparison between forecasting and backcasting.

- Sectoral coverage of the models- most bottom-up models cover the energy sector, but some are multi-sectoral models.
- The time horizon: short (a few years), medium, and long term (typically until the end of the century),
- Mathematical approach, which includes: linear programming, mixed-integer programming, dynamic programming, and
- Data Requirements of the models: aggregated (typically in top-down models) and disaggregated (in bottom-up models).

Sathaye and Shukla (2013) combine several criteria and provide a classification, as shown in Figure 1. The classification follows the analytical approach in which models are primarily categorised as top-down and bottom-up models. They then combine it with the methodology (theoretical basis) used in each category, time horizon and geographic coverage in each category resulting in sub-categories as shown in the figure.

Figure 1: Classification of models



Source: Sathaye and Shukla (2013)

Top-down models lack technical details, whereas bottom-up models do not have macroeconomic consistency. However, each type of model, whether top-down or bottom-up, has comparative advantages arising from its structure. For example, bottom-up models can be used to estimate the potential for mitigation at a technology level, including from the introduction of new technology, are readily available and are less resource consuming. In contrast, top-down models can analyse the impact of pricing policies and consider cross-sectoral impacts. Both are complementary in addressing questions related to energy and climate policy. Hybrid models take advantage of this complementarity by establishing soft linkages between the two types of models. Another strategy adopted by modellers is to include technological details in top-down models or incorporate macroeconomic feedback in bottom-up models. For example, if the imposition of carbon tax leads to a reduction in gross domestic product (GDP), it will decrease demand for output, which a macro model can bring out. By soft-linking with the macro model, this reduced demand is fed as input to the bottom-up model. Thus, models do not change in this kind of linkage, but typically outputs from the top-down model are used as inputs to the bottom-up model. This enhances the capacity of the bottom-up model to analyse the impact of policies such as carbon tax. An iterative approach is ideal, but it requires hard linkage between the two types of models, necessitating changes in model codes and leading to increased complexity.

The model categorisation is not always strict. Some models may have features or versions that fall into more than one category. The Low Emissions Analysis Platform (LEAP; erstwhile Long-range Energy Alternative Planning model), for example, was developed as a bottom-up tool in an accounting framework, but recent versions include a hybrid version with soft links to top-down macroeconomic modelling on the demand side.

Brief descriptions and characteristics of these two categories of models are presented below.

3.1.1 Top-down models

Top-Down models are characterised as follows:

- Highly aggregated economic models that primarily focus on interactions between the energy sector and other sectors of the economy.
- The impact of policies on all sectors is considered, and the cost and benefits of the policies are captured through the impact on sectoral outputs and GDP.
- In general, top-down models do not consider energy technologies in detail and primarily focus on the impact of energy and environment policies that impact markets: carbon taxes, the tradeable quota, for example.
- Therefore, less suitable for assessing energy technology improvements but suitable to assess the impact of the market-oriented policies like quotas, taxes and other fiscal policies.

Input-output models, macroeconomic models, including econometric models and general equilibrium models, fall in this category.

Input-output (IO) models: Input-output models typically capture only the demand side and assume no capacity constraints in the economy. Input-output tables usually are made periodically, though not every year, and data are available only after a lag. They thus provide a current picture of the underlying economic structure based on historical data. In other words, an IO model is suitable to show a static picture of the economy that does not take substitution effects, technological progress, and economies of scale into account. Therefore, they are more suitable for the short-term evaluation of energy policies. Mitigation analysis, on the other hand, can extend far into the future. Input-output models, therefore, are not popular for mitigation analysis in isolation.

Econometric models: Econometric models use a combination of economic theory, mathematical tools and statistical methods. Econometric analysis uses empirical evidence to test economic theory. Most of them use time-series data at a high level of aggregation and require a huge amount of data for long periods. An example of this type of model is E3ME, developed by Cambridge Econometrics to address the long-term effects of energy-economy-environment (E3) policies at the European level.

Computable general equilibrium (CGE) models: Within general equilibrium models, CGE models have primarily been used for mitigation analysis and are briefly described here. CGE models are large numerical models which combine economic theory with real economic data and compute the impacts of policies or shocks in the economy. All sectors of the economy and their interdependencies are considered, including both the demand and supply side, with the market as the clearing mechanism.

CGE models usually assume markets in perfect equilibrium, which means they may not consider barriers (and hence costs), for example, to renewable energy and energy efficiency. Policy interventions such as taxes or subsidies lead to a new equilibrium through adjustment in prices and quantities as various actors (households, firms and government), who are price-takers, maximise their welfare through quantity adjustments. Thus, through a general equilibrium approach, CGE models rule out energy efficiency gaps, adjustment delays and consequently neglect the importance of market failures and obstacles (Herbst, 2012). CGE models also do not contain technological details and therefore are not suitable for assessing policies that may be planned to impact technologies. The GEM-E3 model of the European Commission and the GTAP model are examples of CGE models.

The comparative strength of the top-down models is their ability to assess the macroeconomic costs of policies and economy-wide feedbacks on prices, income and economic welfare. However, the impact of technological substitution is difficult to assess, particularly in computable general equilibrium (CGE) models; bottom-up models, including partial equilibrium models, handle it through a detailed description of the technological system and its functioning (Frei et al., 2003.) Table 1 indicates typical top-down models used in GHG mitigation analysis.

These models have been developed and employed widely by governments, international organisations, research institutions and academics. Most of the applications have been in developed countries where these models have originated, and the top-down models are not available off the shelf. Some top-down models have been applied in developing countries through collaboration between developing country institutions and the model developers. These types of models require considerable resources and skill to use. Also, data requirements of top-down models are usually high, and the type of data required can be a constraint for their use in developing countries: for example, time-series data for econometric models, social account matrices for CGE models etc. As a result, most of the mitigation modelling has been done using bottom-up models, which are relatively easily available, as are the technology and sectoral data needed to run the model.

Considering the objective and audience of this publication, top-down models are not discussed here further. Any user interested in a specific top-down model should get in touch with the institutions that have developed/used these models.

Table 1: Top-down models used for GHG mitigation analysis

Model	Institution	Theoretical Framework
AIM CGE	National Institute for Environmental Studies (NIES), Japan	General equilibrium (CGE model)
E3ME	Cambridge Econometrics	Macroeconomic (Econometric)
E3MG	Cambridge University	Macroeconomic (Econometric)
EPPA	Massachusetts Institute of Technology (MIT)	General equilibrium (Multi-sector, multi-region CGE model)
G-CUBED	*McKibbin Software Group* Pty Ltd (Australia)	General equilibrium
GEM-E3	National Technical University of Athens	General equilibrium (Recursive, dynamic CGE model)
GTAP	Purdue University	General equilibrium- CGE (Multi-sector, multi-region CGE model)
MIRAGE-e	CEPII, France	General equilibrium (Multi-sector, multi-region CGE model)
OECD-ENV-LINKAGES	Organisation for Economic Co-operation and Development (OECD), France	General equilibrium (CGE model)
Phoenix	Pacific Northwest National Laboratory (PNNL)	General equilibrium (Recursive, dynamic CGE model)
GTEM	Australian Bureau of Agricultural and Resource Economics	General Equilibrium (CGE model)
MERGE	Electric Power Research Institute, United States	General Equilibrium (Integrated Assessment)

Source: Sathaye and Shukla (2013) and Nikas et. al. (2019)

3.1.2 Bottom-up models

Bottom-up models are characterised as follows:

- In the bottom-up models economy is represented at a disaggregated level (at a sectoral level or below) with detailed characterisation of technologies;
- A high degree of detail regarding technology, such as its cost and efficiency, is included in bottom-up models, but the models do not consider the impact of technology or efficiency on demand for energy, as it is exogenously specified;
- Have detailed representation of technologies on both the supply and demand side; capital, operating cost and technical efficiency of technologies, for example, different fuels, etc.;
- The energy sector is primarily investigated, and a partial equilibrium approach is assumed. Thus, the assumption is that other sectors are not affected by changes in the energy sector and vice-versa. Thus, change in aggregate demand does not affect energy prices;
- Potential can be explored and scenarios made for technology-related assumptions;
- Use a variety of different calculation methodologies, including accounting frameworks, optimisation and simulations;
- Bottom-up models are useful in investigating the impacts of energy policy on the portfolio of technologies, which can help identify low-cost opportunities or design technology-based taxes, subsidies or standards;
- Depending on the type of methodology, a model's capacity varies. An optimisation model, for example, can calculate the lowest cost of energy to meet the demand, whereas an accounting framework model simply takes the user inputs on prices and quantities to calculate the total cost. However, based on user inputs, it can investigate energy paths with different technology combinations. Bottom-up models are used for identifying best technologies through assessment of policies (for example, energy efficiency policy), impacts on investments, benefits, including environmental benefits, and overall sectoral costs.
- A significant drawback of the bottom-up models is that they ignore the economy-wide impact of prices. This is due to their "engineering approach" as against the "economic approach" of the top-down models.
- In general, bottom-up models have no economic resource constraints on the use of labour, capital and other intermediate inputs, but they can take into account natural resource use and physical capacity constraints (power plants, refineries, mines, equipment etc. depending on the type of model.

The bottom-up category of models includes partial equilibrium models that can be further categorised, depending on the methodology used, as optimisation models, simulation models, accounting framework models, and other partial equilibrium models, or a combination of more than one of these types.

Partial Equilibrium Models: Partial equilibrium models usually assess only one sector or a sub-set of sectors; in this case, the energy demand and supply sector and include details of technologies. Examples of these kinds of models include the POLES (Prospective Outlook on Long-term Energy System) model of Enerdata, WEM (World Energy Model) of the International Energy Agency (IEA), and the PRIMES Energy System Model of the European Commission. All these models cover several countries/ regions and are capable of analysing the impacts of prices and other policies. The POLES model, for example, analyses the international energy markets for seven world regions, eleven sub-regions and 32 countries, considers about 40 technologies of power and hydrogen production and the final energy sectors in some detail (Enerdata, 2011). PRIMES is used to analyse the impacts of carbon emission trading and renewable and energy efficiency policies on energy markets within each of the European Union (EU) Member States.

