MAPS

Mitigation Action Plans & Scenarios

TECHNICAL SUPPORT PAPER

# Guidelines for the selection of Long-Range Energy Systems Modelling Platforms to support MAPS processes

**Part 1**

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# Guidelines for the selection of Long-Range Energy Systems Modelling Platforms to support MAPS processes

## Part 1

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# 1. INTRODUCTION

A number of countries in South America, including Peru, Brazil, Chile and Colombia are collaborating on long-term national climate planning through the Mitigation Action Plans and Scenarios (MAPS) platform. Under MAPS, countries explore different potential levels of greenhouse gas emissions reductions in the medium to long term and socio-economic implications of these actions, within their national development context.

Setting achievable GHG mitigation targets requires the systematic analysis of potential mitigation actions to quantify the implication of each action, in terms of its benefits and costs. There are many sources of GHG emissions in a country, and to predict how these sources are likely to continue emitting in the future with and without action is a difficult task, so this systematic analysis is done with the help of models. There are a multitude of modelling platforms and approaches available, each with its strengths and weaknesses, and they can be used in different combinations. Generally speaking, the more detailed/specialised a model (or set of models), the easier it is to engage with stakeholders in the different sectors, as the model(s) is able to characterise aspects of the system in a manner that the stakeholder is familiar with and comfortable with, in terms data and assumptions. However, using highly detailed models, and combining different specialised models, comes at a cost:

- The more detailed a model/set of models, the more data is needed. The development and maintenance of the model can become expensive in terms of person hours, although implementation of measures for systematising data collection and updating can reduce the time investment required for model maintenance.
- It becomes harder to integrate models and maintain a level of consistency between them.
- Run time and analysis also becomes more expensive in terms of people hours as the volume of model outputs increases, again unless results can be somehow aggregated and summarized in a systematic way.

One sector that is often modelled in detail when it comes to the analysis of mitigation action is the energy sector. Two primary reasons are identified for this focus. Firstly, in many countries, the energy sector is responsible for the largest share of GHG emissions. Secondly, as energy comes in many forms, which can be substituted to carry out the same services, the consumption of energy to provide a service is dependent on the technology used and its efficiency.

Several modelling approaches are used to analyse demand, supply and mitigation opportunities in the energy sector. Broadly they include simulation and optimisation models, using either a top down or bottom up approach:

- Aggregate top-down models (e.g. econometric models) are generally poor at capturing the substitution and technological change that can take place over long planning horizons in different sectors, because the fuel substitution or technological change has not necessarily already begun and so would not be captured in the historical data.
- Technology rich bottom up models of the energy-sector capture substitution and technology change but do not capture the impacts of the actions on the rest of the economy, and interactions with the rest of the economy cannot easily be quantified. This has prompted the recent interest in trying to combine energy models with economy-wide models as done at University Catolica de Chile (Chile), COPPE at the Federal University of Rio de Janeiro (Brazil) and the Energy Research Centre (ERC) at the University of Cape Town (South Africa).

This paper aims to provide guidance in the selection of modelling platforms to analyse mitigation actions in the energy sector. It does so by describing the main model types and its process and data requirements, as well as discussing key considerations for the choice of model.

# 2. MODEL CATEGORISATION

The two broadest classes of modelling approaches for the energy sector are of **optimisation** and **simulation** modelling.

## 2.1 Optimisation Models

Optimisation models are those that provide as an output, a preferred alternative or set of alternatives out of a larger set of options. Here the term "optimal" refers to that option which provides, for example, the least cost, highest emissions reductions or the greatest number of jobs, to name a few. The model can also be used to optimise towards simultaneously meeting multiple objectives.

Constraints ensure that the requirements of the energy system are met, for example energy supply must equal or exceed energy demand, installed capacity must be large enough to meet peak demand with a reserve margin, fuel supply must not exceed domestic resources and import capacity, and power plants cannot produce more electricity than is possible given their installed capacity and availability.

Optimisation models require that current technologies in the system and future technology options are fully characterised in terms of their technical parameters (existing capacity, efficiency, availability, etc.) and in terms of their economic parameters (investment costs, running costs, etc.). The solution of each optimisation "run" is the level of installed capacity and the level of flow in and out of each technology for each period over the modelling horizon. The level of installed capacity and flow thus determines the market share of each technology providing each energy service.

