THE UNIVERSITY OF WESTERN ONTARIO
DEPARTMENT OF CIVIL AND
ENVIRONMENTAL ENGINEERING

Water Resources Research Report

An Integrated System Dynamics Model for Analyzing Behaviour of the Social-Energy-Economic-Climatic System: User's Manual

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1 ABOUT THIS MANUAL

The User's Manual is planned to assist the user in (i) understanding the ANEMI model structure; and (ii) learning how to use the model for policy simulation. ANEMI model is a research product and is not developed as a commercial software. This manual contains a brief description of the main features of the Vensim system dynamics simulation software (Ventana, 2010), as well as integrated simulation-optimization procedure developed by incorporating MATLAB (MathWorks, 2007) functionalities with Vensim system dynamics simulation. With the help of Vensim and MATLAB software packages, the user can use, modify and/or run the ANEMI models provided with the manual. The step-by-step instructions are provided for using ANEMI model for policy simulation. Advanced features of the ANEMI model, such as subscripting (arrays), linking external functionality to implement optimization within simulation, are presented using ANEMI simulation models as an example to accelerate the learning process. This manual also contains a detailed description of DLL (Dynamic-Link Library) file generation procedure by Visual Studio software package (Microsoft, 2008). The full description of the ANEMI model is provided in Akhtar et al (2011) available on the CD-ROM.

1.1 INTRODUCTION

An integrated system dynamics model is developed to assess the impacts of climate change on society-biosphere-climate-economy-energy system (Akhtar et al, 2011). This manual is prepared for ANEMI model users. The ANEMI system dynamics model consists of nine sectors/components:

- Carbon;
- Climate;
- Land-Use;
- Food Production;
- Population;
- Energy-Economy;
- Hydrologic Cycle;
- Water Demand; and
- Water Quality.

The conceptual links between these nine sectors are shown in **Figure 1.1**. The carbon sector computes the atmospheric carbon dioxide concentration by considering the carbon exchange among ocean, air, vegetation, humus and industrial emissions. The atmospheric temperature is produced by climate sector taking into consideration the radiative forcing from different sources. The land-use sector deals with the change of land-use by converting forest area to agricultural land and agricultural land to urban land to meet the needs of growing population. Food production is driven by the availability of agricultural land, allocated capital, water availability and land fertility. The requirements for the increase in food production are driven by the population growth and per capita food demand. The population sector computes the total population in each year for four different age groups (0 -14, 15-44, 45-65, 65 and above) based on the desired number of children per family, birth control effectiveness, availability of resources, and other factors. The energy-economy sector is formulated on the basis of market clearance optimization. The energy-economy sector produces GDP, energy production and fossil fuel based emissions. Hydrologic cycle is represented as surface water sector in the ANEMI model, which computes precipitation, runoff, groundwater flow and other components of the hydrologic cycle. Water demand sector calculates the demand for agricultural, domestic and industrial water uses. Water quality sector deals with the physical and chemical characteristics of water based on the use and average pollution load that is coming from each type of water use (domestic, industry, and agriculture).

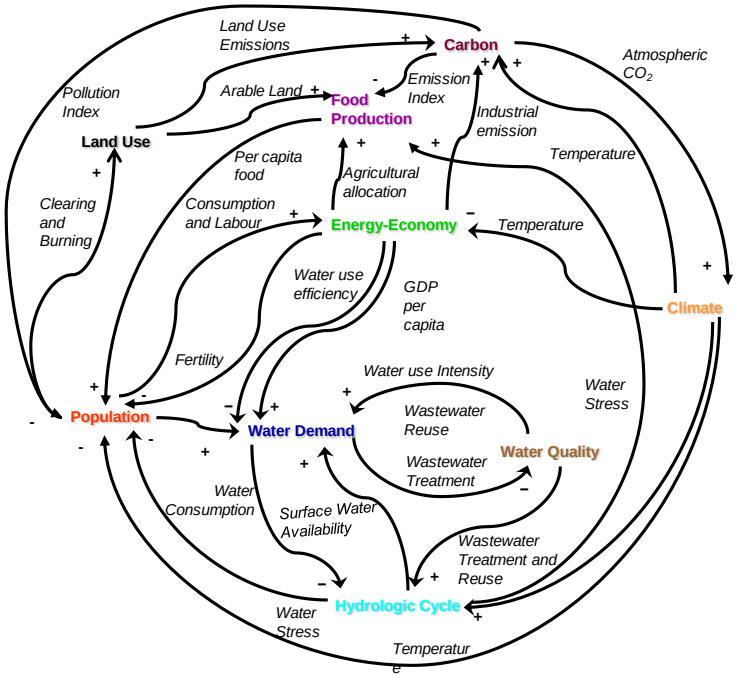


Figure 1.1: Major intersectoral links of ANEMI model

A detailed description of the inter-sectoral as well as intra-sectoral feedback relationships is available in the main report (Akhtar et al, 2011). The ANEMI model is calibrated and verified against available observations from 1980 to 2008 and information available in published literature. The model performance is presented in the report to demonstrate the robustness of the ANEMI model as a climate change policy analysis tool. The intension of this modeling effort is not the prediction of the future system behaviour, but increased understanding of the complex interactions of society-biosphere-climate-economy-energy system and response of different system sectors to various climate change mitigation and adaptation policy options.

