Energy Sector Management Assistance Program (ESMAP)

Model for Electricity Technology Assessments (META): User Manual

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Revision numbering

Revision		Date	Author	Key changes to model
Manual	Model			
1.0	1.0	2 May 2012	ECA	Original User Manual and META Model
1.1	1.1	4 June 2012	ECA	Responding to comments on 1.0 plus changes to META
1.3	1.3	8 June 2012	ECA	Adding further instructions regarding UAM
1.4	1.4	23 July 2012	ECA	Unwinding UAM from META. Correcting process contingency formulae. Adding modifiable technological development parameters. Correcting off-shore wind price forecast formulae, by-product calculations, projection formulae for micro gas turbines, and IDC calculations. Allowing emissions from grid supplied electricity. Expanding fuel options for diesel or gas-using plants. Unlocking the graph of costs. Adding maintenance sheet to lock/unlock. Expanding screen tips. Modifying ash and fly ash formulae. Correcting formula for cost of fuel.

Abbreviations, acronyms and key terms

CAPEX	Capital expenditure
CCGT	Combined-cycle gas turbine
CCS	Carbon capture and storage
ESMAP	Energy Sector Management Assistance Program
IDC	Interest during construction
META	Model for Electricity Technology Assessments
O&M	Operation & maintenance
UAM	Uncertainty Analysis Module

1 Introduction

The **Model for Electricity Technology Assessment** (META) has been developed by Chubu Electric Power Corp. Inc and Economic Consulting Associates on behalf of the World Bank's Energy Sector Management Assistance Program (ESMAP). The META model is a user-modifiable assessment spreadsheet that accompanies the META Guide. The META Guide provides descriptions and cost and performance data for generation, transmission and distribution technologies taking account of global market trends and technological developments. The META Guide and the META model are available to users via ESMAP's website.

The User Manual should be read in conjunction with the META Guide itself. The Guide, in addition to providing full descriptions of the technologies, also lists the sources of data on costs and performance for the three example countries and describes the methodologies for projecting costs into the future.

1.1 Uses of META

META can be used for two broad purposes:

- Generic analysis to answer broad policy-level questions such as "how do the costs of renewable energy technologies compare with conventional technologies inclusive of environmental costs?".
- To help with more specific analysis of project or regional investment decision making or approvals such as "when account is taken of external (environmental) costs and transmission costs should we build coal-fired power plants, gas-fired power plants, or wind farms?"

It can help answer a host of questions of this type. It can also help address questions such as "is it more economic to encourage small distributed generation, which avoids transmission costs, or large scale generation which requires transmission but with the associated economies of scale?".

1.2 Overview of META

META (collectively the Guide, the model, and this User Manual) can usefully be thought of as having three components:

- A written guide to technology options and their costs plus a description of other input assumptions (the ***META Guide***).
- An electronic database that brings together the information from the META Guide into Excel spreadsheets in a standard, condensed format (the ***META spreadsheet database***). The META database currently consists of data for three specific countries classified as large developing,

middle-income, and large developed. These provide the starting point for users who wish to apply the model to other countries or regions.

- A tool for estimating the levelized cost of electricity (the ***META model***). The META model currently incorporates the database but the database and the data can be considered separable from the model itself. Data for other countries can be added and used in the META model.

1.3 Users of the META model

The META model can be used by anyone interested in a comparison of electricity generation and delivery technology costs. The target group is therefore broad and diverse; it is likely to include government ministries and policy makers, environmental groups, NGOs, energy regulatory authorities, manufacturers, equipment suppliers, electricity companies and power system planners. Given this diverse group of potential users and the range of questions that META might be used to address, META has been developed with maximum flexibility to accommodate the varying needs of different users (or, the differing needs of any given user).

1.4 Scope of the META model

The objective of the META model is to allow the **comparative assessment of the economic costs of a range of electricity generation and delivery technologies**, including conventional generation options (thermal, hydroelectric, etc.), non-conventional options (renewables), and emerging options such as power storage and carbon capture and storage (CCS).

These comparisons are based on:

- Consistent performance and cost estimates for a broad array of power generation technologies utilising, to the extent possible, data from actual projects. For this purpose, META has been populated with **default performance and cost data inputs** drawn from *three representative countries*: *India, Romania* and the *USA*, which were chosen as *proxies for developing, middle-income and developed countries*, respectively;

- **User-specified inputs** for key performance and cost parameters, so users with different requirements and project specifications may change key inputs to obtain project-specific estimates. Accordingly, the parameters that a user can specify include:

  - Plant size;

  - Capacity factor;

  - Fuel price;

- Fuel heating value;
- The cost of environmental externalities (SO_2, NOx, CO_2 and particulates);
- Length of transmission line needed or transmission strengthening required; and
- Discount rate.

Also, the software tool has been designed so that it can be updated by users to reflect, among other things, future commodity price fluctuations, changing market conditions for power plant equipment, fluctuations in the price of carbon emissions and technological improvements.

The META model is designed so that performance parameters, capital costs, operation and maintenance costs, externality costs and the levelized unit cost of electricity are specified for each technology option for three reference years - **2010 (actual), 2015 and 2020**.

The META model can also be used to undertake uncertainty analysis for selected key inputs. Hence, for illustration purposes, analysis (Monte Carlo simulation) has been undertaken with a proprietary Excel add-in. The User Manual describes how users can employ Monte Carlo simulation methods with the use of a software tool of their choice for the input variables that they designate.

1.5 General approach

1.5.1 Economic versus financial analysis

The META model calculates the levelized cost of electricity primarily in economic terms. This differs from financial analysis in that the economic analysis considers all the costs to society – not only the monetary costs to a utility. It allows the user to include, for example, the environmental costs and the true costs of disposing of by-products irrespective of whether the utility pays those costs. If there are benefits to the economy from by-products – whether or not the utility receives revenues in monetary terms - these benefits may be off-set against the other costs, thus lowering the overall levelized economic costs. In an economic analysis the costs should exclude taxes and subsidies, the discount rate should be the country's social discount rate, the asset lives should be the time period over which the asset continues to give service, and in some cases the input costs may be adjusted when the monetary prices for local inputs are distorted.

However, while the model is primarily designed to calculate levelized costs in economic terms, it is relatively simple for users to modify the inputs to calculate the levelized costs in financial terms to a utility (if the data are available). To do so, the user should include taxes in costs, take account of subsidies (if any), exclude nonmonetary costs (externalities, by products) and benefits (by-products), and use a financial discount rate[1].

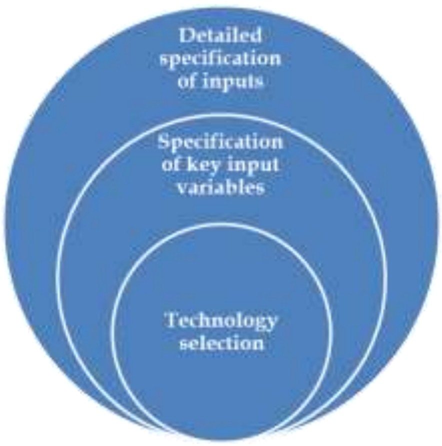
(Note, the model is not, and cannot be used as an accounting financial model – capital costs are not depreciated (they are levelized) and there are no revenues other than from by-products which off-set the levelized costs).

1.5.2 Generic or project/location specific analysis

In broad terms, the model can be employed at three levels, as demonstrated in Figure 1 and explained below:

- **Analysis using default data** – users may only select the technology options they wish to compare (drawing from the database for a given country type and year) and the model will generate cost comparisons on the basis of the default inputs;
- **Tailored generic analysis (specification of some key input variables)** – users may, in addition to the technology options of interest, enter some key parameters that more closely match the specific questions being addressed through a 'one-stop' selection pop-up window developed for this purpose; and
- **More project or location specific analysis (detailed specification of inputs)** – users have the flexibility of further customizing META to their specific needs by entering detailed input data directly into the relevant worksheets and for as many parameters as they consider necessary.

Figure 1 META model user options



[1] Note, we suggest that the user does not change the asset life when switching from economic to financial analysis. Although for accounting purposes assets often continue to provide useful service even after they are fully depreciated, and financial lives are often assumed to be shorter than economic lives, nevertheless even from a financial viewpoint the assets are also continuing to provide service and this should be recognized in the assumed asset lives.

1.5.3 Caveat

It should be emphasized that META is a cost comparison tool and cannot be substituted for detailed power system planning and associated software tools that have been developed specifically for this purpose. Power system planning tools take account of the full complexity of power systems and the operation of power plants within such a system based on their technical and cost characteristics, none of which are accommodated within META. However, META can usefully be employed in conjunction with power system planning tools, by providing information about the technical and cost characteristics of the plants available for expansion and then analyzing them rigorously with the power planning tools.

1.5.4 Inputs and outputs

The structure and the default data of META are based and drawn from the META Guide, which produced performance and cost estimates for an extensive list of generation technologies and for various transmission and distribution options.

The user is referred to the META Guide for a description of the methodology used to derive the performance and cost estimates and the sources of data.

All costs and prices are in real US$ terms and in prices of the year-end 2010. Projected prices are also in prices of the year 2010 i.e. the model employs real (rather than nominal) prices. META uses overnight capital costs as the key metric for quantifying capital cost. Overnight costs reflect the costs of equipment, construction, installation and engineering but exclude financing charges/interest during construction (IDC) costs that are incurred while the plant is being built or, equivalently, the opportunity cost of capital tied up while the plant is under construction but not operating. META model users should specify the phasing of costs over the construction period and the model will then calculate IDC based on the assumed cost of capital and will add this to the overnight cost. Note, however that this will not be necessary if the user, when calculating the capital cost, has already made allowance for the opportunity cost of capital or IDC during the construction period. (See also the discount rate and financing cost in section 4.1).

The output from the model calculation is the levelized cost[2]. This is the total discounted cost of power supply over the life of the asset including the capital cost of generation, transmission and distribution, fixed and variable O&M, the fuel cost, external costs, and the costs or revenues from the disposal of waste products, all converted into US$/MWh or US¢/kWh.

1.6 Structure of this User Manual

The remainder of this User Manual is structured as follows:

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[2] The levelized cost is calculated using the PMT formula in Excel. By default this assumes that the cost in first year is discounted or equivalently that the user is standing in year 0 and the costs are spread over years 1 to n where 1 is the first year of operation and n is the last year of operation (i.e., the economic life of the asset entered that is entered into the dataset).

- **Section 2** is a "***Quick-start guide***" to META, which allows the user to operate the basic model within a few minutes;

- **Section 3** provides a ***general description*** of the model focusing on the general layout of the model and instructions on how to operate the model;

- **Section 4** provides ***specific instructions*** for entering or changing the data used by the model;

- **Section 5** explains how ***uncertainty analysis*** and Monte Carlo simulation methods can be used within META to generate input values for key parameters, and contains examples of results of a number of simulations undertaken for key inputs for five indicative generation plants; and

- **Section 6** explains that updates to the model may be available from time-to-time on the ESMAP website.

Annexes provide some background to META and list reference sources for the data described in the META Guide and used as defaults for the three countries in META.

2 Quick-start guide to the model

Please ensure that Excel's **MACROS are ENABLED**. Macros must be enabled in order to fully use the model.

The **OPTIONS_Selection** sheet is the main 'cockpit' for the model and it is possible to operate the model and see results graphically without moving beyond this sheet.

Choose the ***year*** that you wish to analyse (2010, 2015 or 2020), the ***country grouping***, the ***discount rate*** and financial ***cost of capital***.

When choosing the country, ***start from the country which is closest to the one that you wish to analyse***; pick one of the following India, Romania or USA and then modify the inputs (see below) as appropriate. India is intended to be the starting point for anyone wishing to consider a developing country, Romania the starting point for a middle-income country and the USA is the starting point for a large developed country.

***Warning**: it is important to select the proxy country before you start modifying the input data*. When you swap the proxy country – the model over-writes the input sheets.

Reminder – Macros must be enabled. If macros are not enabled then please follow the instructions in section 3.1.2 below.

Click the first '***Define Option***' button to define the technology option that you wish to analyse. Choose a ***generation technology*** from the drop-down menu (top left of the screen). You may also choose ***transmission*** (bottom left) and ***distribution*** (bottom right) technologies if you wish, but this is optional.

Float the cursor over the information symbol ? to find information about the input variable.

Change any of the parameters for the technology or technologies you have chosen.

Note: Where values are normally expressed as percentages, the values should be entered as percentages or as decimal values. Thus, a capacity factor of 30 per cent should be entered as 30% or as 0.3.

Click 'Insert Option' (bottom right of the sheet).

You can define up to 5 different options for comparison by clicking on the other '*Define Option*' buttons and following the same procedure described above.

The result in US$/kWh is shown graphically and in a table at the bottom of the OPTIONS_Selection sheet and in full in the OPTIONS_Results sheet.

The default parameters or the parameters that you have selected are also listed in the OPTIONS_Selection sheet.

To go beyond this level of analysis and customise the inputs and results, guidance is provided in the remainder of this Manual.