Optimisation models have been extensively used in energy planning and climate change modelling. They are often used in supply side modelling (especially the power sector), but can also be used to model demand side sectors of the energy system. The main advantages of optimisation models are:

- Once the model is set up, many different scenarios can be investigated relatively quickly, as the model finds a new optimal solution every time a constraint or technology parameter is changed.
- If linear programing is used, the dual of the "level" for an energy commodity flow can be used as a proxy for the "marginal cost/shadow price", which can be interpreted and the "price" of an energy commodity.[1]

The main disadvantages of optimisation models are:

- Knife-edge/winner takes all effects: given that the optimisation will try and meet the objective, "winning" technologies will dominate the system even if other technologies/fuels are only slightly more "expensive" than the winner. In reality technologies with similar costs will share the market, as consumers pick slightly more expensive technologies based on other criteria which are not very easy to parameterize, for example, convenience, aesthetics, etc. This "knife-edge" behaviour has to be limited by imposing additional constraints on the rate at which new technologies take up market share.
- The model requires detailed economic parameterisation as well as technical characterisation.
- If linear programming is used for the optimisation, the model is made up of "linear" components, which sometimes limits the complexity of the characterisation of certain technologies or patterns of consumption, for example feed-back loops – demand price response.

[1] see MARKAL or TIMES manuals or "Energy Policy Analysis and Modelling" by Mohan Munasinghe for a more detailed explanation on this.

- Optimisation requires specialised software, with the high performing ones being relatively expensive.
- Optimisation models are generally framed as deterministic models. It is already quite onerous to get a basic model with one data point per input parameter, so to think about having to deal with “ranges” for each input parameter can be quite daunting. However, some modelling platforms have tried to integrate features that allow for the explicit handling of some of the more critical uncertainties via multi-stage stochastic optimisation (TIMES/MARKAL), and others with the possibility of combining optimisation with Monte Carlo Sampling (AIMMS).

Examples of applications of optimisation models that have been used for mitigation analysis at a national level are the UK MARKAL model and the MARKAL model used in the South African LTMS. Examples of applications of optimisation models utilised at a global level (disaggregated by region) are the supply sectors of the IEA Energy Technology Perspective (ETP), a bi-annual IEA publication, using a TIMES model; and the supply sectors of the Global Energy Assessment, a recent IIASSA publication using MESSAGE.

## 2.2 Simulation Models

Simulation models have no “objective function” as such, and generally the models have fewer degrees of freedom, requiring more exogenous input from the user. In the simplest case, the simulation model is an accounting model, or a table where there are no degrees of freedom, and all the flow and capacity variables have to be specified by the user. However, depending on the sophistication of the model, other system constraints (such as annual electricity output per unit of capacity given availability) are still enforced. In the most complex case, the relations between variables are expressed as differential equations, which are solved using specialised software (such as the systems dynamics tool called Vensim). These models are very helpful for representing and understanding complex interactions that exist within the energy system, that are generally poorly represented in optimisation models, such as price-demand responses, and other feedback loops.

Advantages of simulation models include:

- They can be more accessible and easier to interrogate for a wider audience than optimisation models, as they don’t always require a “solver”. This also means that they generally rely on less expensive software.
- There is no systematic “knife-edge” behaviour, but if cost is not going to be the deciding factor for switching from one technology or fuel to another, it is up to the user to define how the switching will occur and to ensure that the chosen switching equations do not also cause “winner-takes all” results.
- If the user is exogenously specifying the market share of different technologies, then economic parameters are not required. This eliminates a significant number of required input parameters. However, if a cost-benefit analysis is required then they would be needed anyway.
- Uncertainty is more easily integrated in the model using computer applications e.g. using @Risk or Crystal Ball in Excel or Analytica).

The main disadvantage of simulation models over optimisation models is that more “decisions” have to be made by the user. The onus is thus on him/her to ensure that whatever configuration he/she has come up with is still consistent with all the system constraints. If the model is detailed, then generating many different configurations for different scenarios is a very onerous task.