Depending on the methodology used, partial equilibrium framework models have been further categorised as follows:

Optimisation Models: Optimisation models seek to maximise or minimise a mathematical objective function under a set of constraints. In the case of the energy sector, these models select a set of technologies to achieve a specified target (emissions reduction, for example) at minimum cost with given constraints. The supply and demand are in equilibrium at the prices discovered by the model. The MARKAL model, used in many countries, is an example of an optimisation model. Other models include TIMES- also from MARKAL family, MESSAGE (Model for Energy Supply Strategy Alternatives and their General Environmental Impact) developed by the International Institute for Applied Systems Analysis (IIASA) for the energy sector covering the period up to 2100, the DIMENSION (Dispatch and Investment Model for Electricity markets in Europe) etc. Optimisation models normally require data in numbers for end users - number of cars, houses, for example, and technology-wise cost information on the supply side. Market imperfections are not considered by optimisation models.

Variable renewable energy (VRE) penetration has been of particular interest recently, and within energy system modelling, models such as EMPIRE, REMix, and EUCAD have been used to find the optimum solution with VRE in the system without affecting the grid stability. With their capacity to include new technologies, the models can assess proposed solutions to the issue of VRE; for example, the impact of vehicle-to-grid technology on VRE penetration.

It is important to be aware that optimisation models assume perfect information on several parameters such as technology availability and prices, which help the model to arrive at an optimal solution for the future. However, in real life, neither perfect knowledge of the future is possible, nor it can be ensured that actions and policies are taken as assumed in the model.

Simulation Models: Simulation models provide a descriptive, quantitative illustration of energy demand and conversion based on drivers and technical data (population, income, house area, car mileage, energy prices, for example) provided exogenously. The drivers are also used for scenario development. Simulation models are flexible and allow aspects such as strategic behaviour or the absence of complete information to be integrated, which help mirror market imperfections and failures (Herbst, 2012). Some examples of such models include the Residential End-Use Energy Planning System (REEPS), World Energy Model (WEM) etc.

Accounting Framework Models: Accounting frameworks models are also included in the category of simulation models as these models account for the physical and economic flows of the energy system. Scenarios are constructed using external drivers and assumptions on the penetration of new technologies. Examples of these kinds of models include the Low Emissions Analysis Platform.[3] (LEAP), Greenhouse Gas Abatement Cost Model (GACMO), National Impact Analysis (NIA), Model for Analysis of Energy Demand (MAED-1 and 2), and the Policy Analysis Modelling System (PAMS). Accounting framework models are popular with developing countries due to their simple structure. Table 2 lists some typical bottom-up models used for mitigation analysis. Some of these, such as GACMO and LEAP, are used by several developing countries due to their simple structure (spreadsheet-based), low skill requirements, and free availability.

3 Formerly called the Long-Range Energy Alternatives Planning model.

Table 2: Bottom-up models used in GHG mitigation analysis

Model	Institution	Theoretical Framework
GACMO	UNEP DTU Partnership	Accounting Framework
LEAP	Stockholm Environment Institute	Accounting Framework*
MAED	International Atomic Energy Agency	Partial equilibrium
EnerNEO	Enerdata	Partial equilibrium
MARKAL	Energy Technology Systems Analysis Programme (ETSAP)	Partial equilibrium (optimisation)
MESSAGE	International Institute for Applied System Analysis, Austria	Partial equilibrium (optimisation)
POLES	Enerdata, JRC IPTS and University of Grenoble-CNRS	Partial equilibrium (Econometric)
PRIMES	European Commission	Partial equilibrium
PROSPECTS+	New Climate Institute	Accounting Framework*
REEPS	Electric Power Research Institute	Partial equilibrium
TIAM-World	ETSAP	Partial equilibrium (optimisation)
TIMES	ETSAP	Partial equilibrium (optimisation)
WEM	IEA	Partial equilibrium

* Base model. Advance versions have soft-linking with other models/frameworks.

Source: Sathaye and Shukla (2013) and others models sites

3.1.3 Hybrid Models

Policymakers, while designing energy policies, may require models that can evaluate the effect of economy-wide policies, contain details of technologies and fuel-specific measures, and are also able to analyse the impact of regulations as well as market-based policies. Thus, they may need models that incorporate features from both top-down and bottom-up approaches. Hybrid models meet this requirement, and a variety of hybrid models have been developed that incorporate features of both top-down and bottom-up modelling approaches in varying measures. The hybrid models thus have the following features;

i. Technological details of current and potential technologies;
ii. Macroeconomic feedback (economy-wide impact of policies) through general equilibrium framework; and
iii. A framework for decision making on technological options – through optimisation modelling, for example.

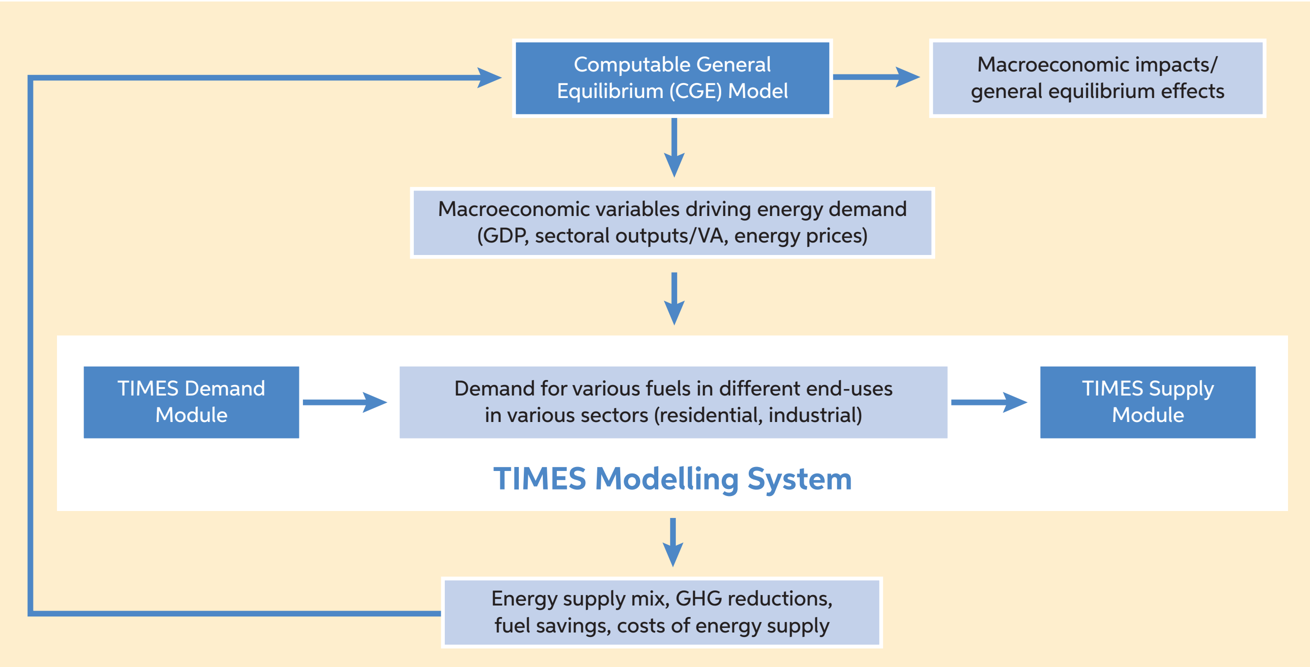
To overcome the weaknesses and limitations of conventional top-down and bottom-up energy models mentioned earlier, energy modelling is currently moving in the direction of hybrid energy system modelling, which combines one or more macroeconomic models with one or more bottom-up models for each final energy sector and the conversion sector. This helps bridge the gap between top-down and bottom-up models either by incorporating macroeconomic feedback into bottom-up models or by including technological details in top-down models.

To address the deficiencies, two strategies have been followed. The first, "soft linking", is the manual transfer of data, parameters and coefficients. In this, a given scenario is run on both top-down and bottom-up models, and output from one model (top-down model) is typically fed into the other (bottom-up model). Therefore, the optimum solution may require an interactive process (Figure 2). It ensures macroeconomic consistency by making GDP growth comparable; for example, certain GDP losses due to a carbon tax can also be applied when calculating energy demands in the bottom-up models.

Figure 2 illustrates the soft-linking in a hybrid model.

Another simple example of this link is the simple hybrid bottom-up CGE model SCREEN (Sustainability Criteria for Regional Energy policies) for Switzerland, which combines technological details of the electricity sector with a macroeconomic CGE framework (Kumbaroglu and Madlener, 2001). It was used to analyse the effects of a CO_2 tax in Switzerland. MARKAL-EPPA, MARKAL-MSG are other examples of hybrid models with soft linkages.

Figure 2: Process of linking the CGE and TIMES models



Source: Timilsina et al. (2019).

In the second approach, the data transfer is further evolved using automatic routines, indicating a 'hard link' between the different models. Thus, it amounts to a top-down model incorporating technological details or a bottom-up model incorporating macroeconomic feedback. Two models are linked to each other in a way that both are solved simultaneously. The MARKAL-MACRO, a MARKAL family model, is an example in which the bottom-up model MARKAL has been combined with some limited macroeconomic sub-models. MESSAGE-MACRO is another example in which the bottom-up MESSAGE model has been hard-linked to a top-down model MACRO. MESSAGE-MACRO also has a version with a soft link.

In summary, in soft-linking, the processing and transfer of information (between the models) are controlled by the user. The user evaluates results from the models and decides if and how the inputs of each model should be modified to bring the two sets of results more in line with each other. In hard-linking all information processing and transfer is formalised and usually handled by computer programs (Holz et al., 2016).

Hybrid energy modelling challenges include theoretical consistency, keeping them manageable in size and computable. Some other examples of the hybrid models currently in use include WITCH, ReMIND, and IntERACT.

3.1.4 Integrated Assessment Models (IAMs)

In addition to the above three categories, there are IAMs that, as the name suggests, explore a variety of impacts and integrate them. They represent the complex physical and social systems, focusing on the interaction between the economy, society and the environment. The energy system models that have been discussed so far for mitigation modelling purposes primarily cover the impacts of human activities on GHG emissions. IAMs contain additional modules to assess the impacts of these GHG emissions on the atmospheric concentration of GHG emissions, the implication of increased GHG concentrations on global temperatures and sea level, and the impact of these changes on ecosystems. The IAMs consider impacts from human activities from sectors other than energy also, as well as impacts of human activities on ecosystems and human beings.