3 General description of META

3.1 General instructions on using the model

3.1.1 Excel compatibility

The model is compatible with Excel 2007 and later versions of Excel. Some functions used by the model are not recognized in Excel 2003 and it is not therefore suitable for use with Excel 2003.

The model runs on Apple-Mac as well as PCs. It is compatible with Excel for windows on a Mac but the macros are not compatible with Excel for Mac. A user who wishes to use Excel for Mac may use the model but will not be able to use the buttons and some of the model's functions will be limited.

3.1.2 Use of macros

The model has minimized the use of macros but some macros are used and must be enabled in order for some elements of the model to work.

Macros should normally be enabled by the user when requested on start-up. If macros are not enabled and you were not asked to enable them on start-up, then this will be because the security settings have been set to block all macros without notification. To enable macros, the simplest method is to change the security settings[3] to something other than the highest level (the highest setting may be something like "Disable all macros without notification") and then re-open the model.

3.1.3 Colour coding

The following colour coding conventions are used in the model:

Colour cells	Meaning
Blue cells	Input values directly into these cells.
Grey cells	Inputs chosen by the user from a drop-down box that appears after clicking on the cell.
White cells	Model calculations and outputs. The user should not modify these cells.

[3] The location of security settings differs depending on the version of Excel but in later versions of Excel it is in the "Trust Centre".

3.1.4 Cell protection and un-protecting cells

White cells will normally be protected to prevent the user accidentally over-writing formulae. The user may, however, change protected cells by removing protection using the protection settings in the Tools menu. The password is ETOAG. We suggest that the user restores the protection after making changes.

There is sheet at the end of the model labeled “Maintenance” that contains two buttons allowing the user to unprotect all sheets and then re-protect them. The model will, in any case, be re-protected the next time the user clicks one of the other buttons in OPTIONS_Selection or INPUTS_ sheets.

3.1.5 Additions or changes

Users wishing to modify the spreadsheet should be aware that the formulae used in the model use named ranges and the location of columns is important. ***Users are advised not to add or remove columns***. The model is generally tolerant of additional rows.

3.1.6 Resuming normal mode after using uncertainty analysis

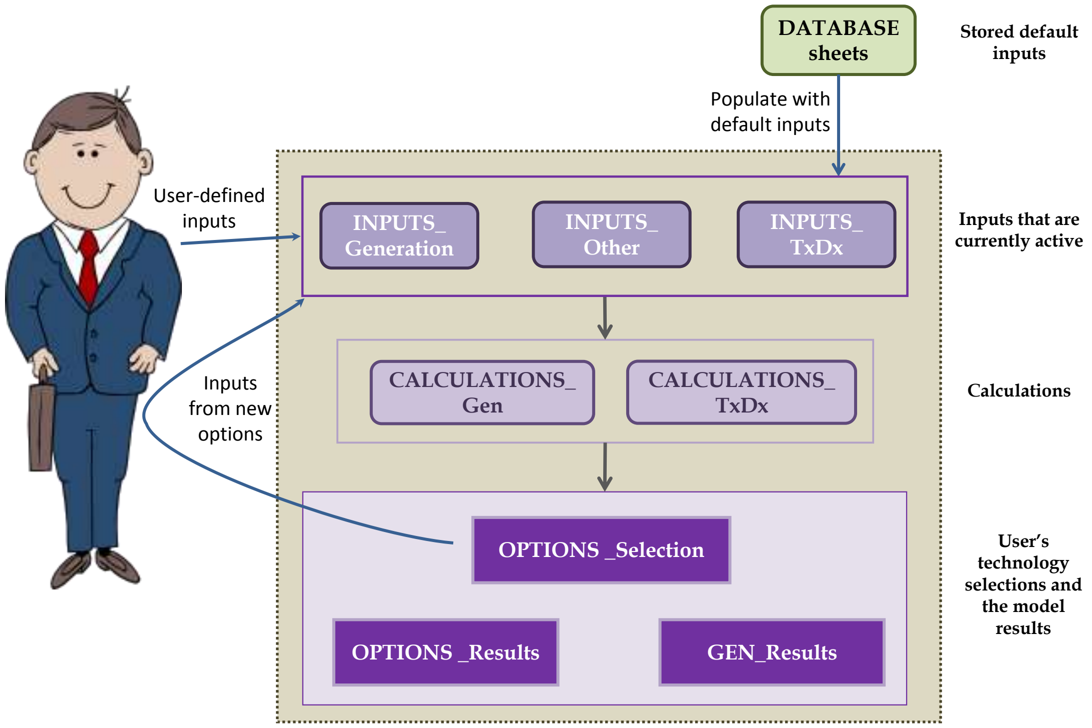
Instructions on using the Uncertainty Analysis Module are provided in Sections 5 (and specifically Section 5.5 of this Manual). However, users who have used the uncertainty analysis part of the model and have resumed normal use (without uncertainty analysis) of the model should ***ensure that the button (Use Uncertainty Analysis) in the Uncertainty Analysis sheet is unticked***.

3.2 Model structure and operation

3.2.1 Overview

Figure 2 below is a stylized representation of META.

Figure 2 META model structure



3.2.2 Naming conventions

The naming conventions for the worksheets are as follows:

- ***Gen*** is for Generation, ***TxDx*** is for Transmission and Distribution.
- Sheets containing input data begin with: ***INPUTS_***. These contain all the required input variables for running the model. These sheets extract default data from the database worksheets of the model, or users can themselves define their preferred input data in the relevant input worksheets directly.
- Sheets containing outputs or results have names ending with: ***_Results.*** Two results sheets provide cost comparison information for the selected technology options (OPTIONS_Results) and for the full set of generation technologies (Gen_Results), respectively.
- Sheets containing calculations begin with: ***CALCULATIONS_***. These contain all relevant computations and should not have any data entered into them (or be altered) by users.
- Sheets starting with ***DATABASE_*** contain the default data for each of the three countries that proxy the three country types (large developed country, middle-income country and developing country).

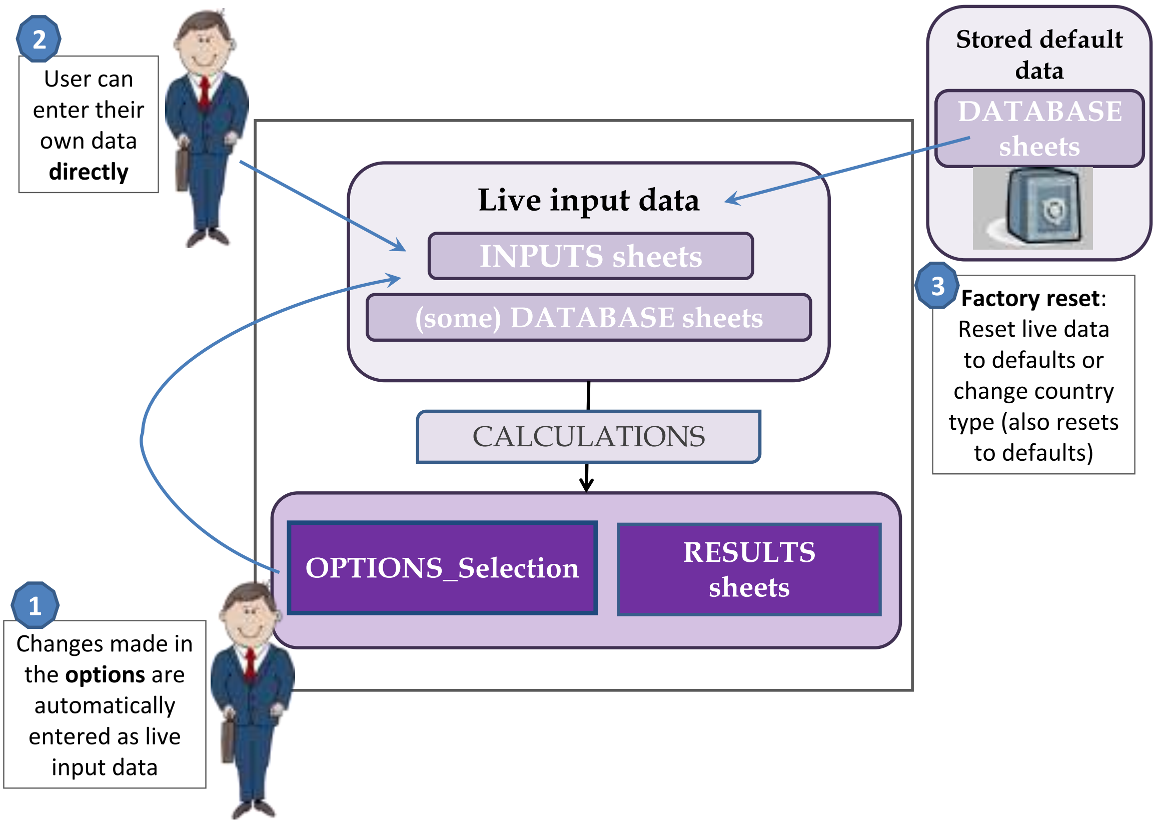
Additionally, there is an options selection sheet (***OPTIONS_Selection***), where users define the technology options they wish to have compared and are given the choice of selecting input values for a number of key parameters that drive the cost comparisons.

3.2.3 INPUT sheets and DATABASE sheets

Three ***input worksheets*** (INPUTS_Gen, INPUTS_TxDx and INPUTS_Others) ***temporarily*** hold all the required input data that are used to obtain the technology assessment results in the OPTIONS_Results and the GEN_Results sheets.

The three input sheets take data from three sources as illustrated in Figure 3.

Figure 3 Three routes for entering data



The user may:

1. modify a pre-selected set of the most important data in the input worksheets using the ***OPTIONS_Selection menu***;
2. define their preferred ***input data directly*** into one or more of the relevant input sheets,
3. modify the default data in the ***database worksheets*** – these will become permanent changes to the default data,

The INPUT sheets should generally be considered as ***temporary holding areas*** and the data that the user enters in those sheets will be overwritten whenever the user switches to another country/region or if the user clicks on the Restore Defaults buttons (see below).

The DATABASE sheets are the more permanent storage areas for the input data and these form the default values. Users who wish to make permanent changes to default input data should enter this data into the appropriate DATABASE sheets and create a customised version of the model.

However, users who wish to work on only one country/region may work entirely with the INPUT sheets and save the model with new data in the INPUT sheets (or re-save the model with a new name) and the new values entered into the input sheets will be saved in the INPUT sheets. (However, ***beware***: if the Restore Defaults button is clicked or a new country/region is selected, as described in the following section, these values will be lost and replaced with the default values).

3.2.4 Comparing costs between years

The model contains data for the base year which is always 2010 and escalates/reduces cost values to 2015 or 2020 (described in more detail below). The user may choose to examine costs per kWh in any one of those three years (2010, 2015 or 2020). To compare costs 2010 with 2015 and 2020 for the selected options (up to a maximum of five options), the user should look at the OPTIONS_Results sheet. Alternatively, if users wish to compare costs in the three different years for a greater number of generation technology options, they should turn to the GEN_Results sheet.

3.2.5 Results

The resulting costs per kWh are summarised in the OPTIONS_Selection sheet and in full in the OPTIONS_Results sheet for the selected technologies. Specifically, the OPTIONS _Results sheet contains the unit cost results for each level of the 'value chain' (generation – transmission line – transmission sub-station – distribution network) for the selected options and for all the years of analysis (2010, 2015, 2020). The OPTIONS_Selection sheet also graphs the results.

The full set of costs per kWh for all generation technologies are shown in the GEN_Results sheet. Some users may wish to jump straight to the GEN_Results sheet to find typical unit costs for a wide range of different technologies for the three years (2010, 2015, 2020) using default input values.

3.2.6 Restoring the defaults

If you have changed the input parameters for a technology using either the OPTIONS_Selection menu or by entering values directly into the inputs sheets, and you decide you would like to restore the defaults, you may do this by clicking on ***Restore Default Values*** on the top right of the menu after first clicking on Define Option. This restores the defaults only for the technology you have selected using Define Options.

Restore Default buttons are also found in the INPUTS_Gen, INPUTS_TxDx and INPUTS_Others sheets. These restore the default values for ***all of the input data*** in these sheets.

Note: if you change from one country/region to another, then the model will replace all data you have entered in the inputs sheets with the default values for the new country/region.

3.2.7 Changing the defaults

You may change the default values in the appropriate cells in the ***Database sheets*** and re-save the model (with a new name). New default values will then be saved permanently.

3.2.8 Navigating the model

The model contains a number of hyperlinks allowing you to navigate more easily between different parts of the model. These are generally found at the top of the worksheets.

3.2.9 Percentage values

Where values are normally expressed as percentages, the values should be entered in the model as percentages or as decimal values. Thus, a discount rate of 10 per cent should be entered as 10% or as 0.1.

This applies to the discount rate, financial rate of return, capacity factor, plant efficiency, auxiliary power consumption, load factors, etc.

3.3 Model architecture

The following contains a more detailed description of the model architecture and can be skipped by those more interested in the practical aspects of the model.