An example of the use of simulation models for mitigation analysis at a global level are the IEA Energy Outlook, and annual IEA publication where analysis is done using Vensim System Dynamics Modelling platform.

## 2.3 Typical Energy Systems Modelling Platforms

Table 2 provides a summary of various commonly used modelling platforms that have been applied to a variety of planning and mitigation action evaluations for the energy sector.

**TABLE 1: TYPICAL ENERGY SYSTEMS MODELLING PLATFORMS**

| ACRONYM | FULL NAME | BRIEF DESCRIPTION | Distributor/ website | Cost |
|---|---|---|---|---|
| **Simulation Energy Systems Modelling platforms** | | | | |
| LEAP | Long Range Energy Alternative Planning Model | Provides an information bank, an instrument for long-term projections of supply/demand configurations and a vehicle for identifying and evaluating policy and technology options. Model starts with a blank sheet, and it is up to the modeller to define the topology of the energy system. It is very flexible but sometimes daunting for a first time modeller. There is a new plug in that allows for some supply side optimisation using OSeMOSYS but this add-in is still being refined. | COMMEND Energycommunity.org | Free |
| MAED | Long Range Energy Alternative Planning Model | Spreadsheet based model for analysis energy demand, which has been pre-configured for national studies and allows some partial configuration by the use. It is up to the user to calculate emissions based on the final energy consumptions level computed by the model. | IAEA. IAEA.org | Free |
| Analytica | Analytics | Simulation modelling package with nice user interface and built-in functions for stochastic analysis (MC) and can do some systems dynamics. | Lumina Lumina.com | Fee |
| Vensim | Vensim | Systems dynamics model | Venata Systems Vensim.com | Fee |
| Optimisation Energy Systems Modelling platforms | | | | |
| MARKAL/ TIMES | Market Allocation Model | Bottom-up, Multi-period, Technology-orientated Energy systems Optimisation model | ETSAP/IEA Iea-etsap.org | Fee |
| AIMMS | AIMMS | Optimisation model that integrates some stochastic analysis (MC) | Paragon Aimms.com | Fee |
| MESSAGE | Model for Energy Supply Strategy Alternatives and their General Environmental Impacts | Optimisation model that is used for medium to long-term energy planning, energy policy analysis and scenario development, and is mainly used for supply analysis | IAEA. IAEA.org | Free |
| MODEST | Model for Optimisation of Dynamic Energy Systems with Time dependent components and boundary conditions | National, regional and local studies; finds operation profile of existing plants and potential investments that satisfy heat and power demand at lowest cost | | |
| EFOM | Energy Flow Optimisation Model | Energy-orientated, Bottom-up, National level, Optimisation model | | |
| OSeMOSYS | Open Source Energy Modelling System | Bottom-up, Multi-period, Technology-orientated Energy systems Optimisation model | KTH, Modelling community | Free |
| OREM | Optimal Renewable Energy Model | Optimum allocation of renewable resources for different end-uses | | |

# 3. OVERVIEW OF MODELLING PROCESS AND DATA REQUIREMENTS FOR MODELLING

As discussed previously, the MAPS process seeks to support long term planning towards climate change mitigation by supporting engagement and policy setting with defensible quantitative information. Steps in the modelling process can be summarised broadly as follows:

## 3.1 Phase 1: Base year characterisation

**These steps are common to all approaches:**

1. Identify global parameters:
    - Discount rate (range)
    - Modelling Horizon
    - Period resolution over horizon (e.g. annual or every 3 years)
    - Spatial disaggregation (if required by the geography of country, and if such an analysis can be supported by data and providing that there is enough time to disaggregate)
2. Establish the base-year energy system, describing it in as much detail as data permits in order to capture the full range of possible mitigation actions, from primary energy supply, to transformation from primary to secondary, to final energy and to useful energy (energy services e.g. cooking). This should be done while taking care that the energy balance is fully captured, the existing stock of technologies and retirement profiles are characterised and that all energy-sector emissions (including process emissions) are accounted for.
3. Identify the main drivers of future demand for energy services in terms of activity (e.g. Population, GDP, tons of steel to be manufactured for domestic market and for exports).
4. Calculate the base-year intensity for each energy service in terms per unit of driver (e.g. GJ of cooking heat per household).
5. Identify and parameterise the technologies available over the planning horizon (including hydro sites), taking care to capture technical performance improvements and investment cost reductions from technology learning.
6. Identify energy resources available to the system over the planning horizon (including fossil fuel reserves and annual production limits, renewable energy and hydro resources – including seasonal/di-urnal availability of resource, and dry-year availability of hydro resource for each hydro site)
7. Describe topology of model (placing each technology in its designated position in the energy chain).
8. Perform load curve analysis for base year.