Thus, IAMs are generally global models, and their typical use has been to determine climate change impacts, including global temperature rise from human activities and resultant interaction with other global systems leading to changes in them. These models go beyond mitigation in terms of impacts, have huge resource and skill requirements and hence are not discussed here.

4 Modelling tools and developing countries

Energy system models vary in terms of data requirements, the technological details they cover, and the skill and computing demand required to run them. Bottom-up models that detail technologies require huge databases, which may be challenging to construct in most developing countries. The top-down models' skill and computing requirements can also be beyond the capacity of most developing countries. As a result, most of these models have been developed in industrialised countries to assess energy policies or analyse a specific issue. Even in instances where models with good capabilities have been developed or adapted in developing countries, their use has often been limited by researchers in the institutions who develop or adapt them, and forgotten, once allocated resources have been used up. In many cases, experts who work on mitigation modelling related to national communications may have no collaboration with experts in research institutions. Therefore, the work of expert researchers is often only represented in publications.

Some of these models have also been applied in developing countries. However, there are a variety of issues, including the applicability of data available in the database, rural energy (non-commercial energy) and informal sector dominance in developing countries. A few models have also been developed in developing countries, but their use has been limited to the developer. Also, such models need regular updates, requiring resources periodically for that. Most of the developing countries, therefore, choose to use the models developed in industrialised countries. Since the number of models is large, a comparison of the models in terms of their purpose, features, methodology used, capabilities etc., can help developing countries select an appropriate model. This is the focus of the next section.

4.1 Comparison of selected modelling tool types

A two-step process has been adopted to compare the models that can help select a model for energy system analysis in developing countries. The first step is to identify attributes on which models comparison should be made, and the second step is to decide the type of models that should be compared. However, there is a wide disparity in terms of development across developing countries. The distinguishing features relevant in the context of model selection could be the level of urbanisation, the extent of the informal sector, availability of markets, supply shortages, availability of skill, etc. Thus, the spectrum is characterised by the least developed countries (a large number in Africa and Asia) at one end to fairly advanced countries such as Russia, China, Malaysia, Argentina, India, etc., at the other end. Advanced developing countries have capacity and institutions that are already engaged in modelling in line with their requirements. The characteristics considered here in model selection may therefore not apply equally to all.

Selection of attributes: Some attributes can be important for many developing countries, for example, the inclusion of the informal sector and traditional energy use in the analysis (Shukla, 1995). Other features pointed out by researchers include traditional markets in rural areas, multiple social and economic barriers and radical changes in energy industry policies (Pandey, 2002), which could introduce bias from the use of models that assume no barriers and perfect equilibrium through the price mechanism. Urban (2007) has indicated an interesting array of features that characterise developing countries and need to be considered by models, which include the informal economy, supply shortages, poor performance of the power sector, structural economic changes, electrification, traditional biofuels, and urban-rural divide. Therefore, the suitability of a model for a country would depend on the extent of the presence of these factors. The selection of a model that does not reflect these realities may lead to incorrect interpretations of the country's energy systems. Several attributes were considered, and the final list of the attributes to compare the models included the following:

- Geographical coverage: Models have been used to analyse energy systems at sub-national, national, regional and global levels. Most models can be applied at the national level, but some can be applied at sub-national levels also, which may be an important criterion in specific cases.
- Sectoral coverage: Models cover one or more sectors in the analysis. In general, models covering one sector do not consider the impact of a policy on other sectors (a drawback.)
- Level of disaggregation: It is important for models that are being used for mitigation assessment to have adequate disaggregation as individual technologies may need to be assessed.
- Technology coverage: It is important in a mitigation assessment model to have coverage of all important technologies to be able to assess mitigation potential.
- Addition of new technologies: An option to add new technologies is most often needed to assess mitigation potential from new technologies- energy storage, for example.
- Traditional bio-fuels: Many developing countries have bio-fuels as one of the primary energy sources, and a large part of them can be non-commercial. An important criterion in selecting an appropriate model is, therefore, that it should be able to include biofuels in the analysis.
- Urbanisation and the urban-rural divide: The energy system in urban areas is at variance with the rural counterpart, and the model should be able to handle this appropriately.

- Capability to analyse pricing policies: Pricing policies impact across the sectors. This can be a limitation of many bottom-up models.
- Capability to analyse non-pricing policies: Regulatory measures are used by countries to address issues of pollution and GHG reduction, and it is widely prevalent in developing countries where the pricing mechanism may be less effective due to the large informal sector. This capability, therefore, is highly desirable in any model selected for analysis.
- Other features: Capacity to handle mechanisms like emissions trading, the introduction of renewable energy, etc., can also be useful. Most models provide this feature.
- Data requirements: Many models need extensive data, which is a constraint in many developing countries. Data gathering can be a resource and time-consuming affair since it requires setting up appropriate institutions and mechanisms, which can take several years. This, therefore, is a critical selection parameter for the model.
- Skill requirements: Top-down and hybrid models may need a high level of expertise. Some bottom-up models like GACMO and LEAP (basic version) are relatively easy to learn and use.[4] Other bottom-up models also need a varying amount of expertise- some such as TIMES (with optimisation framework) and POLES (with econometric framework), for example, require a fairly high level of expertise compared to GACMO and LEAP (basic). However, the skill can be developed over a period of time through training and collaboration, which some institutions offer.
- Computing requirements: Most of the top-down models and some bottom-up models also have heavy computing requirements. The resource requirement can be high in such cases.
- Training Facilities: Training facilities are available to use some models, and that can help develop skills. It can, however, be time and resource-consuming depending on model complexity.
- Time-frame: Models have varying capacities to analyse energy systems from the short term (a few years) to the medium and long term (end of the century in most cases).
- Documentation: Availability of documentation also varies- for some popular models such as MARKAL/ TIMES and LEAP, extensive documents may be available, whereas, for some top-down models, documentation may be minimal or difficult to get.

4 According to Gordon, who has provided training on LEAP in the past, it generally requires at least a one-week training course. The same is true of GACMO. Both are non-trivial and do require time to master.

- Availability of the model: Some models are readily available and downloaded freely- primarily bottom-up models such as GACMO, LEAP (free for developing countries only) etc. Some are available on a license basis- such as MARKAL and TIMES, also requiring commercial software to run the model and database. Some other bottom-up models are open source (**https://en.wikipedia.org/wiki/Open_energy_system_models**) but may require a high level of skill to use them, and documentation may not be adequate/available.

Selection of type of models for comparison: As this comparison aims to assess the suitability of models for developing countries, various model types have been compared on the attributes identified in step 1 in this section. These include as follows:

***Bottom-up Accounting Framework Models*:** This category is included on account of the easy availability of the models, suitability indicated in the literature and pre-dominance of use in developing countries. Models include LEAP (basic model), GACMO, PROSPECT+ (basic model) and others.

***Bottom-up Optimisation Models*:** For countries interested in exploring the achievement of an objective through a mix of technologies, including potential technologies, an optimisation framework is a good choice. The objective, for example, can be to achieve NDC commitments of emissions reductions, and model results can provide a mix of technologies to achieve it at minimum cost. The most popular models in this category are MARKAL and TIMES (both from the same family), with good infrastructure in terms of availability, support and training. IEA uses TIMES extensively in member countries through its ETSAP programme.

Top-down Models: Among top-down models, CGE models have been used in many countries, though developed and used primarily by developed countries. However, several developing country institutions are also using these models in collaboration with countries/institutions where these have been developed. As already mentioned, top-down models have their advantages and countries more ambitious and with adequate capacity can explore the use of these models also.

Hybrid Models: Hybrid models are gaining popularity as they combine top-down and bottom-up approaches, thus adding benefits of both approaches. At the same time, some of the disadvantages of the approach, such as the complexity of the top-down models and high skill and computing needs are also drawbacks of hybrid models. The complexity depends on the type of model selected. Examples of hybrid models include Poles, WEM etc.

The selected model types are compared in Table 3.

Table 3: Comparison of models by modelling approaches

Criteria	Bottom-up Accounting Framework	Bottom-up Optimisation	Top-down (CGE and others)	Hybrid
Model examples	GACMO, LEAP[5]	MARKAL / TIMES	E3MG, GEM-E3	POLES, WEM
Geographical coverage	National but can be regional	Local to Global; primarily National	National or global	National or global
Sectors covered	Energy, Environment	Energy, Environment	Energy, Environment, and all others	Energy, Environment, and all others
Level of disaggregation	High	High	Low	Low to medium
Technology coverage	Detailed coverage	Detailed coverage	Limited coverage	Medium to detailed coverage
Adding new technology	Can be added	Can be added	Not useful	should be possible but depends on the type of hybrid model
Traditional bio-fuels (Rural energy)	Can be included	Can be included	Limited possibility	Possible (depending on model)
Urbanisation and the urban-rural divide	Can be included	Can be included	Difficult to add	Possible (depending on model)
Capability to analyse the impact of pricing policies	No	Yes, at the sectoral level (not economy-wide)	Yes	Yes
Capability to analyse non-pricing policies	Very good	Good	Very good[6]	Very Good

5 This is the basic LEAP considered here without any links to other modules. LEAP also supports both top-down macroeconomic modelling as well as optimisation modelling through soft links. LEAP now includes NEMO (Next Energy Modelling system for Optimisation), which adds the capabilities of the optimisation models to LEAP.

6 For example, EU models examine quotas and similar things.

Criteria	Bottom-up Accounting Framework	Bottom-up Optimisation	Top-down (CGE and others)	Hybrid
Other features Emissions trading, Renewable energy etc.	Yes, possible	Yes, possible	Possible, but the level of utility low	It could be added depending on model
Data needs	Medium - very high	Very high	High	High to very high
Skill requirements	Medium	High	Very high	Very high
Computing requirements	Low	High, Solver software required (commercial)	High end, including software needed (commercial)	High end, including software needed (commercial)
Training facilities	Possible	Possible	Usually not	Usually not
Time-frame	Medium to long term	Medium to long term	Medium to long	Medium to long term
Documentation	Good in most cases	Good in most cases	Varies	Varies
Model availability;	Some free for DCs, license depending on model	License	Propriety/License/ collaboration	Propriety/ License/ collaboration

Sources: Bhattacharya and Timilsina (2010); Urban (2007) and information from the literature.