3.3.1 Option selection sheet

At the most fundamental level, users may select from a minimum information set and obtain a comparative cost assessment for their defined technology options (up to a maximum of 5 options), by relying largely on the default inputs provided by the model. Such users need only work with the 'Principal modules' of the model (see Figure 2). These consist of the following:

- o **"OPTIONS _Selection" module** - in this module, users define the technology options they wish to compare for a specified country type and year. At a minimum, users must define:

- the technology options of interest for generation, transmission (lines and sub-stations) and distribution[4] - up to 5 options can be selected simultaneously from a drop-down list within the relevant "Define Option" buttons;

- the year for which the analysis should be conducted - 2010 actual figures, or projected costs for 2015 or 2020; and

- the country type – developing, middle income or large developed.

In the absence of any other user specifications, the input worksheets of the model draw from the default data contained in the model's database sheets to generate the cost comparisons.

In order to derive project-specific cost estimates, users also have the option of changing values for all or a sub-set of key parameters provided in the "Define Option" buttons of this module, such as the level of generation capacity, the plant's capacity factor and the fuel price.

To assist users, this OPTIONS_Selection sheet also contains all the key information needed for comparative purposes for the selected year of analysis, specifically:

- Descriptions of the defined technology options;

- A summary table with the key inputs; and

- An overview of the cost comparisons/results in tabular and graphic form.

- **"OPTIONS _Results" module**, which contains the unit cost results for each level of the 'value chain' (generation – transmission line – transmission sub-station – distribution network) for the selected options and for all the years of analysis (2010, 2015, 2020). This module also contains the key cost components for each level of the value chain, which underpin the unit costs. For example, in the case of generation, the following cost information is presented:

  - Capital costs – total capital investment cost, levelised capital investment cost and levelised unit capital cost;

  - Operation and maintenance costs – fixed, variable and fuel costs;

  - Environmental costs; and

  - By-product (gypsum, bottom ash, fly ash) net revenues or net costs in cases where there are disposal costs.

[4] In the case of delivery technologies, such choice might entail a "No transmission", "No substation" and "No distribution" option.

- **"Gen_Results" module** - the 'principal' part of the model contains an additional results module, which presents the unit costs and the cost components just listed above for all 54 generation technology types and for all three reference years (2010, 2015 and 2020). This allows the user to compare the cost results for their chosen technology options with the full suite of available generation technologies across all time periods contained in the model.

  If no further inputs are specified directly in the input sheets, the results calculated in this module derive from the user specifications (if any) for the defined technology options (in the "OPTIONS_Selection" module) and the default values (in the "DATABASE_Worksheets") for all residual generation technology options.

3.3.2 Bespoke modelling

The META model has added flexibility which allows users to change an even greater number of input values according to specific circumstances. This can be done by inputting the desired input values for the parameters contained in the following input sheets:

- **"INPUTS_Gen"** – this contains all the information describing the design and performance parameters and associated costs of each generation technology. There are 54 generation technology options contained in the model covering conventional, renewable, emerging and storage technologies.

- **"INPUTS_TxDx"** - this contains all the information describing the design and performance parameters and associated costs of each delivery technology. In the case of transmission, there are options for single and double circuit lines, which may be overhead lines or subterranean, and for different standard rated voltage levels found in the three country types. For distribution, only high level unit cost estimates as a function of demand can be entered, as distribution costs cannot be readily standardised in advance of a more detailed design stage.

- **"INPUTS_Others"** – this sheet contains miscellaneous data inputs necessary for the technology cost assessments and comparisons. Specifically, the following parameters can be found in this module:

  - Forecast price changes for commodities, labour and fuel costs, and by-product prices/costs, which are used to determine capital, fuel and operational costs in the 2015 and 2020 projection years;

  - Inputs needed to determine environmental costs, namely fuel heating rates, pollutant content by fuel, carbon emission prices and environmental damage costs (SO_2, NOx, CO_2 and particulates).

4 Detailed instructions

The following provides specific instructions to users relating to some of the input parameters with descriptions of how these are handled by the model. The Manual does not describe input parameters that are largely self-explanatory.

4.1 Discount rate and financing cost

Two parameters entered into the OPTIONS_Selection sheet are the discount rate and the financing cost. The discount rate is the economic discount rate and is the primary parameter used to calculate the levelised cost of electricity. The financing cost is used to calculate interest during construction – where appropriate – to add to the basic overnight unit capital cost.

The financing cost only has an impact on the resulting costs per kWh if the "Construction time" entered in the Options_Selection sheet or the "Build time" columns in the INPUTS_Gen or the DATABASE_Gen_ sheets are greater than zero. Users should normally specify a build-time greater than zero. The exception is where the capital cost entered in the model is not the overnight cost and has already incorporated cost of IDC within that cost.

Since the default data and default analysis in the model is based on economic (rather than financial) parameters, the default values for the "financing cost" are the same as the real discount rate. Nevertheless, the user has the option to enter different values for the discount rate and financing cost if he/she chooses.

4.2 Capital and related costs

4.2.1 Overnight capital costs and construction period

The capital cost is expressed as an overnight cost. This means that no allowance is made in that cost for interest costs during construction (or, equivalently, no allowance is made for the opportunity cost of money tied up during construction and before the plant is operational).

The user should normally enter a value above zero for the construction time. This will allow the model to take account of the cost of interest during construction and its equivalent in economic terms. (See also section 4.1 regarding discount rate and the financing cost).

Construction or build periods in the model should be interpreted as follows:

- 0 - effectively assumes that the construction costs are incurred during the first year of operation of the plant and that there are no opportunity costs of capital during the construction of the plant;

- 1 - effectively assumes that the construction costs are divided equally between the year before operation begins and the first year of operation – this results in an opportunity cost of capital for 50% of the cost that is tied up during the year before operation;

- 2 - effectively assumes that the construction costs are spread equally over three years including the two years before operation begins and the first year of operation – this implies two years of opportunity costs and IDC and one year without.

- 3 or more years should be interpreted similarly.

4.2.2 Generation capital costs

The base year generation unit capital costs are entered in the INPUTS_Gen and DATABASE_Gen sheets. ***The user cannot modify the base capital costs in the OPTIONS_Selection sheet.***

The default capital cost values in the model are formulae whereby the unit cost (US$/kW) depends on the unit sizes selected. Smaller units have a higher cost per kW. The parameters for these formulae are hidden (columns F and G) and the equations are explained in the META Guide. The user may over-write the formulae with fixed values in the INPUTS_Gen or DATABASE_Gen sheets but should be aware that the unit costs will not then vary with unit size. A better approach would be to un-hide the columns and modify the parameters in columns F and G and/or the formulae – but this is for more advanced users.

The base capital costs exclude ***contingencies*** (see section 4.2.10) and are defined for a specific seismic zone (see section 4.2.9 below) – usually the least seismically active zone. Annex A3 provides a further explanation of calculations specific to the default values in the original META. Provided that users understand the principle that the base capital costs entered into META should exclude contingencies, the explanation in Annex A3 should not be needed by most users.

The base capital costs should include the cost of environmental control technologies if they are available for that technology – see section 4.2.8 below.

The base capital costs for coal-based technologies depend on the quality of fuel expected to be used – see section 4.2.13 below.

4.2.3 Unit size ranges

The capacity of power plants is normally constrained within certain ranges. Diesel plants, for example, will normally never be more than 25 MW each while unit sizes for coal-fired steam plants will normally be at least 300 MW but not more than 900 MW. The size ranges are explained in the META Guide but the user can remind himself of the size range by double clicking the “Installed capacity” box in the OPTIONS_Selection sheet and the model will then alert the user to the range of available unit sizes.

4.2.4 Economies from multiple plants

In case of multiple plants there may be some cost savings from shared facilities (roads, fuel handling etc.). However, since the extent of these savings is very project-specific they have not been included in the costs in the model. The user should be aware that for multiple plants there is likely to be some cost reduction compared with the cost indicated by the model and may need to factor this into the assumed capital cost.

4.2.5 Generation capacity factor

The capacity factor determines the kWh generation from a given generation technology. The higher the capacity factor, the lower the levelized cost per kWh. However, some technologies are deliberately chosen to serve in peaking or mid-merit roles with lower capacity factors.

Note that comparison between two plants with different capacity factors is not always valid. A plant which is designed for peaking duty and with a capacity factor of 10% is not, for example, directly comparable with a base load CCGT power plant with a capacity factor of 85%, and the results must be interpreted appropriately.

A 'screening curve' is provided in the OPTIONS_Selection sheet of META. This shows the levelized cost per kWh for a range of capacity factors from 10% to 90% and allows the user to check the existence of cross-over capacity factor points at which the levelized costs per kWh of two technologies are equalized.

4.2.6 Comparing generation technologies with different capacity

Users who wish to compare two generation options with significantly different capacity (e.g., a 300 MW oil-fired steam plant versus solar PV) may legitimately do so because the model calculates costs per kWh supplied with or without transmission/distribution costs.

The default formulae for capital cost (which the user can modify or the user can replace the formulae with a simple number) in the model takes account of economies of scale by adjusting the unit costs for unit sizes (see section 4.2.2).

4.2.7 Other costs that depend on capital costs

Note that several other costs are entered in the model in the INPUTS_ and DATABASE_ sheets as a percentage values relative to capital costs. This includes fixed O&M costs for generation and transmission and project and process contingencies. These costs will therefore automatically change when the capital cost of a technology is changed.

4.2.8 Environmental controls and costs

Important point to note: **The model assumes that the capital and operating costs associated with environmental control technologies are included in the base costs**

whenever those technologies are available – even if they are not routinely used in that country.

The use of environmental controls technologies (flue-gas desulfurisation (FGD) and selective catalytic reduction (SCR)) incurs higher capital costs and leads to additional operating costs.

The model assumes that the capital and operating costs associated with environmental control technologies are included in the base costs whenever they are available – even if it is not routinely used in the country[5].For example, FGD is clearly not necessary and not available for solar PV technologies and the capital and operating costs clearly would not include the costs of FGD. However, FGD is available for coal-fired steam plants and in India, even though FGD may not be routinely fitted, the base capital and operating costs should (and do) include the costs of FGD.

The model then allows the option of removing environmental control technologies and thereby reducing capital and operating costs. Three columns under "Environmental emission control equipment" in the INPUTS_Gen or DATABASE_Gen_ sheets indicate the percentage reductions in capital costs and fixed and variable O&M costs if environmental equipment is not installed. The adjustments in the model are expressed as a percentage of the base capital costs, fixed O&M costs ($/kW) and variable O&M ($/MWh). The user may change the assumed percentage adjustments in these sheets.

These percentage reductions are only applied if the user selects "FGD not installed – base costs reduced" in the OPTIONS_Selection sheet or in the INPUTS_Gen or DATABASE_Gen_ sheets. Similarly for SCR.

Note, if no percentage reductions are entered into the appropriate columns of the INPUTS_Gen or DATABASE_Gen_ sheets then the user will not be able to select "FGD not installed – base costs reduced" in the OPTIONS_Selection_Sheet. Similarly for SCR.

When changing the environmental control parts of the INPUTS_Gen or DATABASE_Gen_ sheets, the user is presented with three choices in the drop-down box – see Figure 4. For SCR, the choices are:

- SCR installed and included in the base costs
- SCR not installed, base costs reduced
- Not applicable

<u>If environmental control technology is available</u> (for example for a coal-fired plant) then the <u>first or the second option should be selected. In this case the base capital and operating cost should include the cost of SCR</u> and you should have included percentage reduction values in the associated columns.

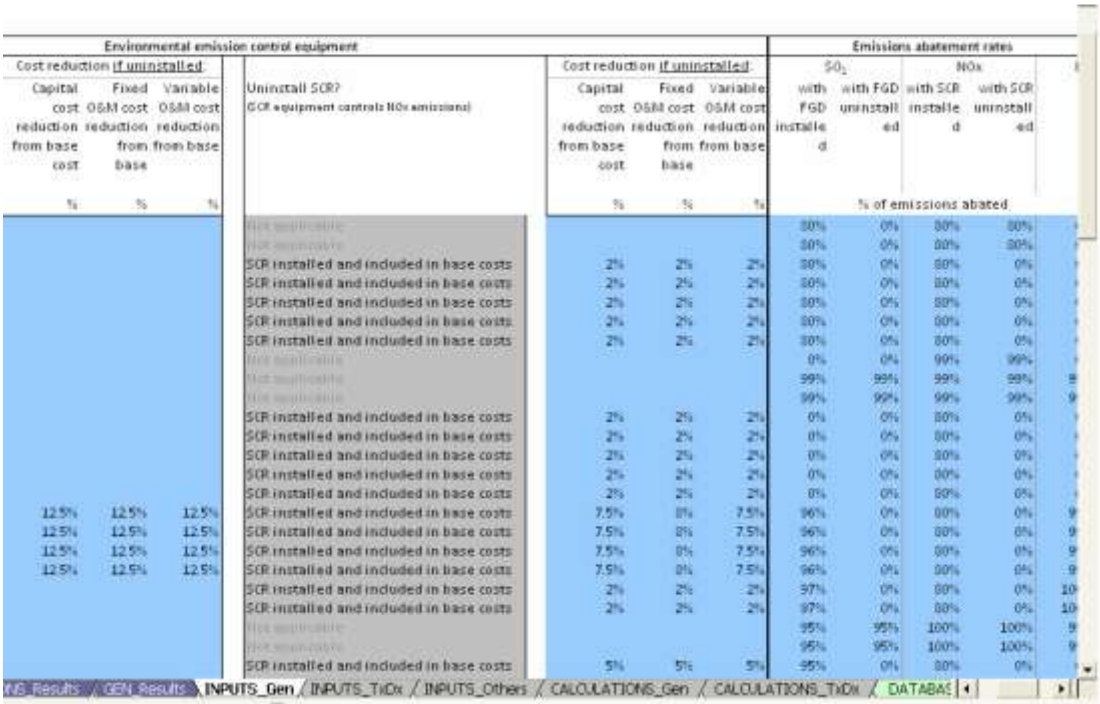
[5] Clearly some technologies do not normally require environmental controls but the model is set up such that it is possible to apply environmental control technology to all generation technologies.