If this modelling is done as a participatory process, this would be a good place to have a stakeholder meeting to make sure everyone is on board and comfortable with the way base year has been characterised, the choice of global parameters, and the range of plausible economic growth over the modelling horizon.

## 3.2 Phase 2: Reference Case Formulation

**If an accounting model is to be used on the demand side (e.g. LEAP/MAED) or if an exogenous demand projection is required (e.g. MARKAL/TIMES):**

1. Project future trajectory of drivers for the reference case scenario.
2. Project useful energy demand based on projected intensities (these are typically assumed as constant by default, but often allow for some autonomous technology improvement that wouldn't explicitly be captured by the model's technology inventory).

**If an accounting model is to be used on the demand side (e.g. LEAP):**

1. Exogenously specify the market shares of demand technologies over the modelling horizon to meet each energy service and obtain final energy demand for all fuels.
2. Perform load curve analysis over the modelling horizon given electricity demand.

**If an accounting model is to be used on the supply side:**

1. Exogenously specify the share (or annual investment) of supply technologies to meet the energy demand and the peaking and reserve requirements in each case, and resource constraints.

**If an optimisation model is to be used on the supply side (e.g. MESSAGE):**

1. Formulate constraints that control market penetration of new technologies
2. Run optimisation to establish optimal investment schedule to meet final energy demand, and peak demand (+reserve) for the power sector.
3. Review results looking at indicators such as final energy costs and if costs increase significantly in real terms then possibly review demand projection assumptions.

**If an optimisation model us to be used on both the demand and supply side (e.g. MARKAL/TIMES):**

1. Formulate constraints that control penetration of new demand and supply technologies (this could include sector specific discount rates).
2. Run the optimisation to establish the optimal configuration of system given objectives and constraints.
3. Review results looking at indicators such as final energy costs and if costs increase significantly in real terms then possibly review demand projection assumptions.

**If a simulation model is to be used to converge demand and supply levels (e.g. Vensim):**

1. Exogenously specify the share for demand and supply technologies (or investment in supply technologies), unless some form of endogenous rules have been specified.
2. Use software to solve differential equations that balance demand and supply based on demand-price elasticities.
3. Review the results and possibly adjust the technology shares.

**Steps common to all approaches:**

1. Calculate the Reference Case emission projection based on fuel consumption by the energy system. This is done endogenously using emissions coefficients, which can be added in different parts of the system, depending on the user and what is required in terms of results.
2. Report in as much detail as possible parameters including:
    a. Greenhouse gas emissions
    b. Primary and final energy demand
    c. Installed capacity per technology and electricity outputs from each technology
    d. Investment requirements over horizon
    e. Final energy costs
    f. All underpinning assumptions

This is also a good place to have a stakeholder meeting to ensure that everyone is on board with how the Reference Case is specified. It may be quite difficult to get an agreement on a single "line" given all the uncertainty and it may be necessary to settle on a "range" spanning from the worst-case to the best-case.