From the table, it can be surmised that the bottom-up accounting type of framework may be one of the potential options for developing countries with a sizeable non-commercial energy sector, limited skill and potential to benefit from existing technologies yet to be adopted. These models can also capture rural-urban differences and informal sector (non-monetary transactions). The bottom-up accounting framework models, however, cannot assess the impact of pricing policies. Hybrid models offer this feature where linking with a macro-model allows them to assess the impact of prices. Most of the top-down models are global or regional models and are not suitable for use in developing countries. It may require huge resources to adapt or develop such models, yet they may not capture the informal sector where transactions are non-monetary.

Annexe 1, Tables 5, 6 and 7 give a comparison and characteristics of some of the useful energy models used widely.

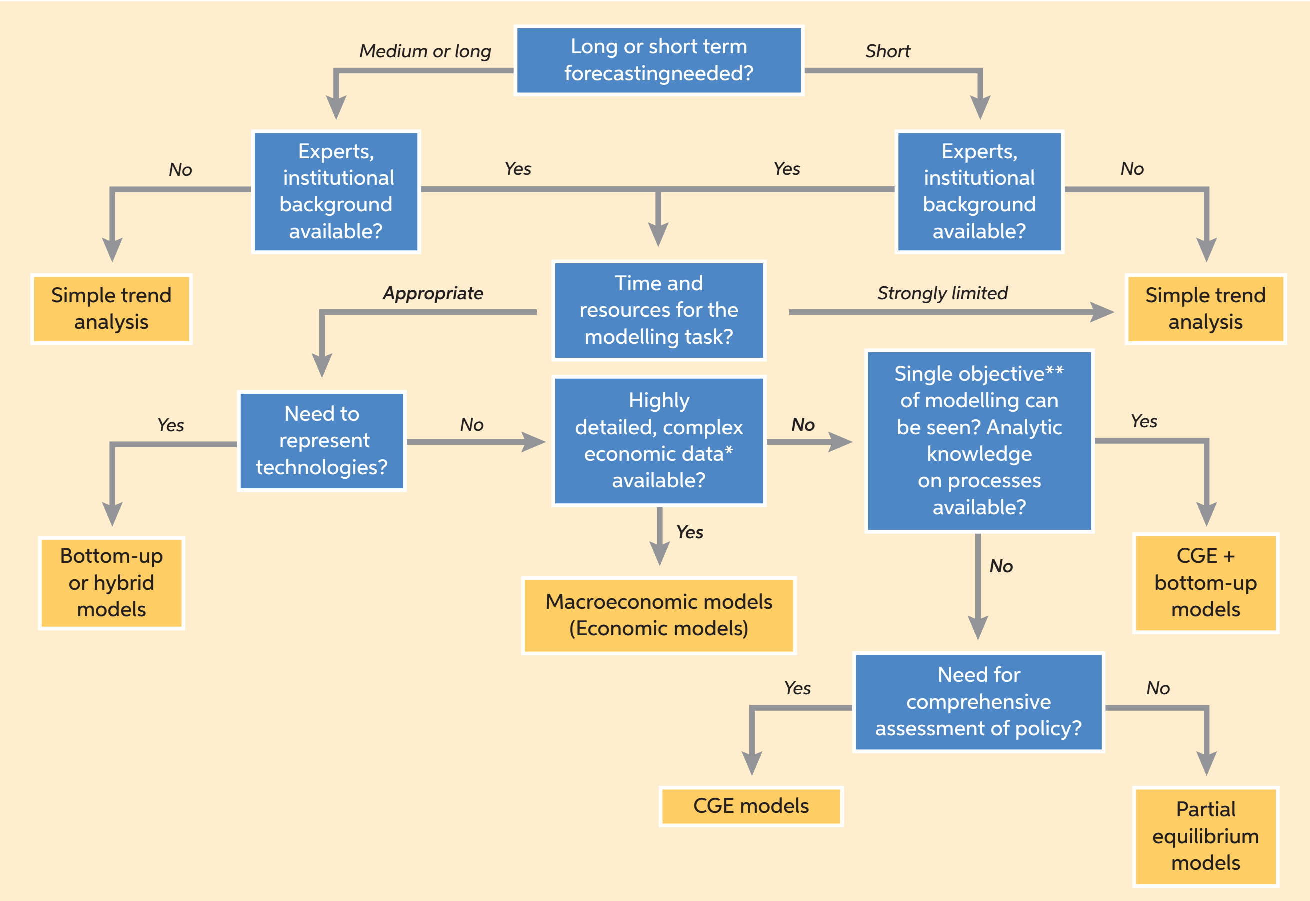
5 Selecting an appropriate model

Model selection depends on several factors. First and foremost is the objective - what is planned to be investigated through the model; the research question. Key features of different model types have been indicated in the previous section. However, it may be not easy to apply so many criteria to several models and arrive at a list of models that meet most of the requirements. It can be quite time consuming, and the required information may often not be readily available. Some of the features of these models can turn out as constraints for the user in selecting an ideal model for the country. A two-step approach is therefore proposed.

STEP 1: The starting point is the objective of the modelling - referred to as the research question. This may help identify the category of models (bottom-up hybrid category, for example) suitable for the analysis. A model can be selected after filtering the models within the category using relevant criteria from the list. If the user does not have the capacity to work with the ideal category of models, the most important criteria, which are immediate constraints for the user, can be identified and applied to the model categories indicated in Table 3 to come out with a feasible set of categories. Model availability, skill requirements, and data availability, for example, are three important criteria, which, acting as constraints, may lead to the selection of a sub-optimal model. However, once identified, a plan can be made to address these constraints. Some of these can be addressed in the short term- a lack of model availability through identification and collaboration with appropriate organisations; and a lack of skill through training, for example. However, some constraints, such as a lack of data availability, can be addressed only in the medium term.

A flowchart presented in Figure 3 provides a way to select a suitable model approach. The selection process focuses first on identifying an ideal model, and then constraints are applied to filter the categories and arrive at an appropriate category. National characteristics, including the structure of the economy, reflected in industrialisation level, population size, and scale of economic activity, are considered deciding factors for selecting an ideal model category for a country. These are then filtered through the constraints such as level of expertise, institutional background (e.g. existing agencies, existing research initiatives and past modelling experience) and data availability etc., to select simple or complex models.

Figure 3: Flowchart for selecting an appropriate modelling approach



* Data on the structure of the economy, interactions of markets, price elasticity of demand, international trade balance, consumer preferences and other data.

** For example, minimal social cost of complying with emission cap, attainment of an emission cap for the economy or the industries that the cap covers, and least cost expansion of the power system.

Abbreviation: CGE – computable general equilibrium

Source: Reproduced from UNFCCC (2016). Compendium on Greenhouse Gas baselines and monitoring; National Level Mitigation Actions (page 34).

The UNFCCC (2016) suggests three key factors for selecting an appropriate model, comprising the objective of developing the baseline and mitigation scenarios, national characteristics, and relative magnitude of emissions reduction compared to the baseline. In general, the more complex an economy, the more complex the model required to obtain reliable results.

In summary, ideally (and assuming availability of expertise in the country), the main criteria to select a model is the objective of the modelling- the research question that is sought to be answered. For example, If the research question is to find out the impacts of carbon pricing instruments, CGE models should be selected. If the question is to determine the impact of technological improvement in an industry (say, in the iron and steel industry), TIMES or a similar model containing technological details should be selected. Finally, to answer complex questions such as the economy-wide impacts of introducing a technology (cleaner technologies in an industry- say in the cement industry), a hybrid model should be selected. The parameters given in table 3 can be used to select a suitable model within the category that the research question requires. In the short term, the final selection may be based on other constraints indicated in the table - data availability, available skill, resource availability, etc. The necessary action can be taken to address the identified constraints in the medium and long term so that appropriate models are used to meet the objectives.

The UNFCCC (2016) also provides a table, reproduced in Table 4 below, with examples of model choices depending on country circumstances.

Table 4: Examples of model choices suitable for different national circumstances

National circumstances	Suitable models	Main sources of data*	Costs of input data and time required for data collection
Developing country with low carbon intensity (low GDP/capita and high share of agriculture	■ Trend analysis (simple models)	■ United Nations agencies, World Bank, IEA and OECD ■ National statistics	Low (3–6 months)
Developing country with growing carbon intensity of economy (low–medium GDP/capita, growing share of industry or services sector, e.g. tourism)	■ Trend analysis ■ Macroeconomic models	■ United Nations agencies, World Bank, IEA and OECD ■ National statistics ■ National data development (measurements and modelling)	Low to medium (3–12 months)
Advanced developing countries with high carbon intensity of economy (industry not diversified, but a few major industries)	■ Trend analysis ■ Macroeconomic models ■ Equilibrium models	■ United Nations agencies, World Bank, IEA and OECD ■ National statistics	Low (3–6 months)
Countries transitioning from high carbon intensity to a services-oriented economy (polluting industries, transfroming economies and growing services sector)	■ Macroeconomic models ■ Equilibrium models	■ National statistics ■ Specialized technical agencies (IRENA and IEA) ■ National data development (measurements and modelling)	Low to medium (3–12 months)

Source: Reproduced from UNFCCC (2016). Compendium on Greenhouse Gas baselines and monitoring; National Level Mitigation Actions

STEP 2: The first step is likely to lead to the selection of a category of models. In the second step, a suitable model within the selected category needs to be picked up. Available models within the category can be reviewed at this stage, and the best model that meets the requirements is selected. Short descriptions and reviews of models can be found in several documents. A few bottom-up models widely used by developing countries, and which can be useful for countries to quickly review and select a model, are described briefly in the next section. A list of publications that provide a brief review of various models is also given to those interested in exploring and checking other models for suitability.

5.1 The MRV Hub Mitigation Modelling Tool Selection Guide

An excel sheet based model selection tool has been recently developed by the Caribbean Corporative MRV Hub Modeling and Projections Programme (Boodlal et. al., 2021). The tool currently covers three bottom-up models; GACMO, LEAP and Prospectus+ and compares them on several parameters.

6 Review of a few selected modelling tools

In this section most widely used and relatively simple bottom-up models have been reviewed. The selection acknowledges that a large number of developing countries have used these models.