- o You should select the first of the drop-down options if you wish to assume that the technology is installed.
- o You should select the second of the drop-down options if you wish to assume that the control technology is not installed for this technology – the capital and operating costs will then be reduced (though emissions and emission costs will increase).

Lastly, if SCR is not available with this generation technology then you should choose "Not applicable" from the drop down menus.

The same instructions apply for FGD.

Figure 4 Environmental control technologies



When a user wishes to modify the base capital costs in the INPUTS_Gen sheet or in the DATABASE_Gen sheets, normally, where FGD or SCR is available for that technology, the base capital and operating costs should include the costs of using these control technologies and appropriate percentage cost reductions should be entered into the INPUTS_Gen or DATABASE_Gen_ sheets. However, if the user never intends to consider the option of dropping FGD or SCR then it is not absolutely necessary to include the capital and operating costs of FGD and SCR in the base data or to enter percentage cost reductions.

4.2.9 Seismic zones

Plants located in seismically active zones will incur higher costs of civil works in order to withstand earthquakes or tremors. Different regions classify seismic zones in different ways. The zones in each region and the escalation factors for different zones are defined in the DATABASE_INPUTS_Other.

If the user changes the default seismic zone for a particular technology then the base capital cost also changes by the relevant scaling factor for that zone, shown in the DATABASE_INPUTS_Other sheet.

4.2.10 Contingencies

In META the base costs are shown separately from the contingencies.

When attempting to estimate capital costs for technologies, care must be taken in distinguishing between:

- costs used in feasibility studies where base costs are first estimated and then a contingency is added, and

- outturn costs.

Contingencies are used to reflect potential unknown factors that affect costs and that cannot be anticipated at the design stage. So costs are estimated from first principles, perhaps using a quantity surveyor and based on data on the market price of major cost components, and then a contingency is added to reflect other costs that might occur.

In the case where costs are derived from projects that have been completed, there are no unknowns and therefore no need for contingencies. However, outturn costs may be used as the basis for estimating costs to be used for studies of other projects and care must then be taken to avoid double-counting contingencies. If users wish to use the costs from completed projects as the basis for costing technologies within META, then either:

- The capital costs (per kW) should be entered directly into META in the INPUTS_Gen or DATABASE_Gen_ sheets, and zero contingencies should be assumed.

- The contingency factor should be estimated and the outturn cost reduced by the amount of the contingency factor to give a cost per kW. This would then be entered into the INPUTS_Gen or DATABASE_Gen_ sheets, and contingency factors should also be included in these sheets.

Two types of contingencies are considered by the model – project and process. Project contingencies reflect uncertainties over the final installed cost for known technologies. Process contingencies refer to uncertainties over the costs of technologies that are not yet fully commercialised. These are used by the model to escalate the base capital costs.

Contingencies should be entered in the model with a percentage sign or as a decimal (i.e., 20% or 0.2).

As noted in section 4.2.2, the formulae in the original META model reflect specific circumstances that are described in Annex A3, but these should not be a concern to most users.

4.2.11 Adding or replacing generation technologies

Users may rename one of the 54 existing default technologies. This can be done by changing the names (and other parameters) for an existing generation technology in the INPUTS_Gen sheet or DATABASE_Gen_ sheets.

However, ***"Off-peak electricity from the grid" should not be re-named***.

Although the model allows the insertion of new rows and new technologies in the INPUTS_Gen and DATABASE_Gen_ sheets, this requires the addition of corresponding blocks in the DATABASE_Proj_Gen_ sheets and adjustments to some formulae. This should only be undertaken by the model authors or by someone very familiar with Excel. ***The model should therefore be considered to be constrained to having a choice of up to 54 technologies***.

In cases where the user ***changes the name*** of a generation technology to something very different from the original or default technology, then care must be taken to change all the corresponding characteristics of the plant. In addition to those shown in the corresponding row of the INPUTS_Gen or DATABASE_Gen_ sheet, the user should also change the capital cost breakdown of the re-named technology in the DATABASE_Proj_Gen_ sheet (the name of the technology will change automatically when it is changed in the DATABASE_Gen_ sheet, but, until it is changed, the cost breakdown will continue to describe the previous technology (see section 4.6).

If a new coal-fired generation technology is introduced that replaces a previous coal-fired technology, the user should change the characteristics in the "***Coal type adjustment factors***" section of the INPUTS_Others or DATABASE_INPUTS_Other sheet (see section 4.2.13 below). If a new coal-fired technology is introduced in addition to the existing coal-fired technologies recognised in the "*Coal type adjustment factors*" then a new row should be inserted in the "*Coal type adjustment factors*" in the INPUTS_Others sheet (for a temporary addition) or in the DATABASE_INPUTS_Other sheet for a permanent addition.

When creating a new technology by re-naming an existing technology – the user should be careful to ensure that the capital and other costs are consistent with the default assumptions relating to seismic zone and coal quality – as described in section 4.2.2 above and sections 4.2.9 and 4.2.13. Where environmental controls (FGD and SCR) are available for the new technologies added to the database, the capital and O&M cost estimates should include the costs of those control technologies (see section 4.2.8).

4.2.12 Adding or changing TxDx technology

In the case of transmission, the user has essentially two choices – overground or underground transmission, and a transmission substation. The user may also select the voltage level of the line and whether it is single or double circuit and, in the case of the substation, the level of MVA output.

For distribution technologies, user choice is limited to entering values for the distribution load factor and loss rate. As mentioned above, distribution choice is limited because distribution costs cannot be readily standardised in advance of a more detailed design stage.

4.2.13 Coal type adjustment factors

The quality of coal supplied to a plant dictates the plant's design and directly influences the capital and operating costs of coal thermal plants. For example, the cost per kW of a coal-fired power plant burning good quality coal will be lower than the cost per kW of a coal-fired power plant burning coal with high ash and low calorific value.

The default capital and operating costs for each country are determined on the basis of the default coal type for that country. If a user chooses a coal type other than the default option, the base capital cost and variable O&M costs are adjusted automatically by the magnitude of the "scaling factor" in the INPUTS_Others or DATABASE_INPUTS_Other sheet (these two sheets have a section entitled "***Coal type adjustment factors***").

		Coal - lignite			
		Base capital cost	Variable O&M cost	Fixed O&M cost	Auxiliary Power Consumption
		scaling factor	scaling factor	+ / - %	+ / - %
Coal Subcritical	Coal - lignite	1.00	1.00	0.00%	0.0%
Coal Supercritical	Coal - lignite	1.00	1.00	0.00%	0.0%
Coal Ultra Supercritical	Coal - lignite	1.00	1.00	0.00%	0.0%
Coal Supercritical with CCS	Coal - lignite	1.00	1.00	0.00%	0.0%
Coal IGCC without CCS	Coal - lignite	1.00	1.00	0.00%	0.0%
Coal IGCC with CCS	Coal - lignite	1.00	1.00	0.00%	0.0%
Coal CFB (subcritical)	Coal - lignite	1.00	1.00	0.00%	0.0%
Coal CFB (supercritical)	Coal - lignite	1.00	1.00	0.00%	0.0%

These *Coal type adjustment factor* section of these sheets contains pair-wise adjustment factors. The default coal types in column B refer to the fuel used to calculate base costs, and the fuel types along the rows refer to the alternative fuels that a user might select instead for that plant.

Adjustments also apply to fixed O&M costs and auxiliary power consumption (as shown in the screen-shot above).

Note, if the user chooses (through OPTIONS_Selection, INPUTS_Gen (column J) or DATABASE_Gen_ (column J)), to use a type of coal for a power plant that differs from the design assumption, and if the coal type adjustment factors have been set appropriately, then ***no further action is required by the user*** – adjustments take place automatically. Note also that the default costs of coal technologies for the three proxy countries in the model have been based on the default fuels chosen for those technologies and the adjustment factors have been set accordingly – so the user may change the coal type without needing to adjust the capital or other costs.

However, the user may choose to change the default. For example, the default coal for all coal-fired power plants in Romania is lignite but the user may wish to change the design basis for supercritical coal plants for their (middle-income) country to high quality imported coal. In this case, the user should, in addition to modifying the capital and other cost parameters in the INPUTS_Gen sheet (or permanently in the DATABASE_Gen_Romania sheet), also change the scaling factors in the INPUTS_Others or DATABASE_INPUTS_Other sheet (though this is not strictly necessary unless this is a permanent change to the defaults).

4.3 Fuel

4.3.1 Fuel characteristics

The ***model uses lower (net) heating values for fuels and corresponding net efficiency for the power plants***.

The model provides default values for the characteristics of different fuels including their heating values, sulfur, carbon and ash content and price.

Heating values of the fuels may be entered through the OPTIONS_Selection sheet or directly into the INPUTS_Other sheet (and DATABASE_Environmental sheet).

The sulfur, carbon, and particulate matter (PM) content of the fuels are entered through the INPUTS_Other sheet or DATABASE_Environmental sheet.

If changes are made to the heating value of fuel in the OPTIONS_Selection sheet, the change will also apply for that fuel when used by other generation technologies. As it is currently configured, META does not allow multiple variants of the same fuel (unless you add a new fuel or re-name an existing fuel – see Section 4.3.4 below).

4.3.2 Plant efficiencies

The power plant efficiency used in the model is the Lower Heating Value or Net efficiency and corresponds with the Lower Heating Value of the fuel. The efficiencies are also net of the auxiliary consumption of the power plant. i.e., the efficiencies are calculates as:

> [kWh sent out] / [energy input in LHV expressed in kWh units]
>
> where:
>
> "kWh sent out" is the output from the power plant as received by the transmission system (if transmission grid connected) or distribution system (if distribution grid connected) or the consumer (if off-grid), net of auxiliary power consumption by the plant itself.

See also Section 4.7 explaining the calculation of the kWh used in calculating the cost per kWh.

4.3.3 Fuel prices

Fuel price values may be entered through the OPTIONS_Selection sheet or directly into the INPUTS_Other sheet (and DATABASE_Commodities sheet).

If you enter the values through the OPTIONS_Selection sheet the values will be changed for the year 2010 and, because fuel price values are escalated in subsequent years (using escalation factors in the DATABASE_Commodities sheet), the fuel price values will also change in later years. For example, if you have selected 2015 in the OPTIONS_Selection sheet and then click on a "Define Option" button and enter a value of US$500/tonne for fuel oil, the value of US$500 will apply for 2010 while for 2015 and 2020 the value will be US$500 plus the escalation factor.

4.3.4 Adding or changing fuels

It is possible to add a new fuel or to change the name of an existing fuel. This needs to be done carefully and consistently in:

- the DATABASE_Environmental sheet (with heating values and environmental characteristics)
- the DATABASE_Commodities sheet (with fuel prices and projections)

To insert a new fuel, the user should insert a new row ***above*** the row labelled " --- spare row ---". Please do not insert a new row below this.

Note, too, that the model has restrictions on which fuel types can be associated with which generation technology types. The restriction is based on key words in the generation technology name and in the fuel type name. Currently the pairing restrictions are based on conventional fuel types such as coal, oil, gas, diesel, gasoline and generation technologies such as coal, CCGT, and oil steam. If a new fuel is introduced it may be necessary to amend the restriction. This is done in the Lists sheet (normally hidden) in the lists under the heading "Fuel type lists for Options_Selection pop-up". If you extend these lists then you should also extend the named range List_fuel_coal, List_fuel_oilgasturbines, List_fuel_oilsteam.

4.4 Emission values and emission reductions

The model includes parameters representing emissions of CO_2, SO_2, NOx and PM_{10}. These are entered as kg of CO_2 per TJ or grammes of the other emissions per GJ. These emission values are before any abatement using environmental control technologies (see below) and are per GJ at the lower heating value.