This manual should guide the users in operation of this system dynamics model for a range of land-use conditions, water use policies, carbon tax implementation options and other policy alternatives. Two versions of the ANEMI model are available: global and regional. The instructions in the manual apply to both of them. The manual should help the users get familiar with:

- Vensim;
- MATLAB;
- VisualStudio; and
- Microsoft-Excel.

1.2 Organization of the Manual

This Manual is broadly divided in three parts. The first two chapters (Chapter 1 and Chapter 2) provide basic information on the use of Vensim software (Ventana, 2010). Chapters 3 and 4 cover the mechanics of building ANEMI model by integrating Vensim with other supporting software, and Chapter 5 demonstrates some advanced features of ANEMI model for policy implementation and analysis.

Chapter 1 provides an overview of this Manual. Chapter 2 introduces the user to the Vensim User Interface and provides instructions for the installation of Vensim software. This chapter provides an overview of Vensim's functionalities, along with information on the Sketch tools, Analysis tools, and Control windows. Chapter 3 provides a brief description of the ANEMI model, model experimentation

and policy description. Chapter 4 introduces other software packages required for the ANEMI model simulation and their installation procedures. A detailed description of the integration procedure of MATLAB and Vensim modeling tools through Visual Studio are also presented. Chapter 5 describes three simulations which are related to different policy scenarios presented in the main report (Akhtar et al, 2011). This chapter also contains step-by-step procedure for the implementation of three policy scenarios in both, global and regional versions of the ANEMI model. Appendix A contains the MATLAB optimization code MATLAB for the energy-economy sector. This appendix contains programming code for both, global and regional model, where 'fsolve' functionality is used to find a root (zero) of a system of nonlinear equations. Appendix B includes all the necessary programming code in Visual Studio to generate a Dynamic Link Library (*.DLL) files, which are utilized by Vensim; and Appendix D presents the parameter estimation codes (in R programming language) developed for the disaggregation model.

2 VENSIM

Vensim (Ventana, 2010) is a visual system dynamics simulation modeling tool, which allows user to conceptualize, document, simulate, analyze, and optimize models of dynamic systems. Vensim provides a simple and flexible environment for building simulation model from the causal loop diagram, as well as presenting it using stock and flow diagram. By connecting words with arrows, relationships among system variables are entered and recorded as causal connections. The model can be analyzed throughout the building process, looking at the causes and uses of a variable, and also looking at the loops involving a variable. After completion of the model development, the model can be simulated and user can thoroughly explore the behaviour of the model.

2.1 Vensim Basic Information

2.1.1 Directories

The typical installation path for Vensim is C:\Program Files\Vensim\models. However, the user can install Vensim software at any location. When working with the model, it is strongly recommended that the Vensim subdirectory be avoided (in this case C:\Program Files\Vensim).

2.1.2 Screen Shots

There is difference in the appearance of Vensim PLE, PLE Plus, Standard, Professional and DSS software versions. All the pictures/screen views in this manual are extracted from the Vensim DSS and default Toolsets (Ventana Systems, 2010).

2.1.3 Tab Dialog Boxes

Tab Dialogs are special dialog boxes common for Windows 95 and later versions of Windows. These dialog boxes simplify controls by separating information into different "folders" with tabs. The user can switch between folders by clicking on the appropriate tab.

2.1.4 Vensim Installation

To install Vensim, user needs to get the software, either from the CD or as a download from the VENTANA Systems, Inc. website (http://www.vensim.com, last accessed, August 2011).

The Vensim CD

The Vensim CD contains the installation programs for all Vensim configurations. The label of the CD will show the version number. Though installers for all configurations are included, the user will only be able to install the specific configuration, as per the license agreement.

Downloading Vensim

The user is allowed to download Vensim from the website of VENTANA Systems inc. after the purchase of Vensim license that includes one year of free electronic updates. The direct link for downloading Vensim is http://www.vensim.com/cgibin/download.exe (last accessed, August 2011). This link is available only with the valid registration code. The registration code identifies the productTo download Vensim PLE (free version of software) for educational purpose, user needs to visit http://www.vensim.com/freedownload.html (last accessed, August 2011).

The Windows installer is broken into a number of relatively small files. The first of these files has a name that depends on the product (for example, vendss32.exe for Vensim DSS). The remaining files are labelled disk2.vip, disk3.vip and so on. When downloading, users must save all the files in the same directory and it is very important that user should not change the name of any file.

2.1.5 Vensim Installation

Installation of the software can be done from the provided CD or downloaded files.

From CD

Insert the CD into the computer and follow the installation dialog. If there is any other previous version of Vensim installed then the user may see the screen as shown in Figure 2.1. If this dialog does not open, user needs to double click on the program file (setup.exe) on the installation CD.