6.1 Greenhouse gas Abatement Cost Model (GACMO)

GACMO is an accounting framework modelling tool developed at UNEP DTU Partnership (UDP) more than 20 years ago and used in several developing countries. It provides users with a tool that allows them to carry out rapid calculations of the GHG emission impact of a variety of mitigation options.

GACMO is a spreadsheet-based model, and the primary data required are the energy balance data on the sectoral energy consumption of fossil fuels and electricity of a country (or region, or city). The model calculates the GHG emissions for the base year from this energy consumption data and emission factors in the model database. To construct a baseline (a Business As Usual (BAU) scenario), the model calculates emissions using growth rates specified for each sector. The model contains 100 mitigation options divided into 24 categories derived from the CDM Pipeline. The categories include Agriculture, Biomass Energy, Energy Efficiency in Households, Forestry, Geothermal, Hydro, Solar, Wind etc. GACMO uses the Intergovernmental Panel on Climate Change (IPCC) database of emission factors (2006 IPCC Guidelines) and has a built-in reporting tool to generate graphs.

GACMO can be used at the national level (country level) and can then be used for the preparation of reports such as National Communications, Biennial Update Reports (BURs), or for updating the Nationally Determined Contributions (NDCs). To date, GACMO has been used in several countries, including Afghanistan, Angola, Antigua and Barbuda, Colombia, Eritrea, Ghana, Guinea Bissau, Lesotho, Maldives, Macedonia, Mozambique, Myanmar, North Korea, Panama, Sao Tome and Principe, Senegal, Swaziland, Zambia, Zimbabwe and others. GACMO has also been used to make a global study of GHG reduction potential at the level of the Latin American region.

Finally, GACMO can also be used for monitoring the GHG emission reductions achieved through the effective implementation of mitigation options. Therefore, GACMO can be used additionally as a tool for Monitoring, Reporting and Verification (MRV) of climate change mitigation options.

The GACMO tool is based on Excel and can be freely downloaded onto an individual computer from the UDP website (**https://unepdtu.org/publications/the-greenhouse-gas-abatement-cost-model- gacmo/**).

For more information on GACMO:
Jørgen Villy Fenhann, Senior Scientist
UNEP DTU Partnership, Technical University of Denmark
jqfe@dtu.dk

6.2 LEAP: the Low Emissions Analysis Platform (LEAP)

Previously known as "Long-range Energy Alternatives Planning System", LEAP is a widely-used software tool for energy policy analysis and climate change mitigation assessment developed at the Stockholm Environment Institute. LEAP started as a simple spreadsheet model in an accounting framework for mitigation assessment of various options and to assist in energy policy analysis, and now has developed into an integrated, scenario-based modelling tool that can be used to track energy consumption, production and resource extraction in all sectors of an economy. It can be used to account for both the energy sector and non-energy sector GHG emission sources and sinks. In addition to tracking GHGs, LEAP can also be used to analyse emissions of local and regional air pollutants and short-lived climate pollutants (SLCPs), making it well-suited to studies of the climate co-benefits of local air pollution reduction.

LEAP facilitates medium- to long-term modelling of different emissions scenarios and compares and analyses these scenarios to assess their energy requirements, environmental impacts, and social costs and benefits. Different reduction policies or options may be modelled separately or as part of an integrated framework. LEAP can be used as a database for baseline and historical data, a forecasting tool for modelling future energy supply and demand; and as an analysis tool that can compare options and feed into target-setting and strategic plan development.

LEAP can perform an Integrated Energy Planning analysis by combining various LEAP capabilities to conduct end-use energy analysis, energy conversion from extraction to final consumption (transformation) analysis, environmental analysis (GHG and other air pollutants), and cost-benefit analysis.

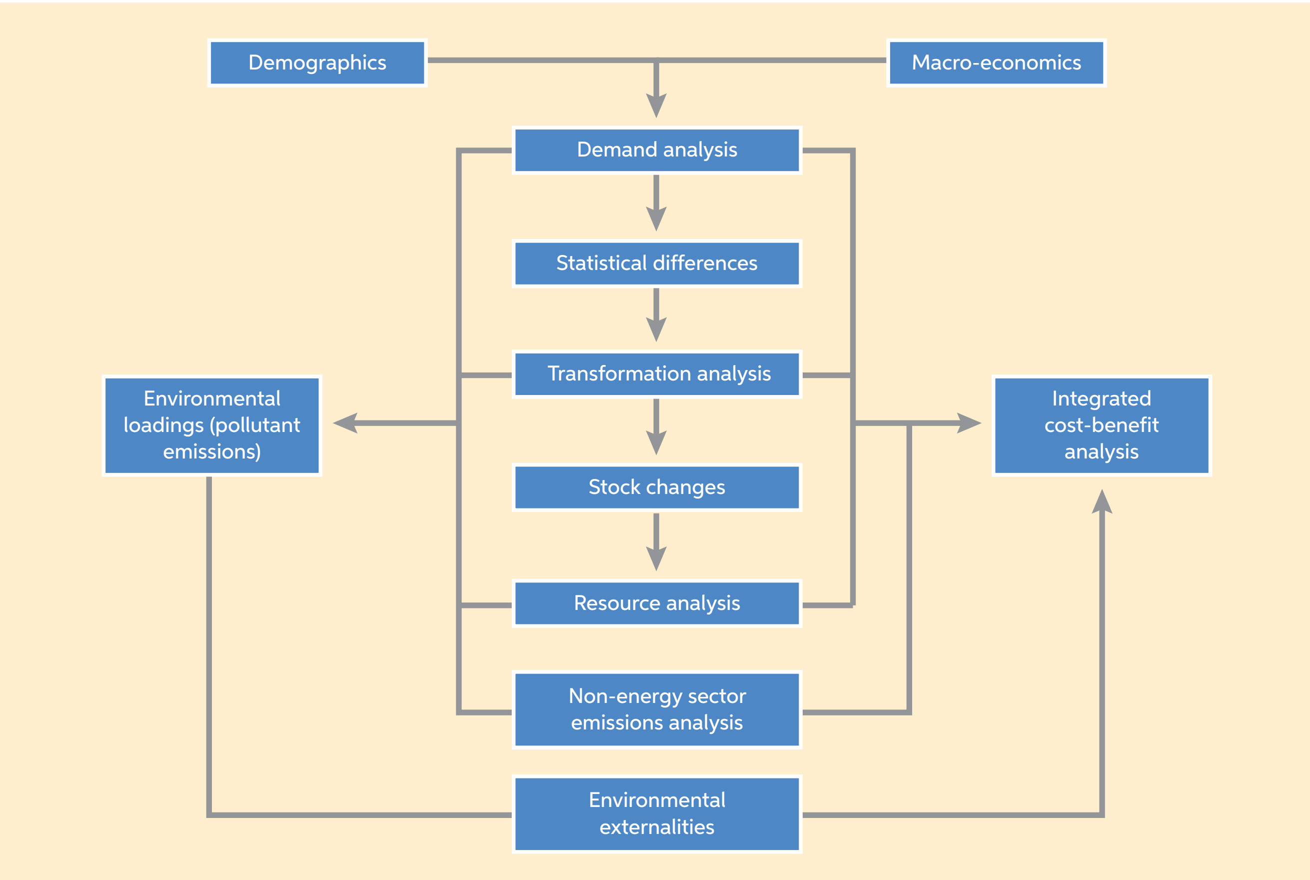
LEAP supports a wide range of different modelling methodologies: on the demand side, these range from bottom-up, end-use accounting techniques to top-down macroeconomic modelling. On the supply side, LEAP provides a range of accounting, simulation and optimisation methodologies that can help energy and power sector planning.

LEAP has an in-built Technology and Environmental Database and contains default emission factors for energy-consuming and energy-producing technologies. The user can, however, also customise emission factors, overriding the defaults.

LEAP has a very good reporting tool. It can display results as charts, tables, or, in some cases, GIS (Geographical Information System) maps. Results are as varied as the inputs to the tool. They include current and projected energy demand, fuel consumption, costs, and emissions according to the sector, end-use, or other user-specified variables. The program can also generate a cost-benefit summary report, which provides a comparative overview of the costs and benefits of different scenarios relative to the baseline scenario.

A fully developed version of LEAP as an integrated modelling tool is shown in Figure 4.

Figure 4: The Structure of LEAP's Calculations



Source: https://leap.sei.org/default.asp?action=introduction;

LEAP has been adopted by organisations in more than 190 countries worldwide. Its users include government agencies, academics, non-governmental organisations, consulting companies, and energy utilities. It has been used at many different scales ranging from cities and states to national, regional and global applications.

LEAP is provided free of charge to academic, governmental and not-for-profit organisations based in the developing world.

For more information:
Heaps, C.G., 2021. *LEAP: The Low Emissions Analysis Platform*.
[Software version: 2020.1.30] Stockholm Environment Institute. Somerville, MA, USA.
https://leap.sei.org

6.3 MARKAL/TIMES Models

MARKAL was developed by the Energy Technology Systems Analysis Programme (ETSAP) of the International Energy Agency (IEA). Markal is an optimisation model with a database of technologies at national levels and is used for energy and environmental policy analysis. Energy and emissions control technologies, both existing and future, with details of cost and performance characteristics are input to the model. Both the supply and demand sides are integrated to respond automatically to changes in the other. The model selects a combination of technologies that minimise total energy system cost.

The model requires as input projections of energy service demands - lighting energy demand, heating energy demand, vehicle-miles to be travelled, for example, along with current and projected resource costs. For environmental analysis, a target can be set - emissions reduction by a certain percentage by a future date, for example, 50% emissions reduction by 2040, and the model can be run several times for various targets. The model checks the feasibility and finds the least expensive combination of technologies to meet the exogenously given requirements along with user-generated constraints.