Note, emission factors may also be introduced for electricity purchased from the grid. This allows like-for-like comparison between levelized costs of grid supplied electricity options and isolated or off-grid grid technologies (the generation supplying the grid has emissions and environmental costs). This also allows like-for-like comparison between technologies – such as batteries or pumped storage – that rely on grid-supplied electricity. However, the default values are currently set to zero. Default values of greenhouse gas emissions are available from published sources and, should users wish to enter these, the values at the time of drafting this User Manual were (grammes of CO_2 equivalent per kWh generated)[6]:

Country	g CO2 equivalent per kWh	kg CO_2/TJ
Romania	414	115,000
India	951	264,167
USA	508	141,111

The emission reductions resulting from the use of FGD or SCR technologies are determined by the "***Emissions abatement rates***" in the INPUTS_Gen or DATABASE_Gen_ sheets (columns AE to AI). The emission abatement rates will differ depending on whether the FGD or SCR technology is installed or not. If not installed then the abatement rate will normally be zero while the abatement rates with the technology installed vary between 80% and 99% (see the main Guide for appropriate abatement rates).

Default values of emission abatement rates have ***not*** been included for all technologies so you may find that by choosing an emission abatement technology the emissions will not fall unless you have entered an appropriate value in the emission abatement rate column.

4.5 By-products and externalities

Power plants produce by-products which may be collected and sold, or collected and disposed of (at a cost), or they may be dispersed into the air or soil and have external costs that are not directly monetized.

Fly ash, bottom ash and gypsum[7] may, for example, be used by the construction industry but depending on the volumes and location of the power plant there may not be a demand for these products and they may have to be disposed of at a cost to the power plant owner.

The ***by-products*** may be given a value in the OPTIONS_Selection sheet or INPUTS_Other, which is either negative (where there is a disposal cost), or a positive value (if it can be sold). The default value used by the model if users do not enter their own is zero (0) for all by-products. The amount of products collected for sale or disposal is calculated automatically by the model depending on the characteristics of the fuel (see section 4.3) and the environmental control technologies selected. If the by-products have a market value then this is credited to

[6] IEA, ***CO2 emissions from fuel combustion highlights***, 2011 edition, p.109. These are 2009 values. www.iea.org/co2highlights/co2highlights.pdf

[7] Gypsum is a by-product from flue-gas desulfurisation used to reduce SO_2 emissions.

the technology and the levelized cost is lowered. If there is a cost to disposal and the by-product has a negative value, then the levelized cost is increased.

Note that when entering by-product values in the OPTIONS_Selection sheet, the values will be changed for the year 2010 and, because by-product values are escalated in subsequent years (using escalation factors in the DATABASE_Commodities sheet), the by-product values will also change in later years. For example, if you have selected 2015 in the OPTIONS_Selection sheet and then click on a "Define Option" button and enter a value of US$10/tonne for bottom ash, the value of US$10 will apply for 2010 while for 2015 and 2020 the value will be US$10 plus the escalation factor.

Externality costs refer to the damage cost to people (primarily health) and the environment (CO_2, SO_2, etc.) resulting from emissions from the power plants. The emissions are calculated by the model depending on the carbon, sulfur and other characteristics of the fuels and technology and on the environmental control technologies selected. Users who do not wish to allow for environmental damage costs may enter zeros in these fields through the OPTIONS_Selection menu or via the INPUTS_Other or DATABASE_Other sheet. The default values in the database are described in Section 1.5 and in Annex 20 of the META Guide.

Note that when entering externality values in the OPTIONS_Selection sheet, the values will be changed ONLY for the year selected. This is because externality values in one year are independent of those in every other year. Therefore, if you make the CO_2 cost equal to US$50/tonne in 2015, this will change the value only for 2015 and when you examine results in the GEN_Results sheet you will find that CO_2 values have changed for the year 2015 but not 2010 or 2020. If you wish to change the value in all three years then the simplest way is to change these three values in the INPUTS_Other sheet but in the OPTIONS_Selection sheet you could also choose a year click "Define Option", change the externality values, choose another year, click "Define Option" again, etc., for all three years.

4.6 Projecting capital costs to 2015 and 2020

The methodology for projecting costs to 2015 and 2020 is described in the META Guide and is based on the proportions of inputs (steel, copper, concrete, unskilled labor, skilled labor) in the different parts of the overall equipment or plant (building, switchgear, emission control (SNCR), generator, installation, other).

For example, we estimate that in India the boiler and turbine components make up around 18% of the overall capital cost of a coal-fired power plant. In turn, steel makes up 80% of the cost of these components. Taken together this implies that around 14.5% of the future cost of boiler and turbine components depends on changes in the steel price. Similar steel input proportions can be estimated for the remaining capital cost components of the power plant. Combining these with proportions for each component and summing for all components gives an estimate of the overall input proportion for steel in the production of the power plant. This, together with forecasts of steel prices, can then be used to forecast equipment costs over time.

An input sheet showing input proportions for a coal-fired steam plant are illustrated in Figure 5 below.

The input proportions of the inputs for each technology and for each part of the technology cost are entered into the DATABASE_Proj_Gen_ sheets for each of the three countries.

Forecasts of the input costs (steel, copper, concrete, etc) are entered into the INPUTS_Others sheet or, for a permanent change in the default values, in the DATABASE_Commodities sheet (see Figure 6).

The same approach to projecting the capital costs is used for transmission and distribution. These are entered in the DATABASE_Proj_TxDx_ sheets for the three countries.

A similar approach is also used for projections of O&M costs. These are entered in the same DATABASE sheets mentioned above.

Figure 5 Input proportions for a coal-fired power plant

Capital cost		Input proportions for key commodities				
Capital cost component	Proportion of total cost	Steel	Copper	Concrete	Unskilled labor	Skilled labor
Earthworks & Civil	3%	-	-	35%	60%	5%
Boiler and accessories	32%	60%	5%	-	10%	25%
Steam-turbine and accessories	19%	40%	15%	-	15%	30%
Combustion turbine and accessories	-	40%	15%	-	15%	30%
Electrical equipment	4%	60%	15%	-	5%	20%
Instruments and controls	2%	30%	20%	-	10%	40%
Other mechanical equipment	9%	30%	20%	-	10%	40%
Fuel supply equipment	4%	60%	-	10%	-	30%
Bottom ash hopper	1%	60%	-	20%	10%	10%
Stack and Piping	4%	50%	25%	-	-	25%
Flue gas clean-up (FGD)	17%	60%	5%	-	10%	25%
CCS equipment	-					
Building and architecture	4%	40%	-	20%	10%	30%
Gasifier and accessories	-					
Construction Labor	1%	-	-	-	40%	60%
	-	-	-	-	-	-
Spare row	-	-	-	-	-	-
Checksum	100%					
Weighted proportion of each key commodity in total capital cost		50%	9%	2%	12%	27%

		2010	2015	2020
Estimated base-year capital cost	US$M	351	-	-
Expected total input cost change	% change from base year	-	1%	5%
Projected capital cost -	**US$M**	-	**354**	**372**

Non-fuel O&M cost		Input proportions for key commodities				
O&M cost component	Proportion of total cost	Steel	Copper	Concrete	Unskilled labor	Skilled labor
Labor	75%	-	-	-	30%	70%
Materials	25%	85%	15%	-	-	-
Spare row						
Spare row						
Spare row						
Checksum	100%					
Weighted proportion of each key commodity in total O&M cost		21%	4%	0%	23%	53%

		2010	2015	2020
Estimated base-year O&M cost	US$M	13	-	-
Expected total O&M input cost change	% change from base year	-	12%	14%
Projected O&M cost - Capital cost	**US$M**	-	**15**	**17**

Figure 6 Screenshot – projections of commodity and fuel price forecasts[8]

		USA 2010	USA 2015	USA 2020	India 2010	India 2015	India 2020
Commodity and labor prices							
Forecast real price changes (over previous 5 years)							
Iron ore	%		-29.2%	-6.1%		-29.2%	-6.1%
Copper	%		-12.7%	-13.6%		-12.7%	-13.6%
Coal	%		-14.5%	6.3%		-14.5%	6.3%
Aluminum	%		12.4%	7.5%		12.4%	7.5%
Timber	%		1.6%	10.8%		1.6%	10.8%
Unskilled labor	%		10.0%	10.0%		20.0%	20.0%
Skilled labor	%		10.0%	10.0%		20.0%	20.0%
-- spare row --	%		-	-		-	-
-- spare row --	%		-	-		-	-
Fuel prices							
Forecast real price changes (over previous 5 years)							
Crude oil	%		12.6%	-9.5%		12.6%	-9.5%
Natural Gas	%		17.9%	32.6%		8.3%	-9.6%
Coal (Australian)	%		-14.5%	6.3%		-18.9%	6.3%
Uranium	%		5.0%	5.0%		5.0%	5.0%
Biomass	%		-	-		-	-
Off-peak electricity from the grid	%		10.0%	10.0%		10.0%	10.0%
-- spare row --	%						

4.7 Explanation of kWh calculation in the cost per kWh

4.7.1 Divisor to calculate cost per kWh of generation

The kWh of generation used as the divisor in the cost calculation is calculated by the model **net** of auxiliary power consumption (i.e., it is the cost per kWh of electricity sent out to the network).

The annual kWh value used to calculate the cost per kWh of generation depends on the capacity factor chosen by the user for the power plant, the kW capacity of the plant and auxiliary power consumption.

4.7.2 Auxiliary power consumption

If the User increases the auxiliary power consumption, this will lower the **net** electricity generation (for a given gross generation capacity), and vice versa. Note that lowering or increasing auxiliary power consumption has no affect on the cost of fuel per kWh in the META model because the power plant fuel efficiency used in the model is per net kWh (see Section 4.3.2). Lowering or raising the auxiliary consumption does affect overall costs per kWh by changing the divisor used when estimating the capital cost per kWh.

If you wish to change auxiliary power consumption for a particular technology you should consider simultaneously changing the net plant efficiency since the two are partly related. Increasing auxiliary power consumption will normally result in lower net plant efficiency, and vice versa.

[8] Romania is also included but is not shown here.

4.7.3 kWh used when there is transmission and distribution

The annual kWh value used to calculate the cost per kWh of transmission/ distribution when no generation is selected depends on the capacity of the transmission/distribution line and the load factor (see Section 4.9).

When combining generation and transmission/distribution, the net generation kWh is used as the divisor less the losses on the transmission/distribution line.

Further discussion on combining generation with transmission and distribution, please see Section 4.8.

4.7.4 Losses and costs per kWh

Generation, transmission and distribution costs are summed in the OPTIONS_Selection sheet to give the total cost per kWh. This is a simple summation of the costs. Depending on the purpose of the calculation, for a more strictly accurate calculation of the cost of electricity delivered at different points of the supply chain, the user should take account of the cost of losses. For example, a generation cost of US$0.10/kWh when delivered along a transmission and distribution network with losses of 10% would result in a generation cost delivered to the end user of US$0.11/kWh.

4.8 Combinations of Gen and TxDx

The user may choose any combination of generation, transmission and distribution but should be aware that some combinations are not technically possible or not sensible.

A large power network will normally include several transmission and distribution voltages along the supply chain between generation and the end user, while for small grids there may be only one distribution voltage. The model only allows the user to include one transmission voltage and one step-down transformer. The step-down transformer options in the default include 400kV/220 kV and 220kV/132kV. If the user selects a generation technology, a 400kV transmission line and a 400kV/220kV substation, then it would be sensible only to estimate costs of supplying electricity to the 220kV network and not additionally select the distribution option (because there would then be a need to add additional costs of the 220kV network and step-down transformation from 220kV to a distribution voltage, but the model does not permit this and results that include distribution would not be sensible).

Similarly, if the user is considering options for supplying a small grid then it would not be sensible to select 400kV or 220kV transmission for such a grid. However, if the user wishes to consider the option of large-scale wind farms (multiple 5 MW units) supplying a national grid but where the transmission grid will need reinforcing to allow the evacuation of power from remote areas of the grid, then it would be acceptable to consider a relatively small-scale wind plant with a high voltage transmission (but see below).

The user is allowed to choose any combination of generation, transmission and distribution but needs to be careful to choose combinations that are reasonable for the situations being examined.

The annual kWh value used to calculate the cost per kWh of transmission or distribution depends on whether generation is chosen or not:

- If a generation technology is chosen as well as transmission/distribution, then the kWh used to calculate the cost per kWh of transmission/distribution is the kWh generated by the power plant minus the transmission/distribution losses. Thus, if a power plant is 100 MW with a capacity factor of 80% and transmission losses are 2%, then the transmission costs will be divided by 686,784 MWh. This approach is particularly suited to:
    - a large power plant that requires a dedicated transmission line to connect it to the main grid, or
    - a small power plant or plants that serve a small isolated grid.
- If the transmission or distribution technologies are chosen but not generation, then the kWh used to calculate the cost per kWh of transmission/distribution depends on the capacity of the transmission or distribution line – an input parameter in the INPUTS_TxDx sheet or in the DATABASE_TxDx_ sheets – and the load factor selected in the same sheets (or in the OPTIONS_Selection sheet using the Define Option button).

If you are choosing generation and transmission/distribution together then care must be taken to ensure that the transmission line capacity matches the generation capacity; if you choose a large capacity transmission line and substation to transmit electricity from a small power plant, then the overall costs will unreasonably be dominated by transmission and the cost per kWh will be excessive.