## 3.3 Phase 3: Mitigation Action Evaluation

**If an optimisation model is to be used both on demand and supply sides (e.g. MARKAL/TIMES)**

1. Identify mitigation actions where it may not be desirable for impacts to be endogenously calculated by the optimisation process or where they cannot be calculated by the optimisation process (for example mode switching in the transport sector, financing incentives that lowers the discount rate in certain sectors, educational/information programs for energy efficiency, or appliance and building standards). This is to keep these options more tightly constrained.
2. For mitigation action impacts that are evaluated endogenously, constraints in the reference case may be freed up, or additional technologies added.
3. From here on several techniques could be used, with separate runs potentially being needed to incorporate the measures that the model cannot do endogenously. These include setting:
   a. *Cumulative $CO_2$ target*: i.e. setting a constraint that limits the cumulative emissions relative to the Reference Case cumulative emissions. Different targets would be set. For each target, various indicators (e.g. total system cost, investment, electricity price) would be monitored. As mentioned above it may be necessary to adjust the demand driver projection if certain of these cost indicators (e.g. electricity price) significantly increase relative to the base year. The optimisation results will also provide an idea of the $CO_2$ price that would be needed to meet the cap for each period in the horizon. The national target would then become the target that results in energy prices that are politically acceptable. The optimal mitigation actions would be the ones identified by the optimisation, or would be based on the ones suggested by the optimisation results. There would be different policies and incentives that would be available to replicate the model's results, and the modeller would have to work with a policy analyst to come up with the most appropriate ones. Since the model only deals with the energy sector, mitigation actions in other sectors would also have to be analysed in order to see how to best balance the overall reduction target.
   b. *Annual $CO_2$ target*: i.e. setting a constraint that limits annual $CO_2$ emissions. The approach is basically the same as above except that instead of a cumulative limit, an annual limit is imposed.
   *c.* *$CO_2$ Price*: set different $CO_2$ price levels and see how the system responds and what mitigation is achieved at different price levels. Again, care needs to be taken to adjust the demand if energy prices rise too much. In MARKAL/TIMES there is a demand-response module that has been developed (Elastic-Demand) and could be implemented relatively easily. Another alternative is to link the energy model to an economy wide model (e.g. CGE/IMACLIM)

**If an optimisation model is to be used on the supply side only (demand side done using accounting/simulation model):**

1. Identify mitigation actions on the demand side. Regroup the mitigation actions such that actions that cancel out the effects of others are combined in a consistent manner. Try and estimate the $CO_2$ price that would be required to enact the mitigation.
2. Follow one or a combination of measures listed above on the supply side by making sure that the demand side mitigation options implemented are consistent with the $CO_2$ prices used in the supply optimisation model.

**If an accounting model is to be used:**

1. Identify mitigation actions on the demand and supply side. Regroup the mitigation actions such that actions that reduce the impact or energy savings of others are combined in a consistent manner.

**If a simulation model is to be used:**

1. Perform the demand-supply balancing at different $CO_2$ price levels or constraints, and observe the resulting mitigation impacts. (Note that negative cost mitigation actions such as energy efficiency will not be driven by the $CO_2$ price level, unless market barriers are somehow characterised e.g. with higher technology/sector specific discount rates.)

**Common to all approaches:**

1. Report on mitigation actions, including the impact this has on certain indicators such as the electricity price.

## 3.4 Base year data and other data issues

The starting point for projecting emissions from different sectors of the economy is the gathering of base year data. Base year data on electricity and other energy consumption, transport activity, economic activity, population and any other relevant sectoral activities is collected for the most recent year possible – which is typically at least 2-3 years prior to the year in which the analysis is being done, but may be even further in the past depending on data availability. Data sources include energy balances, records of electricity, fuel and other sales data, import and export data, input output tables, income-expenditure and other household surveys, independent studies etc.

Prior to collecting base year data, it is important that the purpose of data collection is defined to ensure that the correct data, to the correct resolution, is obtained. Failure to do this upfront can result in wasted time and effort by collecting too much information, or the situation where insufficient data is collected the first time around.

Some of the challenges with obtaining and consolidating base year data include:

- Incomplete data
- Not all necessary data being available for a single year
- Overlapping data (with difficulties in disaggregation)
- Data from different sources which differ substantially
- Lack of reporting of methodologies used for data collection
- Different levels of disaggregation of data for different sectors of the economy.