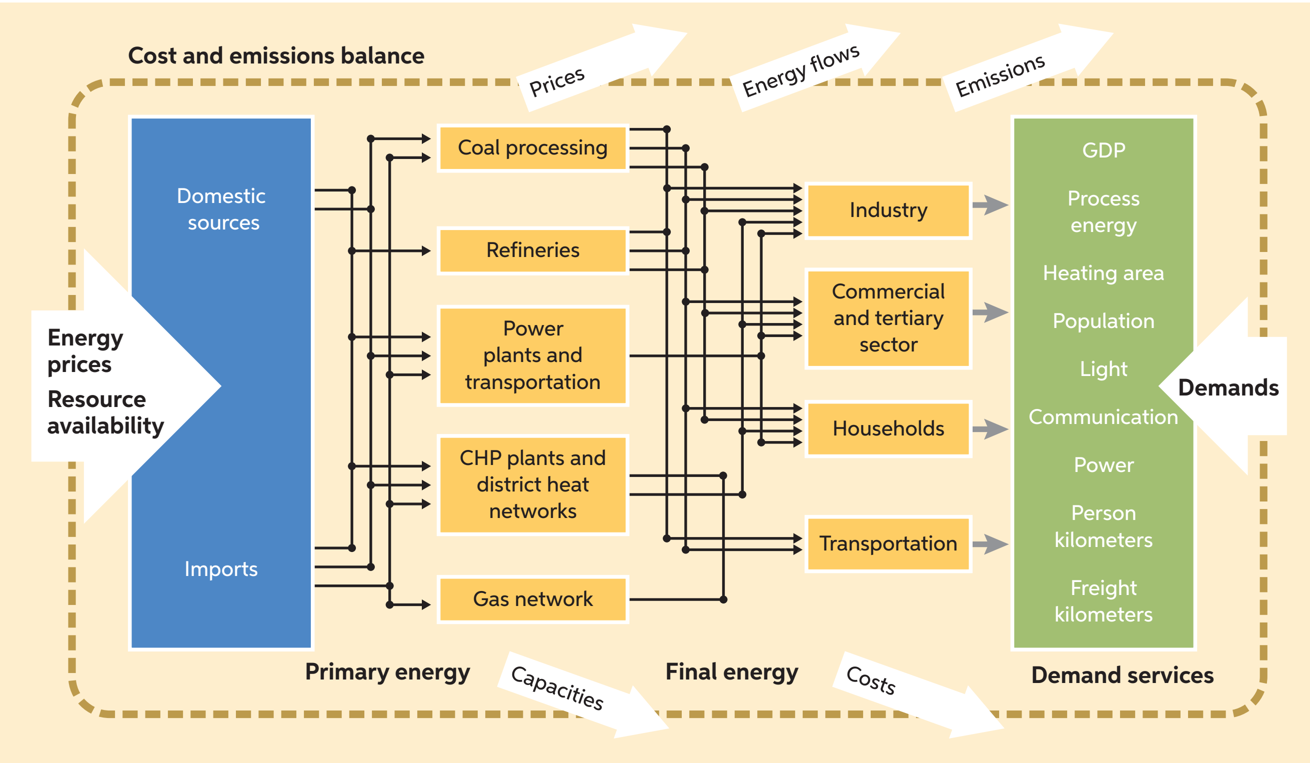
Some of MARKAL's applications are:

- to identify least-cost energy systems
- to identify cost-effective responses to restrictions on emissions
- to evaluate new technologies and priorities for R&D
- to evaluate the effects of regulations, taxes, and subsidies
- to project inventories of GHG emissions

TIMES is the successor of MARKAL, and both models share the same basic modelling approach, but both have their unique features also. TIMES, for example, offers variable-length time periods, whereas MARKAL has fixed length time periods. ETSAP now offers TIMES to the users.

The TIMES model generator combines two different but complementary, systematic approaches to modelling energy: a technical engineering approach and an economic approach. TIMES is a technology-rich, bottom-up model generator, which uses linear programming to produce a least-cost energy system, optimised according to several user constraints over medium to long-term time horizons. TIMES is thus used for "the exploration of possible energy futures based on contrasted scenarios" (Loulou et al., 2005). The model outputs include energy flows, energy commodity prices, GHG emissions, capacities of technologies, energy costs and marginal emissions abatement costs. Figure 5 shows a schematic of the TIMES model along with the model outputs.

Figure 5: Schematic of TIMES inputs and outputs;



Source: (Remme et al., 2001)

MARKAL and TIMES model generators were in use in 177 institutions in 70 countries by 2015, according to ETSAP.

For more information on MARKAL/TIMES:
Gary Goldstein, International Resources Group Sag Harbor, New York, 11963, USA
Email: ggoldstein@irgltd.com
http://www.etsap.org

6.4 PROSPECT+

Developed relatively recently by New Climate Institute (NCI), PROSPECT+ is a sector level bottom-up spreadsheet model in an accounting framework.

PROSPECTS+ can be used to generate and track the projection of sectoral and overall GHG emissions of a country. It uses historical emissions and decarbonisation relevant actions and GHG intensity indicators to track and project overall and sectoral GHG emissions trends. A simplified tool derived from the Carbon Transparency Initiative (CTI) tools, PROSPECTS+ covers all emissions-generating sectors: electricity, heat, buildings, transport, various industrial sectors, waste, and agriculture. Users can construct their own emissions scenarios by adjusting policy-relevant indicators in this open-source, user-friendly tool.

The general objective is for the model to be able to provide a bottom-up projection of a country's future emissions, considering user-defined sector-level developments of activity and intensity. The tool user can construct (one or more) emission scenarios based on the assumed impact of certain external drivers—policies, socio-economic changes, market developments—on sector-level activity and intensity data.

PROSPECT+ is a part of the COMPASS Tool Box developed by NCI and can link it with other tools like air pollution and health modules of the COMPASS.

More information can be obtained, and Prospect+ downloaded from; https://newclimate.org/2018/11/30/prospects-plus-tool/

and COMPASS can be referred at; https://newclimate.org/expertise/compass-toolbox/

6.5 Some recent applications of other models in developing countries[7]

6.5.1 EnerNEO

EnerNEO is used and developed by Enerdata to assess the possible long-term evolution (up to 2050) of national energy demand and power supply under various conditions for climate and energy policies, including the agreement on INDCs at the COP21. It gives a detailed quantitative assessment of energy demand by fuel, sector and sub-sectors, and the development of power generation and capacities.

EnerNEO is a partial equilibrium simulation model of the energy sector. The simulation process uses dynamic year-by-year recursive modelling, which gives full development outcomes to various long-term horizons.

7 This section 5.1 was contributed by Pallav Purohit, Researcher, IIASA

The purpose of this tool is to provide a stand-alone Excel model allowing users to create their customised scenarios and to assess the long-term impacts of climate and energy constraints on energy demand and power production.

Besides its standard module, this Excel tool offers great flexibility through an advanced mode enabling users to define their variables and parameters as inputs, creating customised scenarios.

For details, refer to https://www.enerdata.net/solutions/national-energy-outlook-model.html.

6.5.2 MedPro

MedPro belongs to the MEDEE models family: it is a bottom-up demand forecasting model that enables users to assess the impact of energy efficiency policies at the country level. MedPro has been and is being used in more than 60 countries in the world, both by public bodies or companies.

MedPro addresses energy demand by main sectors (industry, households, service, transport, etc.) and main categories (end-use/appliances/vehicle type). The bottom-up approach enables the assessment of energy demand use and analyses the impact of different policies thanks to different scenarios and potential sensibility studies. This model is highly flexible and can be easily adapted, depending on objectives and data availability.

For details, refer to https://www.enerdata.net/solutions/medpro-medee-model.html.

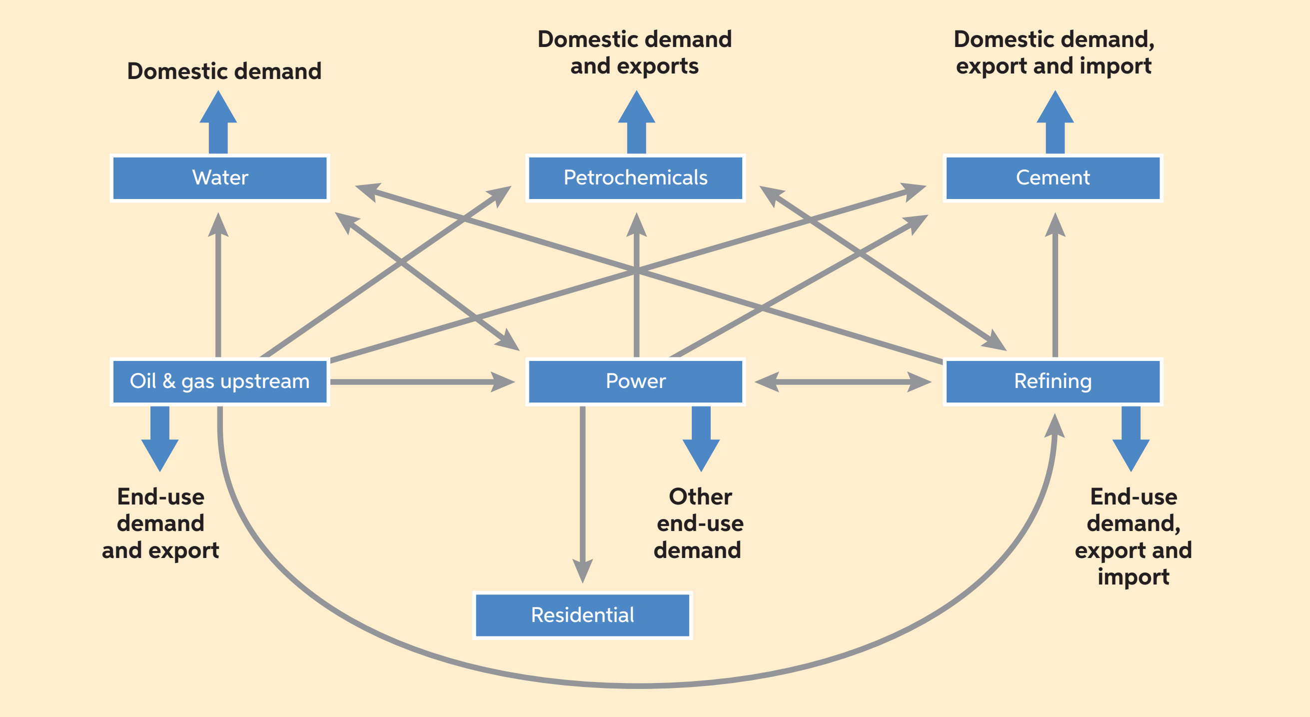
6.5.3 KAPSARC Energy Model for Saudi Arabia

The KAPSARC Energy Model (KEM) represents six major energy-producing and consuming sectors in Saudi Arabia. These sectors are:

- Power generation
- Water desalination
- Upstream fuel production and export
- Refined products export
- Petrochemical's production and export
- Cement production

Each sector makes its own decisions about investment in technologies and fuel consumption to meet demand at least-cost (or maximise profit for export-oriented sectors).