You may wish to analyse the cost of connecting a small power plant to a large grid and wish to account for the costs of transmission (or distribution). For example, suppose you wish to analyse the costs of connecting a 100 MW wind farm comprising of a number of 5 MW wind turbines, but you know that the main 220 kV grid will need to be reinforced and you would like to measure the combined costs of generation and the marginal costs of transmission. If, in this case, you combine a 100 MW wind farm and a 220 kV transmission line as an option in META, the transmission costs will be too high. The best approach in this, or similar situations, is to do the calculation of the transmission costs separately from the calculation of generation costs and add these two costs per kWh together off-model[9].

[9] You could also potentially enter an artificially large capacity for the wind turbine – for example, instead of entering a 100 MW wind turbine you could enter it as a 250 MW wind turbine. The model does take account of economies of scale so that the costs per kW for a 250 MW wind farm are US$1,129 compared with US$1,132 per kW for a 100 MW wind farm, which distorts the resulting costs per kWh slightly, but this lowers generation costs by only 0.3%.

4.9 TxDx capacity

The INPUTS_TxDx and DATABASE_TxDx sheets include a parameter ("peak load carried" and "peak load on the distribution network") showing the capacity of the transmission or distribution lines. These values, together with the load factors, are used to estimate the cost per kWh of the transmission or distribution lines when generation is not selected.

The carrying capacity of the lines is not a parameter in the OPTIONS_Selection sheet and the user should therefore visit the INPUTS sheets in order to adjust the default assumptions.

4.10 Constraints

4.10.1 Comparing costs between countries

To compare costs between countries/regions, the user should run the model for one region, store the results, and then select another country/region and again store those results.

4.10.2 Creating a new proxy country

Some users will wish to tailor META for a specific country that is not USA, Romania or India. This is possible by simply changing the default values for one of these three countries. However, at the present time the model does not allow the user to easily change the names of the default proxy countries. Users can, however, simply use the existing country/region names but use data for different countries in their place.

Some users might also wish to add a fourth or more country database to the model (in addition to the existing three) and have the option of choosing from other proxy countries in addition to the three (USA, Romania and India). At the present time, as the model is currently designed, this is not possible but please refer to Section 6 for suggestions on how this might be progressed.

4.10.3 Comparing the same technology but with different parameters

META currently does not allow the user to compare a technology with the same technology but with different parameters. For example, if a 150 MW CCGT plant burning natural gas is selected as one of the five options, it cannot be compared with the same 150 MW CCGT plant burning diesel fuel or crude oil. To compare the same plant with different characteristics, the results would need to be stored and the model re-run. Alternatively, in some cases it is possible to adapt another technology to create a plant that is identical to the 150 MW CCGT. For example, the 250 MW CCGT option (F-type) could be changed to 150 MW and renamed. (Note this is not simple with coal technologies – see section 4.2.11).

4.10.4 Second and subsequent units

The model does not give the user the option of multiple units (e.g., two 300 MW units) where the first unit has higher costs than the second. This might be considered if, for example, the design for the first unit includes civil works to allow a second or subsequent unit. If consideration is being given to a new plant with multiple units then the user may legitimately average the costs of all units at the plant.

5 Uncertainty analysis

5.1 Introduction

This section describes the use uncertainty analysis in combination with META. To illustrate how uncertainty analysis can be used the following describes the commercial software package @Risk to simulate risk in some of the key inputs to the model and show its effect on the levelised cost of electricity.

Section 5.2 describes the uncertainty methodology in broad terms and Section 5.3 describes an example. Sections 5.4 and 5.5 guide users who wish to install and apply uncertainty analysis within META. Section 5.7 notes other add-ins that provide similar types of uncertainty analysis.

5.2 Uncertainty analysis

The aim of the uncertainty analysis is to show quantitatively the effect on the energy generation cost of having uncertain inputs (e.g., capital costs, fuel costs, etc.). To do this, @Risk or similar software runs a simulation with thousands of iterations in which the input values are varied according to a user-specified distribution and then records the results i.e., the values of the generation cost of energy. Once a simulation has run, the results are stored and can be analysed using typical statistical measures, e.g., mean, standard deviation etc. This approach to modelling uncertainty is known as a Monte Carlo simulation.

In order to achieve this, commercially available Excel Add-Ins must be used – here we describe @Risk but other software is noted in Section 5.7. These add-ins provide a means to sample inputs from a distribution, and record and analyse the results. The calculation of the levelised cost of electricity given any particular set of inputs is handled by the rest of META (the 'deterministic' part of the model).

The flow of operations of @Risk is as follows:

- The user specifies the distributions of the set of inputs. e.g., unit capital costs of a gas CCGT, following a normal distribution with a mean of US$650/kW and a standard deviation of US$65/kW.
- The user starts the simulation with a specified number of iterations (e.g., 5,000).
- For each iteration @Risk places a value, sampled from the relevant distribution, in each input cell.
- The rest of the model is used to calculate the generation cost of energy using the values generated by @Risk.
- @Risk records the values of the output for each iteration.

- Once the total number of iterations has been reached, the simulation stops and @Risk creates the output tables and charts.

5.3 Example outputs

For each simulation in this illustration of the uncertainty analysis records two distinct sets of results:

- Energy cost analysis – the properties of the distribution of the energy cost.
- Input impact analysis - the size of the impact of each input on the cost of energy.

The results are shown in the Figure and Table below.

Figure 7 shows in chart format the results of the simulation. The Figure is made up of three panels. The first panel provides the basic information relating to the technology (type, capacity, fuel type, etc.), the second panel gives the energy cost results, and the third panel presents the regression analysis results.

Table 1 shows the same information as the figure but in tabular format (and for the simulations with the discount rate set to its high and low case).

The results of the energy cost analysis are shown in the second panel in Figure 7. Four different sets of outputs are recorded:

- the mean – the average value of the cost of energy;
- standard deviation – a measure of the spread of the cost of energy about the mean;
- the 5th and 95th percentiles of the distribution – 5% of the results are below the 5th percentile, and 5% of the results are above the 95th percentile. Alternatively, the energy cost is between the 5th and 95th percentile 90% of the time; and
- A histogram of the cost of energy. This shows the relative frequency of the outputs over the range of possible outputs. The red bars indicate the 5th (left hand bar) and 95th (right hand bar) percentiles.

The impact of each input on the final value of the energy cost is measured using a regression analysis. The output of this analysis is a set of regression coefficients shown in the tornado chart in the third panel. If the value is positive then an increase in that input will increase the cost of energy. If the value is negative then an increase in that input will decrease the cost of energy. If the value is 0 then any movement in that input will have a negligible impact on the energy cost.

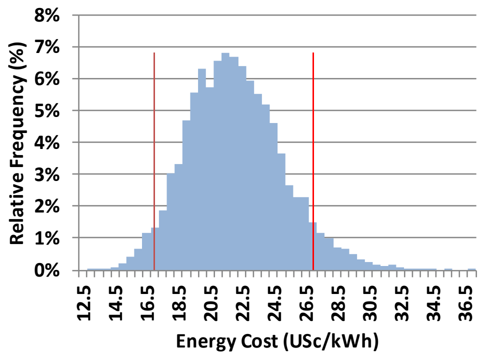
The regression coefficients are standardized (multiplied by the factor 'standard deviation inputs'/'standard deviation outputs') meaning that a coefficient of 1 implies that a change in the inputs by one standard deviation results in a one standard deviation change in the outputs. This is just a way of allowing the regression coefficients to be compared meaningfully between technologies.

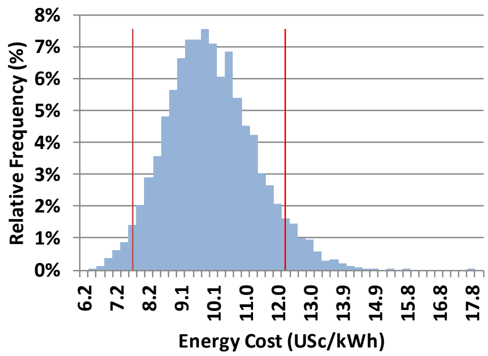
Figure 7 Uncertainty analysis – PV and onshore wind

Simulation 2: Discount rate = 5.0%		**Simulation 2: Discount rate = 5.0%**	
Technology	Solar PV (large)	**Technology**	Wind onshore (large)
Capacity	5 MW	**Capacity**	100 MW
Fuel	Solar	**Fuel**	Wind
Country group	Middle income country	**Country group**	Middle income country
Year	2010	**Year**	2010

Energy Cost Analysis

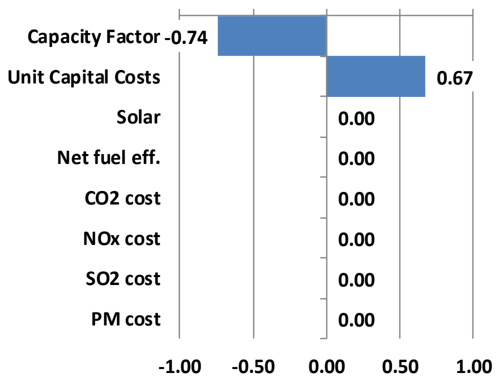
	Solar PV (large)	Wind onshore (large)
Mean USc/kWh	21.85	9.90
Standard deviation USc/kWh	3.02	1.33
5th percentile USc/kWh	17.29	7.87
95th percentile USc/kWh	27.17	12.28





Input impact analysis

Correlation of inputs with outputs



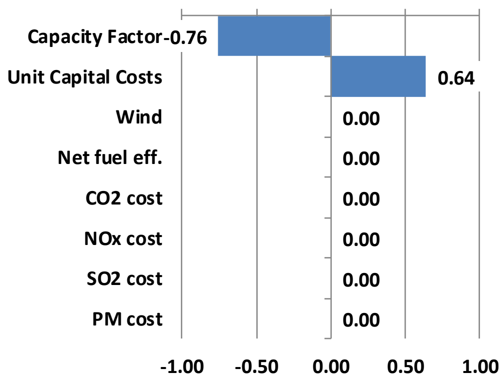


Table 1 Example uncertainty analysis outputs

Technology	Solar PV (large)
Capacity	5 MW
Fuel	Solar
Country group	Middle income country
Year	2010

Discount Rate	3%	5%	7%
Energy cost			
Mean *USc/kWh*	17.46	21.85	26.71
Standard deviation *USc/kWh*	2.40	3.02	3.72
5th percentile *USc/kWh*	13.84	17.29	21.10
95th percentile *USc/kWh*	21.67	27.17	33.23
Regression coefficients			
Goodness of fit	**0.98**	**0.98**	**0.98**
Unit Capital Costs	0.66	0.67	0.68
Capacity Factor	-0.74	-0.74	-0.73
Net fuel eff.	0.00	0.00	0.00
Solar	0.00	0.00	0.00
SO2 cost	0.00	0.00	0.00
NOx cost	0.00	0.00	0.00
PM cost	0.00	0.00	0.00
CO2 cost	0.00	0.00	0.00

Technology	Wind onshore (large)
Capacity	100 MW
Fuel	Wind
Country group	Middle income country
Year	2010

Discount Rate	3%	5%	7%
Energy cost			
Mean *USc/kWh*	8.52	9.90	11.41
Standard deviation *USc/kWh*	1.13	1.33	1.55
5th percentile *USc/kWh*	6.79	7.87	9.04
95th percentile *USc/kWh*	10.55	12.28	14.17
Regression coefficients			
Goodness of fit	**0.98**	**0.98**	**0.98**
Unit Capital Costs	0.63	0.64	0.65
Capacity Factor	-0.77	-0.76	-0.75
Net fuel eff.	0.00	0.00	0.00
Wind	0.00	0.00	0.00
SO2 cost	0.00	0.00	0.00
NOx cost	0.00	0.00	0.00
PM cost	0.00	0.00	0.00
CO2 cost	0.00	0.00	0.00

5.4 Installing and setting up @Risk

5.4.1 Installing @Risk

Download and install @Risk Industrial version from www.palisade.com. Note, this is commercial software and the cost is relatively high. It is possible to obtain a fully functioning trial version for one month free of charge.

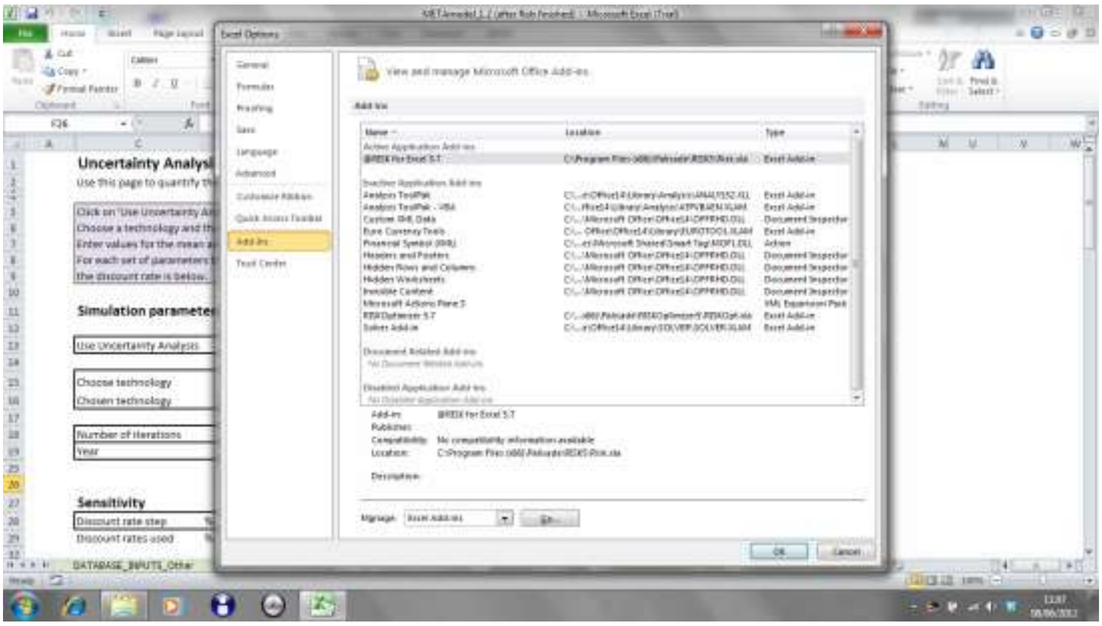
5.4.2 Setting up @Risk in Excel

After downloading and installing @Risk, when you now run Excel, @Risk should show on the main menu. However, it may instead show @Risk Optimizer or it may not show @Risk at all. A number of additional steps may be required to make sure @Risk is running properly.