Ways of dealing with these issues include:

- Filling gaps by inference, for instance estimate energy consumption from output of physical volume assuming an intensity
- Adopting utilisation statistics from similar markets and calibrating with the energy balance
- Normative validation which involves calculating indicators and ratios from suspect data and comparing these to engineering or observed norms to check plausibility
- Consultation with stakeholders and experts
- Balancing input-output data with energy balance data
- Uncertainty and sensitivity analysis during modelling

Once activity data has been gathered, this is used to calculate greenhouse gas emissions in the base year. Ideally country, fuel, region or activity specific emissions factors should be used, however these are typically not available. As such it is common practice to revert to using default factors – here the IPCC's 2006 guidelines for National Greenhouse Gas Inventories are widely used. The guidelines provide a step-by-step approach for determining emissions from all of the sectors, depending on the amount of activity data that is available in the country.

# 4. CONSIDERATIONS TO GUIDE MODEL SELECTION

The previous sections have described broadly the types of models that are available in the energy sector. A host of considerations will help to guide both the types of models that are adopted, and the level of detail and disaggregation in the model. These include:

- Desired outputs of the modelling process – determined by the type of decision making and planning to be supported
- Availability of skills, experience and existing models in the country
- Availability of funding to conduct the modelling work
- Data availability
- Time availability for conducting the study

Each of these is discussed in the sections that follow.

## 4.1 Desired outputs of the modelling process

The choice of model is strongly determined by the desired outputs of the modelling process as identified above. Optimisation models are better suited to situations where analysts wish to choose optimal options from a set of available options, whereas simulation models are better suited to exploring "what-if" scenarios. Within these broad groups of models the level of detail is determined by (amongst other factors – discussed below), the level of resolution required in terms of the mitigation actions, and the available data.

## 4.2 Availability of skills, experience and existing models in the country

The choice of models is often determined by the availability of in-country skills, experience and existing models. Whilst it may be considered to be desirable to use "state of the art" models, it is often preferable to use local experience rather than rely on overseas consultants to build models, as there may be less opportunity to obtain support down the line. If there is opportunity to build local capacity in certain modelling platforms this may be an option, providing the time, funding and backup support is available to ensure that capacity building is effectively achieved.

## 4.3 Availability of funding to conduct the modelling work

Modelling has two primary cost components, which can be substantial and have an impact on the choice of models. The first of these is the cost of modelling software. Specialised software packages can be expensive. Prices for MARKAL vary widely, with the total costs (MARKAL plus user-interface plus GAMS and solvers) ranging from about 3,300 USD for academic users up to 15,000 USD for unaffiliated commercial users. Analytica (used in simulation modelling in place of Excel) costs between 1,295 and 14,000 USD, depending on the options chosen. The majority of people involved in modelling already have access to a spreadsheet tool such as Excel which is well suited to many models. Certain packages are free, which may provide a motivation for their use. For example, LEAP is free to certain users[2], all students, ,not for profits and academic institutions in developing countries, but all users need a licence.

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The second cost is that of paying the individuals to do the work. Depending on the model choice, models can take weeks or months to construct, from collecting baseline data through to running various scenarios and writing reports. The complexity of the models used, and the availability of data, which determines how much time needs to be invested in data collection, will determine the cost of this component. A further consideration here is the potential costs of training users on the tools and acquiring the necessary data.

## 4.4 Data availability

The level of disaggregation or detail in a model is restricted by availability of data. For example, in South Africa in the commercial sector, subsectors are considered, whereas if data allowed it may have been decided to represent different types of commercial building space within the model. Availability of specific technology and cost data on the demand side may limit the representation of technologies in the model, and influence the way mitigation actions are modelled.

An important factor with data availability is that the worse the data is the longer it takes to process it into the form that modelling requires. This is a characteristic common to bottom up models and needs to be taken into consideration when planning to build a model.

## 4.5 Time availability

Following on from the previous point, building and populating models is time consuming, and if results are required quickly, the level of complexity of models needs to be adapted appropriately.

# 5. SUMMARY

This paper has provided an overview of the considerations which need to be taken into account when choosing between modelling options for the evaluation of mitigation actions in the energy sector. What is clear is that there is no “one size fits all” approach – the choice of models is highly country and context specific. What is important is that an informed decision be made early on in a process such as the MAPS process, as data gathering and analysis is strongly shaped by the choice of model, and a poor choice early on in the process can lead to wasted time if decisions are reversed later on.