Figure 6: Overview of the KAPSARC Energy Model and the major flows among the sectors



Source: KAPSARC (https://www.kapsarc.org/research/publications/electricity-transmission-formulations-in-multisector-national-planning-models-an-illustration-using-the-kapsarc-energy-model/)

Each sector is able to consume goods produced by the other sectors. For example, the power sector consumes fuels produced by the upstream and refining sectors. In turn, the power sector can sell electricity to the refining sector. Fuel prices are set below market value by existing policies. KEM can be used to explore how changing fuel prices or adding investment credits alter investment in technologies over time.

There are several reported on the use of this model available at the Kapsarc website.

For details, refer to https://www.kapsarc.org/research/projects/kapsarc-energy-model-kem/.

6.5.4 India Energy Security Scenarios (IESS), 2047

The IESS, 2047 is an energy scenario building tool that explores a range of potential future energy scenarios for India for diverse energy demand and supply sectors leading up to 2047. 21 Energy Demand and Supply sectors and 50 levers that will impact the Indian energy system are available to the user. A combination of the above choices offer hundreds of energy pathways till the year 2047.

For details, refer to http://www.iess2047.gov.in/.

7 Other modelling resources

7.1 National and sectoral models and toolkits

Brief descriptions of several models are available in the following documents. Users can refer to these documents to familiarise themselves with the models.

- **LEDS Energy Toolkit 2.0**

  https://ledsgp.org/wp-content/uploads/2010/10/LEDS-Energy-Toolkit_EDIT_3.15.17.pdf

  The Energy Toolkit is a collection of leading instruments and methodologies for climate-compatible energy planning, offers energy practitioners, policymakers, and experts a quick reference guide to some of the best-established instruments available at no or low cost. The result is a compilation of 25 tools from agencies around the world.

- **Long-term energy models: Principles, characteristics, focus, and limitations.** Gargiulo Maurizio and Brian Ó Gallachóir. (2013).

  The publication gives an overview of the main energy models currently in use. A summary of the models, including key attributes for each model that includes geographic coverage, typical time horizon, model type, focus, and some applications, is also provided. It includes bottom-up energy models, top-down models for climate-change analysis, integrated assessment models (global), and a few hybrid models.

- **Resource guide module 4: Measures to mitigate climate change for preparing the national communications of Non-Annex 1 Parties.**
  UNFCCC (2008). (Pg. 22-27).

  The UNFCCC resource guide module 4 (UNFCCC, 2008) is intended as a supplement to the user manual for the guidelines on national communications from non-Annex I Parties, which supports the implementation of Article 8, paragraph 2(c)of the Convention.

- **Training Handbook on Mitigation Assessment for Non-Annex I Parties, May 2006.** UNFCCC (2006).

  (Refer pages 23-24 for model comparisons)

  UNFCCC (2006) developed materials for use in a Global Hands-on Training Workshop designed to assist non-Annex-I experts in preparing the mitigation section of their national communications through training on a wide range of mitigation assessment approaches, methods and tools and information on their relative strengths and weaknesses in different analytical contexts.

- **Open energy system models**

  https://en.wikipedia.org/wiki/Open_energy_system_models

  A variety of open-source energy system models, such as Balmorel, OSeMOSYS, EnergyPATHWAYS etc., are listed with a brief description of each.

  Top-down and hybrid models have been developed by several countries, international organisations and consultancies. Users interested in such models should contact the related organisations as barring open-source models, these models are not available off the shelf in the public domain.

7.2 Sub-sectoral and city level mitigation models/tools

A variety of models/tools have been developed at sub-sector levels for energy end-use; buildings, transport and industrial energy use, for example, and energy use at the cross-cutting sectoral level, for example, at the city level. These models are primarily bottom-up models but can also be hybrid models with soft-linkages. Some of these models/tools are briefly mentioned here on account of their increasing popularity as an aid in mitigation assessment.

7.2.1 City-level tools for mitigation assessment

- **Benchmarking and Energy Saving Tool for Low Carbon Cities (BEST)**

  The tool is designed to provide city authorities with strategies they can follow to reduce city-wide carbon dioxide (CO_2) and methane (CH_4) emissions. The tool quickly assesses local energy use and energy-related CO_2 and CH_4 emissions across nine sectors (i.e., industry, public and commercial buildings, residential buildings, transportation, power and heat, street lighting, water & wastewater, solid waste, and urban green space), giving officials a comprehensive perspective on their local carbon performance.

  Resource link: https://ccwgsmartcities.lbl.gov/resource/benchmarking-energy

- **Common Carbon Metric (CCM)**

  CCM is a tool for measuring the energy-related GHG emissions and energy savings potential of the stock of new and existing buildings in an investment portfolio, municipality, region or country.

  Resource link: https://www.gbpn.org/databases-tools/common-carbon-metric-20-ccm20

- **Energy Forecasting Framework and Emissions Consensus Tool (EFFECT)**

  EFFECT forecasts GHG emissions for given development scenarios or policy choices. In addition to forecasting GHG Emissions, EFFECT enables consensus building among disparate government departments and forecasts energy balances and amounts of energy generating/consuming assets in a country or sector. EFFECT also produces results for individual sectors such as road transport, agriculture, power, industry, household and non-residential sectors.

Resource link: https://ledsgp.org/resource/energy-forecasting-framework-and-emissions-consensus-tool/?loclang=en_gb

- **Global Protocol for Community-Scale GHG Emissions (GPC)**

  GPC is a framework for accounting and reporting city-wide GHG emissions. It offers guidance to cities on developing a comprehensive GHG inventory, including establishing the base year for the inventory, setting emissions reduction targets and tracking cities' performance. The tool also allows for aggregation of the estimates at the subnational and national levels.

  Resource link: https://ghgprotocol.org/greenhouse-gas-protocol-accounting-reporting-standard-cities

- **ClearPath**

  ClearPath is a cloud based-tool for energy and emission management. It can forecast multiple scenarios for future emissions, analyse the costs and benefits of emissions reduction measures, visualise alternative planning scenarios etc. The tool primarily forecasts and analyse energy emissions savings from energy efficiency measures.

  Resource link: https://icleiusa.org/clearpath/

- **Local Energy Efficiency Policy Calculator (LEEP-C)**

  The tool provides the opportunity to analyse the impacts of 23 different policy types from 4 energy-using sectors: public buildings, commercial buildings, residential buildings, and transportation. Impacts of policy choices are analysed in terms of energy savings, cost savings, pollution reduction, and other outcomes over a time period set by the user. The tool also allows for assigning the weights to different policy options based on community priorities in order to tailor the policy development process to community goals.

  Resource link: https://www.aceee.org/research-report/u1506

- **Climate action for urban sustainability (curb) scenario planning tool**

  The Climate action for URBan sustainability (CURB) tool is a data-driven scenario planning tool designed to assist cities in pursuing climate action across their energy, buildings, transport, waste and water systems. C40 Cities developed the Excel-based tool in partnership with the World Bank, the Global Covenant of Mayors for Climate and Energy (GCoM), Bloomberg Philanthropies and AECOM.

  Resource link: https://www.c40knowledgehub.org/s/article/Climate-action-for-URBan-sustainability-CURB-scenario-planning-tool?

- **The Siemens City Performance Tool (CyPT)**

  This model gives guidance to a city on achieving its environmental targets while indicating how each infrastructure-related decision will influence job creation and the infrastructure sector growth.

  Resource link: https://new.siemens.com/global/en/products/services/iot-siemens/public-sector/city-performance-tool.html

- **Compact of Mayors Emissions Scenario Model**

  The model provides methodologies to aggregate the GHG reduction targets reported by cities and to estimate the likely GHG reduction of cities that have signed up but not yet formally reported their GHG reduction targets to the Compact of Mayors.

  Resource link: http://www.ourenergypolicy.org/wp-content/uploads/2015/12/Compact_of_Mayors_Emissions_Scenario_Model.pdf

- **Tool for Rapid Assessment of City Energy (TRACE): Helping Cities Use Energy Efficiently**

  The tool is designed to give city authorities a quick and easy way to assess their energy use and to identify cost-effective and feasible measures they can take to improve energy efficiency in a variety of public sectors, including lighting, water and wastewater, buildings, transportation, solid waste, and power and heating.

  Resource link: https://esmap.org/node/235

7.2.2 Sectoral level tools/models for mitigation assessment

Transport sector: A variety of tools and models are available for the transport sector, including some models with global transportation as the scope. Some tools of general interest that can be applied at the national level are listed here. Other tools can be referred from various platforms for tools, listed in the next section (“Platforms”).

- **UNEP E-mobility calculator:** It helps calculate mitigation impact from the introduction of e-mobility;

  Resource link: https://www.unenvironment.org/resources/toolkits-manuals-and-guides/emob-calculator

- **The Transport Emissions Evaluation Models for Projects (TEEMP):** It consists of a suite of Excel-based spreadsheet models that may be used to evaluate the greenhouse gas and air pollution impacts of many types of transportation projects, primarily at the local government level.

  Resource link: https://www.itdp.org/what-we-do/climate-and-transport-policy/transport-emissions-evaluation-models-for-projects/

- **Transport Toolkit; Developing strategies for clean, efficient transport**

  This is a platform that lists several tools for the transport sector.

  Resource Link: https://ledsgp.org/toolkit/transportation-toolkit/?loclang=en_gb#transport-tools

Building sector: As in the case of other sectors, bottom-up building modelling tools that assess mitigation potential assessment of building sector in a country are included in this category. Such tools go into detail and can be used to determine the mitigation potential of a building or a cluster of similar buildings. The mitigation potential of representative buildings so calculated can thereafter be extrapolated to estimate the potential at macro levels. These tools can be referred from various platforms for tools listed in the next section ("Platforms").

Industry sector: The greenhouse Gas Protocol has a list of tools developed for specific industries.

Resource link: https://ghgprotocol.org/calculation-tools#sector_specific_tools_id

More sectoral models/ tools can be found in the platforms listed in the next section.