1. **Load @Risk into Excel**: To do this, within excel do the following:

If the @Risk Optimizer is shown on the main Excel menu instead of simply “@Risk” then:

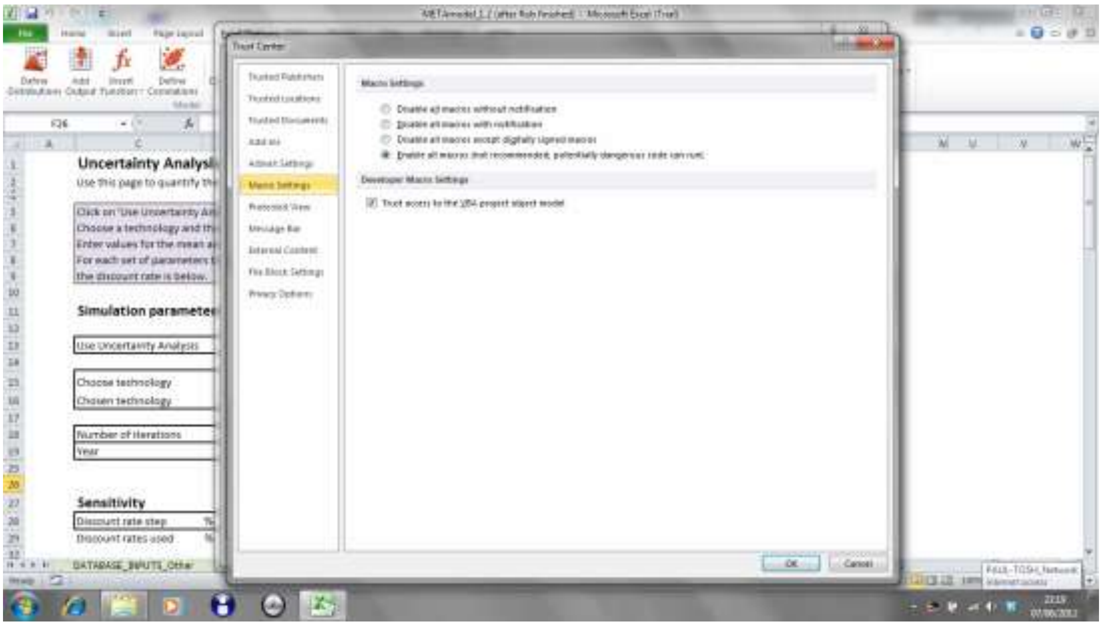
- Click File in the main Excel bar
- Click “Options”
- At the bottom of the sheet there is a button labelled “Manage” next to a drop-down box. Choose “Excel add-ins” from the drop-down menu. Then click Go. (See below).



- o Make sure that @Risk is ticked.
- o If @Risk Optimizer is ticked, please un-tick this.

2. Ensure the **security settings** allow access to @Risk VBA objects:

- o Click File in the main Excel bar
- o Click "Options"
- o Click Trust Center and then Trust Center Settlings
- o Tick the box which says Trust access to VBA project object model (see below).

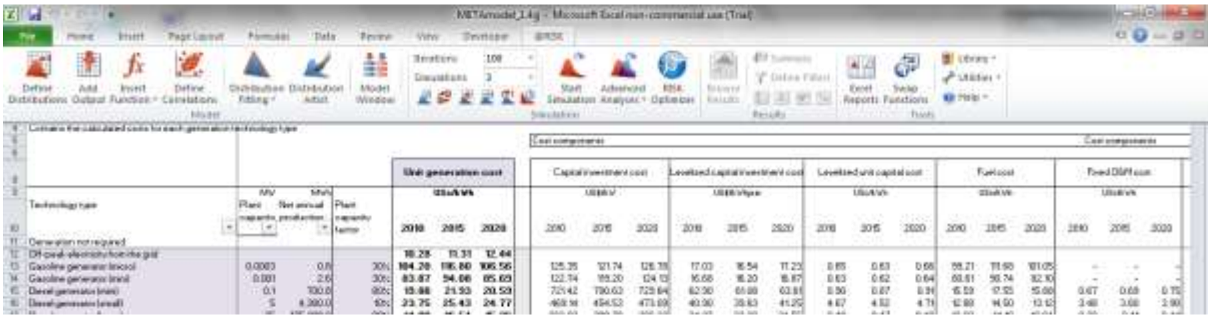


3. **@Risk should now be set up** properly.

5.5 Running uncertainty analysis

As @Risk makes changes to the formulae in your workbook, we recommend that you save your workbook before beginning to use uncertainty analysis.

To run uncertainty analysis, click @Risk on the main menu and you will see a ribbon similar to the one below:

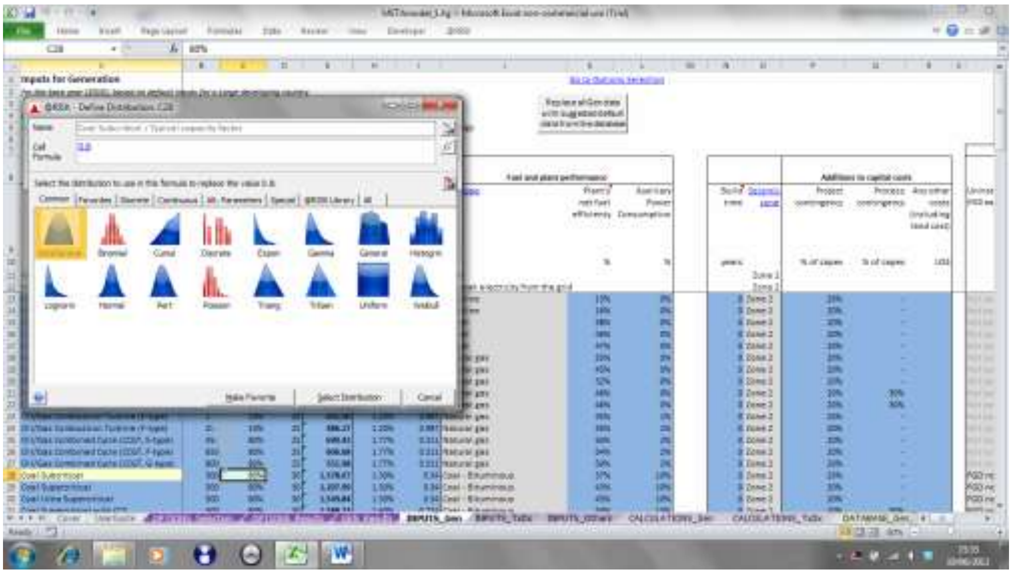


5.5.1 Define outputs

The outputs are the levelised costs in the GEN_Results sheet. To define the outputs select one or more of these in one or more of columns E to G and then click ***Add Output*** on the @Risk ribbon. The outputs are now defined.

5.5.2 Define inputs

The inputs can be any of the parameters that determine the levelised cost per kWh, such as the capital cost per kW, the capacity factor, the fuel cost, the plant efficiency, etc., etc. Most of these are contained in the INPUTS_Gen sheet but, depending on what you wish to vary, they may be in the INPUTS_Others or other sheets. Suppose, for example, you wish to consider the uncertainty surrounding the capacity factor in Column C. If you select the capacity factor for Coal Subcritical (default 80%) and then click on ***Define Distribution***, you will be shown a screen similar to the following offering you alternative probability distributions for that input parameter.



Typically you will choose the ***Normal*** distribution which has a symmetrical shape around the mean but many other options are possible. Click the distribution you wish to use and then click ***Select Distribution***. If you now click OK, the @Risk Add-In will replace the original capacity factor value with a formula:

=RiskNormal(0.8, 0.08,RiskStatic(0.8))

This indicates that the distribution will be Normal with a mean of 0.8, a standard deviation of 0.08, and a value in deterministic mode of 0.8. You could have defined or varied these parameters (mean, standard deviation and static value) using the @Risk screen but alternatively you can also make the formulae flexible by copying the original capacity factor to a cell on the right side of the sheet and putting a standard deviation next to it, and then making the formula refer to those cells. For example:

=RiskNormal(BL28, BM28,RiskStatic(BL28))

You can then copy the formula to other capacity factor input numbers allowing multiple uncertainty analyses.

If you wish to apply define a variable which is itself a formula, such as capital cost, as the uncertain input, then you will need to change that formula into a fixed number (copy and paste-as-value, or simply re-enter the value as a number in the cell). You can then inform @Risk that this is an uncertain input using the Define Distribution button as described above.

You may define as many uncertain input variables as you wish.

5.5.3 Run the simulation

To run the simulation you need to adjust the number of iterations shown on the @Risk ribbon. The greater the number of iterations, the more accurate will be the results, however the simulation will take longer to run (this could be 30+ minutes).

To test the results, choose a small number to start. When undertaking the analysis in earnest, the number of iterations should be at least 5,000 but no more than 10,000.

@Risk also allows you to run the simulations several times. The default value appears to be 3, so that if you entered 1,000 iteration and left the number of simulations at 3 then you would get three sets of results each with 1,000 iterations. This may be useful in some circumstances but for normal usage we suggest only one simulation.

Having chosen the number of iterations and the number of simulations, click ***Start Simulation*** and a box will appear showing the status of the simulation(s).

Once the simulation has started it may be paused or stopped altogether by pressing the pause or stop button in the @Risk pop-up window. If the simulation is stopped before it has had time to finish, no new data will be recorded.

5.5.4 Reviewing results

After @Risk completes the simulation, you will be able to review the results by clicking on ***Summary*** in the @Risk ribbon.

This shows the input distribution and the output distribution – the latter contains the relevant information. Click on the ***Outputs tab*** to see the distribution of the output. This provides a graph and statistics containing the distribution of the levelised costs, the minimum, mean, maximum and the 5% to 95% range. The latter indicates that, for a normal distribution, there is a 90% probability that the levelised cost lies between these two values.

By clicking on one of the buttons on the bottom left of the summary results, you will be able to export the results to an Excel spreadsheet and to undertake secondary analysis on those results.

5.5.5 Finishing

We suggest that you generally discard the workbook after undertaking uncertainty analysis.

If you decide to save the workbook after undertaking uncertainty analysis, you will be offered the option of saving the simulation results and graphs. This can be done and will make the workbook a little larger. But it can also be saved without the simulation results and graphs - the results can be re-created when needed.

Note, if you decide to save the workbook after undertaking uncertainty analysis, the @Risk formulae will be embedded in the workbook. You may remove those formulae by clicking on ***Swap Functions*** in the @Risk ribbon and clicking OK in response to the question "*OK to swap out @Risk functions, replacing them with their Static or Expected Values?*". If you do click OK and then re-save this version, Excel will keep a record of the formulae and will offer you the option "*OK to insert @Risk functions back into their original formula locations*" when you re-open that workbook. If you click ***Cancel***, it will not restore the @Risk formulae (though it will remember the formulae).

5.6 Un-installing @Risk

If you purchased @Risk and subsequently decided not to renew the annual contract, or if you installed the trial version of @Risk and decided not to purchase @Risk, you will need to uninstall @Risk before using META on your computer. The software should be uninstalled in the usual way, through the Control Panel, choosing the Install/Un-install tab, and clicking on @Risk to uninstall the software.

5.7 Other add-ins that performs similar functions

Several commercial providers offer uncertainty analysis Excel add-ins. Crystal Ball and @Risk are the more popular and are high quality but are also relatively expensive. A non-exhaustive list of similar add-ins is provided below:

Add-in	Provider	Website	Price (approx.)[10]
Crystal Ball	Oracle	www.oracle.com/	US$ 1,000
@Risk	Palisade	www.palisade.com	US$ 1,600
Risk Solver	Frontline Systems Inc.	www.solver.com	US$ 1,000
DFSS Master	SigmaZone	www.sigmazone.com/dfssmaster.htm	US$ 400
RiskAMP	Structured Data LLC, USA	http://www.thumbstacks.com/	US$ 130 or US$ 250
Risk Analyzer	Add-ins.com	http://www.add-ins.com/analyzer/	US$ 50

[10] Prices in some cases are in GB pounds and converted to US$ as of June 2012. The prices are for a single user. Prices may be different in different countries and may change from time to time.

6 Updates

The META model may be updated from time to time, and new versions of the model and the User Manual will be provided on ESMAP's website. The model and the User Manual have version numbering to show users whether they are using the most up-to-date version.

To the extent possible the structure of META will be retained in updated versions so that users who create customised data for the model may easily enter their customized data into a new version of the model when it is issued.

Users are encouraged to send country-specific versions of the model to ESMAP who will consider incorporating these into a comprehensive model or models incorporating a wider range of country templates.

Annexes

A1 Background to META

The Energy Sector Management Assistance Program (ESMAP), a trust fund administered by the World Bank, seeks to increase the know-how and enhance the institutional capacity of developing and middle-income countries so that they achieve environmentally sustainable energy solutions for poverty reduction and economic growth. In this context, ESMAP has been providing continuing support, among other things, to the development of knowledge and guidance materials to assist electricity system planners in these countries make informed technology choices based on accurate and consistent cost and performance data.

Previous activities under this work stream sought to characterize and assess the current and future commercial prospects of renewable and fossil fuel-fired electricity generation technologies. These technologies were configured to suit off-grid, mini-grid and grid applications. The underlying objective was to provide planners and policy makers in developing and middle income countries with an assessment of the current and future economic readiness of electric power generation alternatives, and thus contribute to reducing the shortage of electricity supply in developing countries.

This earlier work culminated in the publication of two flagship reports:

- "Technical and Economic Assessment of Off-Grid, Mini-Grid and Grid Electrification Technologies" (December 2007); and
- "Study of Equipment Prices in the Power Sector" (December 2009).

These reports proved to be very useful and substantially contributed to an improved understanding of the competing generation options and their associated performance and costs. The META Guide and the associated META model seek to build on this earlier work by:

- **Updating both performance parameters and costs** to take into account changed global market conditions and technological developments;
- **Expanding the list of technologies** to include Carbon Capture and Sequestration (CCS), large-scale power storage (batteries) and nuclear power, and incorporating a larger set of capacity/size and availability options for the technologies already included in the previous studies;
- **Adding transmission and distribution costs** so that approximate network investment requirements associated with the various generation options are also incorporated; and
- Taking into account the **externalities** of power generation.

To maximize the value of this new work, it was thought that, in addition to producing an updated report (now called the META-Guide) incorporating the above supplementary elements, it would be useful to develop **a user-modifiable assessment spreadsheet model**. Such a tool would be dynamic and user-friendly, allowing users to input project-specific requirements and update both performance parameters and costs by taking account of global market trends and technological developments. Furthermore, the model would be made available to users via the internet.

The Interactive Technology Assessment Tool (the "META model"), which the present User Manual accompanies is the tool that has been developed for this purpose. The development of this tool is consistent with ESMAP's "think tank" and "knowledge warehouse" core functions as espoused in the 2008-2013 Strategic Business Plan.[11]

[11] ESMAP's think tank function entails the sponsoring of high quality analytical and advisory activities to influence policy making by its client countries and broaden knowledge about cutting-edge energy solutions to global thematic challenges. ESMAP's knowledge clearinghouse sponsors knowledge exchange activities and training events to share best practices, tools, and lessons of experience, thus, enhancing client capacity to plan, manage, and regulate energy sector strategies and programs.

A2 List of data sources

Annex A2 provides information on data sources used as defaults in META. Data used for default values for commodities, labor and externality costs are described in Annex A2.1 and A2.1. The sources themselves are listed in Annex A2.3.

Sources of information on the technologies is provided at the end of each technology section of the META Guide.

A2.1 Common input prices

A2.1.1 Commodity, labor and fuel price inputs

Commodity, labor and fuel prices are all user-definable inputs to META. The model requires inputs for:

- Forecast commodity, labor and fuel price changes (a percentage value) in two future years (2015 and 2020 for the analysis used in the Guide) and,
- Current fuel prices for the base year (2010 in this Guide).

The model uses the base year prices in the calculations of results for the base year. Forecast price changes are used to estimate future year prices for the calculation of results in those years. See Annex 1 of the META Guide for further information on the methodology used for projecting capital cost changes based on forecasts of commodity and labor price changes.

The model has been populated with suggested default values for each country. The user is free to enter their own values to reflect local information and updates to the data over time.

The commodity and labor cost drivers incorporated into META are given in Table A2.2. The fuel prices and data sources are given in Table A2.3.

Table A2.2 Commodity and labor and data sources

Commodity and labor cost drivers	Data sources for forecast price changes
Steel (proxied by the iron ore)	World Bank
Copper	World Bank
Concrete (proxied by energy)	World Bank
Aluminum	World Bank
Timber	World Bank

Commodity and labor cost drivers	Data sources for forecast price changes
Skilled labor	Consultants' estimates
Unskilled construction labor	Consultants' estimates

Table A2.3 Fuel inputs and data sources

	Data sources for current prices	Data sources for forecast price changes
Coal (lignite, sub-bituminous, bituminous)	World Bank, BP Statistical Energy Review, Coal India	World Bank
Natural gas (or LNG)	World Bank	World Bank
Crude oil	EIA, IMF	World Bank
Fuel oil	Calculated (see below)	Crude oil (see below)
Diesel	Calculated (see below)	Crude oil (see below)
Gasoline	World Bank, EIA	World Bank
Uranium	EIA, EURATOM	IAEA
Biomass and biogas	Indicative prices from recent actual projects	Consultants' estimates
Average price for electricity from the existing power grid	EIA, Eurostat, Central Electricity Authority India	Consultants' estimates

A2.1.2 Sources for commodity and labor prices

Forecast prices for aluminum, copper, timber and iron ore were based on the World Bank's commodity price indices and forecasts. These are publically accessible from the World Bank's website[12].

Forecasts for labor costs were based on data from the International Labor Organization's (ILO) labor statistics database, the US Bureau of Labor Statistics (US BLS), and the Government of India, Ministry of Labour and Employment, Labour Bureau[13].

Steel is produced locally in all three countries from iron ore. Since consistent price forecasts for finished steel were not available the future price changes for steel were proxied using iron ore prices as the cost driver. The model is designed so that if the

[12] http://go.worldbank.org/4ROCCIEQ50

[13] See http://www.bls.gov, http://laborsta.ilo.org/default.html, http://labourbureau.nic.in/

user has steel price forecasts they can enter these in place of the iron ore price forecasts.

Forecasts of concrete prices were also not available. Energy makes up a large component of the cost of mining and crushing concrete aggregates and producing cement. In the absence of forecasts of concrete prices forecast changes in an energy price were used as a proxy for future changes in concrete prices. Coal was selected as the energy proxy as this was thought to best reflect the baseload nature of energy consumption in cement manufacturing.

A2.1.3 Sources for fossil fuel and uranium prices and forecasts

Fuel prices

Fuel prices in the base year were sourced from the World Bank commodity prices, the World Bank Databank, the Energy Information Administration (EIA), the International Monetary Fund's (IMF) commodity prices, EURATOM, Eurostat, BP Statistical Energy Review 2011, Coal India and agencies in the Government of India.

Fuel oil (HFO) and diesel prices were calculated from the forecast crude oil price based on the historic trend relationship. Specifically, the HFO price was set at 65% of crude price and diesel price was set at 120% of the crude price on a calorific value basis.

Fuel price forecasts were based on the following data sources and assumptions:

- Crude oil, natural gas, LNG and coal forecasts were from the World Bank commodity price forecasts to 2020. The quoted European price was used for Romania while the price for India was assumed to be the LNG price to Japan (Asia).

- Forecast prices for HFO and diesel were based on the crude oil price forecast.

- Forecast uranium prices were based on the International Atomic Energy Agency's (IAEA) study of uranium supply conditions to 2050.

Biomass & MSW and by-product assumptions

In general, biomass fuel is made up of waste by-products from other processes, e.g., wood chip discharged from sawmills and bagasse discharged from sugar mills. Since these fuels would otherwise be dumped, their cost in generation is considered to consist only of cost of transport from the location of the primary production process to the generation plant. However, in this study this cost was ignored on the basis that power stations were assumed to be constructed near to where the biomass fuel would otherwise be dumped.

Municipal Solid Waste (MSW) is also a waste product which tends to be associated with a waste collection, transportation and disposal system. In this case electricity generation is incidental to the cost of the waste system since if the waste was not used for generation it would still need to be transported to a waste treatment centre for disposal.

We assume that a MSW-fired plant would either be associated with a legitimate collection system, or else would be part of the collection contract itself[14].

The price of rice husks (biomass) or MSW in the Model was set to a default value of US$50/tonne (with an assumed energy content of 13.5MMBTU/tonne). The user is free to input appropriate local prices into the model[15].

The user should also be aware that some cost associated with processing may need to be added to the raw fuel price. As is often the case, collected biomass or MSW needs to be properly treated before being used as fuel: high moisture should be dehydrated to some degree, or impurities such as metals and plastics should be removed from raw garbage for anaerobic degradation.

A2.2 Externality costs

Carbon prices were based on the scenarios in International Energy Agency's (IEA) World Energy Outlook 2010.

Estimates of damage costs for NOx, SOx and PM were taken from various surveys of damage cost studies described in the META Guide.

A2.3 Sources

A2.3.1 Commodity and fuel prices

- World Bank commodity price forecasts including fuels: http://go.worldbank.org/4ROCCIEQ50
- World Bank databank: http://data.worldbank.org/
- US Energy Information Administration: www.eia.gov
- BP Statistical Energy Review: http://www.bp.com/
- International Energy Authority: http://www.iea.org/textbase/nppdf/free/2010/key_stats_2010.pdf
- Coal India: http://www.coalindia.in/
- European coal: http://www.euracoal.org/
- Nuclear fuel: http://world-nuclear.org/info/; http://www.uraniumminer.net/market_price.htm

[14] If a user wanted to model black market supply prices then the economic premise would be that the fuel price would be set so that the MSW plant was just viable compared with alternative generation. The user can enter such a price into the model if they so wish.

[15] In case MSW is processed into refuse-derived fuel (RDF) specifically for use in electricity generation there will be an additional processing cost. This additional cost would be considered a cost of the MSW fuel.

A2.3.2 Labor

- US Data from: http://www.bls.gov/oes/
- India data from: http://laborsta.ilo.org/; http://mospi.nic.in/Mospi_New/site/India_Statistics.aspx?status=1&menu_id=14
- Romania data from: http://laborsta.ilo.org/STP/guest

A2.3.3 Externality costs

- International Energy Agency's (IEA) World Energy Outlook 2010
- ESMAP, Technology Assessment of Clean Coal Technologies for China Volume 3— Environmental Compliance in the Energy Sector: Methodological Approach and Least-Cost Strategies Shanghai Municipality and Henan and Hunan Provinces, China December 2001
- AEA, Power Generation and Environment, UK Perspective, Report AEAT 3776, 1998
- J. Spadaro and A. Rabl, Air Pollution Damage Estimates: the cost per kg of pollutant, Ecole des Mines de Paris, Centre d'Energetique
- M. Holland and P. Watkiss, Estimates of the marginal external costs of air pollution in Europe: Benefits Table Database:BeTa, EU DG Environment, 2001
- CEETA, Implementation in Portugal of the ExternE accounting Framework, 1998. Table 3.20.
- K. Lvovsky, G. Hughes, D. Maddison, B. Ostrp and D. Pearce, Environmental Costs of Fossil Fuels, A Rapid Assessment Method with Application to Six Cities, World Bank, Environment Department, Paper 78, October 2000

A3 Explanation of capital cost formulae

A distinction is made between outturn costs and costs that are estimated in design studies. The latter typically include an estimate of base costs plus contingencies to reflect potential unknown costs that cannot be anticipated at the design stage.

In META the base costs are shown separately from the contingencies.

The default base capital costs in the META Guide have generally been calculated from outturn costs. To ensure that the costs in the Guide are consistent and that the base capital costs are similar to those that would have been estimated in a design study, the outturn costs have been adjusted downwards by reducing them by a contingency factor.

When entering new data into META the user should only need to enter the estimated base capital costs plus an estimated contingency factor. In the original version of META, these are formulae but will be over-written with either numbers or alternative formulae in which the capital costs depend only on the unit size. The user should not therefore normally be concerned with the following explanation.

In the specific circumstances of the META Guide, the formulae used to estimate the costs per kW for different plant sizes are based on the outturn costs (i.e., where all cost components are known with certainty). Therefore, in order to apply these formulae, the model needs to know the assumed contingency factors used to estimate the base capital costs. These are not necessarily the same as the future contingency factors that are applied for these technologies. The assumed factors are included in the DATABASE_Gen_ sheets and are also included in hidden columns in the INPUTS_Gen sheet, and the formulae for capital costs refers to both the unit size and to these original contingency factors. The capital cost formulae in the original version of the META model begin by estimating the capital cost based on unit size and then removing the contingencies to give the base costs excluding contingencies.