7.2.3 Other Resources- Platforms

A few platforms provide a collection of tools, including mitigation modelling tools. Some of these are listed below, along with links to the resources that can be referred to for details of the tools.

- **Tools for energy efficiency in buildings**

  The collection of tools was compiled jointly by Copenhagen Centre on Energy Efficiency (C2E2) and World Resources Institute (WRI).

  Resource Link: https://c2e2.unepdtu.org/collection/tools-for-energy-efficiency-in-buildings/

- **LEDS Global Partnership**

  The platform contains the **Development Impacts Assessment (DIA) Toolkit**, which is a mix of models and tools of various categories (energy, transport, buildings, industries, etc.)to assess the impacts of and links between national development priorities and low emission development strategies.

  Resource Link: https://ledsgp.org/toolkit/development-impact-assessment-tools/?loclang=en_gb

- **Climate-Smart Planning Platform**

  The CSPP is a multi-partner initiative with about 60 leading organisations brought together by the World Bank. These partners provide the trusted, proven tools, data, and knowledge products that are linked in the CSPP. The platform's team is actively expanding partnerships with other leading institutions to broaden the offering of products. Over the next 18 months, the team will continue to add tools, data, knowledge products, and learning initiatives to the platform to extend its coverage on low-emissions development and expand to broader green growth and climate-resilient development issues.

  Resource Link: https://www.climatesmartplanning.org/index.html

- **NDC Partnership's Knowledge Portal**

  The NDC Partnership's Knowledge Portal helps countries accelerate climate action by providing quick and easy access to data, tools, guidance, good practice, and funding opportunities. Whether a user is interested in reducing emissions or adapting to the impacts of climate change, the Knowledge Portal draws together the most relevant resources from partners and other leading institutions.

  Resource Link: https://ndcpartnership.org/knowledge-portal

- **Calculation Tools**

  The platform contains the following tools;

  Cross-sector tools: Applicable to many industries and businesses regardless of sector.

  Country-specific tools: Customised for particular developing countries.

  Sector-specific tools: Principally designed for the specific sector or industry listed, though they may apply to other situations.

  Tools for countries and cities: These tools help countries and cities track progress toward their climate goals.

  Resource link: https://ghgprotocol.org/calculation-tools

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Annexe. 1

Table 5: Comparison of bottom-up models

Criteria	RESGEN	EFOM	MARKAL	TIMES	MESAP	LEAF
Approach	Optimisation	Linear optimisation	Linear optimisation	Optimisation	Optimisation	Accounting
Geographical coverage	Country	Regional and national	Country or multi-country	Local, regional, national or multi-country	National	Local to national to global
Activity coverage	Energy system	Energy system	Energy system	Energy system and energy trading	Energy system	Energy system and environment
Level of disaggregation	Pre-defined	User defined	User defined	User defined	Pre-defined sector structure	Sector structure pre-defined
Technology coverage	Good	Extensive	Extensive	Extensive	Extensive	Menu of options
Data need	Variable, limited to extensive	Extensive	Extensive	Extensive	Extensive	Extensive but can work with limited data
Skill requirement	Limited	High	High to very high	Very high	High to very high	Limited
Portability to another country	Difficult	Difficult	Difficult	Difficult	Difficult	Difficult
Documentation	Limited	Good	Extensive	Good	Good	Extensive

Criteria	RESGEN	EFOM	MARKAL	TIMES	MESAP	LEAF
Capability to analyse price-induced policies	Exists	Exists	Exists	Exists	Exists	Does not exist
Capability to analyse non-price policies	Good	Very good	Very good	Very good	Good	Very good
Rural energy	Possible	Possible	Possible	Possible	Not known	Possible
Informal sector	Not possible	Not possible	Not possible	Not possible	Not possible	Possible
New technology addition	Difficult	Possible	Possible	Possible	Possible	Possible
Energy shortage	Not explicitly	Not explicitly	Not explicitly	Not explicitly	Not known	Possible explicitly
Subsidies	Difficult	Possible but often ignored	Possible but normally ignored	Possible but normally ignored	Not known	Not considered explicitly
Rural-urban divide	Possible but not covered usually	Possible but not covered usually	Possible and covered	Possible and covered	Not known	Possible and covered usually
Economic transition	Not covered	Not covered	Not covered	Can be covered	Not known	Usually covered through scenarios

Source: Bhattacharyya* and Timilsina (2010)

Table 6: Comparison of hybrid models

Criteria	NEMS	POLES	WEM	SAGE
Approach	Optimisation	Accounting	Accounting	Optimisation
Geographical coverage	Country	Global but regional and country specific studies possible	Global but regional and country specific studies possible	Global but regional or country specific studies possible
Activity coverage	Energy system	Energy system	Energy system	Energy system and energy trading
Level of disaggregation	Pre-defined	Pre-defined	Pre-defined	Pre-defined
Technology coverage	Extensive but pre-defined	Extensive but pre-defined	Extensive but pre-defined	Extensive and pre-defined
Data need	Extensive	Extensive	Extensive	Extensive
Skill requirement	Very high	High to very high	High to very high	Very high
Portability to another country	Difficult	Difficult	Difficult	Difficult
Documentation	Extensive	Limited	Good	Extensive
Capability to analyse price-induced policies	Good	Good		Good
Capability to analyse non-price policies	Good	Very good	Very good	Good
Rural energy	Possible and covered in a limited way	Possible but not included	Possible and covered in a limited way in recent version	Possible but not included

Criteria	NEMS	POLES	WEM	SAGE
Informal sector	Difficult and not included	Possible but not included	Possible but not included	Not included
New technology addition	Possible but difficult	Possible but difficult	Possible but difficult	Possible but difficult
Energy shortage	Not explicitly	Not explicitly	Not explicitly	Not explicitly
Subsidies	Yes	Yes	Yes	Yes
Rural-urban divide	Possible and considered	Possible but not considered	Possible and included in recent version	Possible but not considered
Economic transition	Not applicable	Considered implicitly	Considered implicitly	Considered implicitly

Source: Bhattacharyya* and Timilsina (2010)

Table 7: Energy models and their features

Model name	Geographic focus	Number of regions/ macroregions	Time horizon	Type of model	Focus	Model applications
MESSAGE	World	11	1990–2060	Bottom up/ Optimization	Energy modeling, energy policy analysis, environmental targets and scenario analysis	To develop energy technology strategies for carbon dioxide mitigation and sustainable development
PET	Europe extended	EU27, Norway, Swotzerland, Iceland and six Balkan countries	2005–2050	Bottom up/ Optimization	Energy modeling, energy policy analysis, environmental targets and scenario analysis	To evaluate energy scenarios, environmental and renewable targets in EU projects (NEEDS, RES2020, REACCESS, REALISEGRID, COMET, Irish-TIMES)
PRIMES	Europe extended	EU27, Norway, Swotzerland, southeast Europe	2000–2050	Bottom up/ Top down	Energy modeling, energy policy analysis, environmental targets and scenario analysis	To evaluate the set of policies and measure for the European Member states
CIMS		Canada, USA and China	2005–2030	Bottom up/ Top down	Energy modeling, energy policy analysis	To evaluate the effectiveness and economic impact of public policies to reduce greenhouse gas emissions
WITCH	World	12		Bottom up/ Top down/ Integrated Assessment Model	Energy modeling, energy policy analysis, environmental targets and climate-change analysis	In assessment and modelling activities for climate-change mitigation analysis

Model name	Geographic focus	Number of regions/ macroregions	Time horizon	Type of model	Focus	Model applications
ETSAP-TIAM/TIAM-WORLD	World	15/16	2005–2100	Bottom up/ Optimization-Integrated Assessment Model	Energy modeling, energy policy analysis, environmental targets and climate-change analysis	In assessment, modelling activities and for climate-change analysis. The model has been used also for Regional economic and energy impication of reaching global climate targets – a policy scenario analysis
POLES	World	18	2030	Top down/ Econometric	Energy modeling, energy policy analysis, environmental targets and scenario analysis	To support the World Energy Technology 2030 report, the WETO-H2 2050 report and the quantitative scenarios of the World Energy Council in 2007
GTAP / GTAP-E	World	113	2004 (or2007)	Top down/ CGE	Climate-change policies	To assess environmental and energy issues
GEMINI-E3	World	28	2025/2050	Top down/ CGE	Climate-change policies	To assess European and world climate-change policies at the microeconomic and the macroeconomic levels
GEM-E3	World and Europe	21 W/24 E		Top down/ CGE	Climate-change policies	To assess European and world climate-change policies at the microeconomic and the macroeconomic levels

Model name	Geographic focus	Number of regions/ macroregions	Time horizon	Type of model	Focus	Model applications
GTEM	World	13	1997–2100	Top down general equilibrium model	Climate-change policies	To evaluate the economic impact of climate-change policy: the role of technology and economic instruments
GCAM (formerly MiniCAM)	World	14	1990–2095	Integrated Assessment Model	Energy modeling, land use, energy policy analysis, environmental targets and scenario analysis	In assessment and modelling activities such as the Energy Modeling Forum (EMF), the U.S. Climate Change Technolgy Program, and the U.S. Climate Change Science Porgram and IPCC assessment reports
FUND	World	16	1950–3000	Integrated Assessment Model	Impacts of climate change and to perform cost-benefit and cost-effectiveness analyses of greenhouse gas-emission conduction policies	To advise policymakers about proper and not-so-proper strategies
MERGE	World	9	2000/2150	Integrated Assessment Model	Climate-change policies	To evaluate regional and global effects pf GHG reduction policies
LEAP	World Europe			Accounting framework	Energy modeling, energy policy analysis, environmental targets and scenario analysis	To evaluate energy scenarios, environmental and renewable targets

Model name	Geographic focus	Number of regions/ macroregions	Time horizon	Type of model	Focus	Model applications
WEPS+	World	16	2030	Econometric model	Energy modeling, energy policy analysis, climate change analysis	To produce to the EIA International Energy Outlook 2007
IMAGE	World	24	1970–2050 (2100)	Simulation	Climate change analysis	To explore the long-term dynamics of global change as the result of interacting demographic, technological, economic, social, cultural and political factors
Phoenix (formerly SGM)	World	24	2005–2100	Dynamic recursive model		To assess climate-change policy analysis

Source: Gargiulo and Gallachóir (2013)