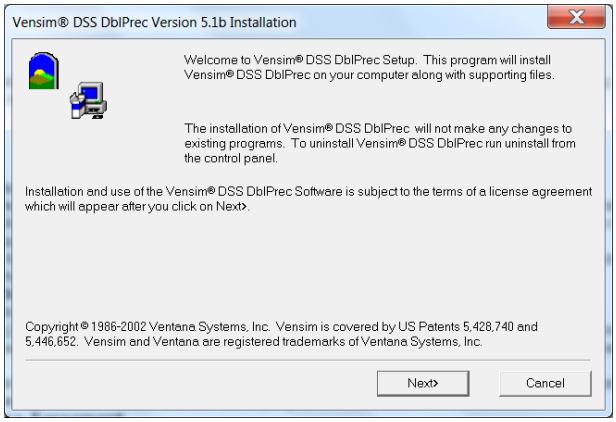


Figure 2.1: Initial Vensim installation screen

From the Installation Choices dialog, select the program that needs to be installed (Figure 2.2). The installation starts by clicking on Install a Registered Vensim Application and entering the registration code.

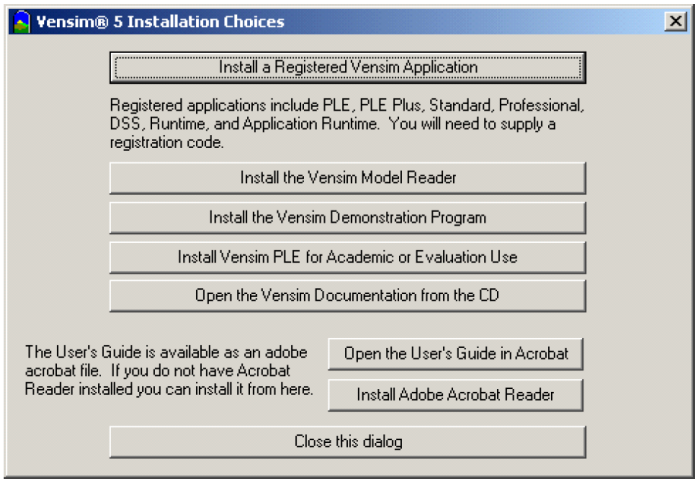


Figure 2.2: Installation choice dialog box

From Downloaded Files

Double click on the first file (for example, vendss32.exe for Vensim DSS). This will be in the directory selected by the user during the download procedure.

2.1.6 Registration Code

Vensim DSS, Professional, Standard, PLE Plus and PLE for commercial use require a registration code. Vensim PLE for educational or evaluation use do not require a registration code. Use of the ANEMI model requires a licensed version of Vensim software, which allows work with the external functionalities.

2.2 Main Features of Vensim Software

Vensim uses an interface workbench and a set of tools. The main Vensim window is the workbench, which always includes the Title Bar, the Menu, the Toolbar, and the Analysis tools. When Vensim model is open (**Figure 2.3**), the Sketch Tools and the Status Bar also appear.

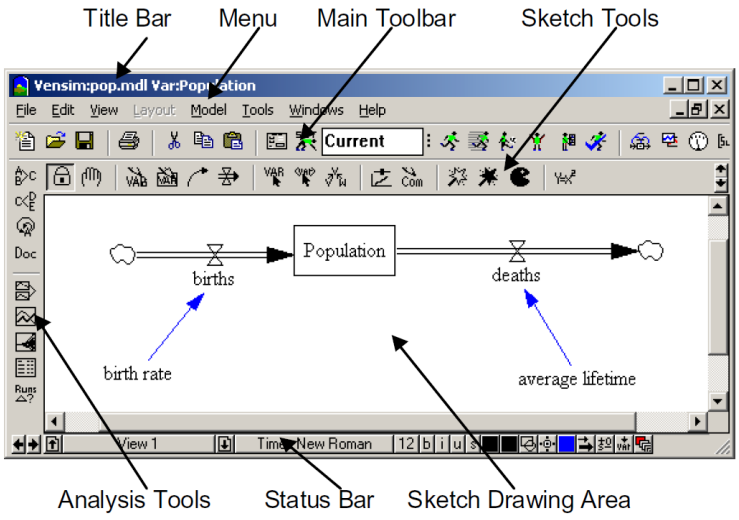


Figure 2.3: View of the workbench window

The workbench variable is any variable in the model selected by the user. The workbench variable is selected by clicking on a variable or by using the variable selection control in the control panel.

2.2.1 Vensim Menu

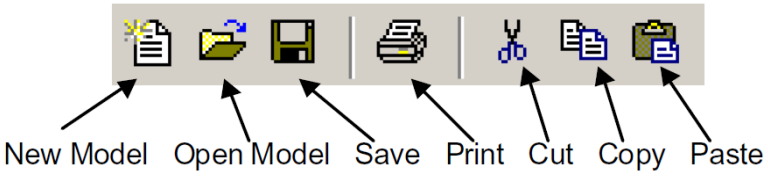
Many operations in Vensim can be performed from the menu.

- The **File menu** contains common functions such as Open, Save, Print, etc.
- The **Edit menu** allows the user to copy and paste selected portions of the model.
- The **View menu** has options for manipulating the sketch of the model and for viewing a model as text-only (available only in Vensim Professional and DSS).
- The **Layout menu** allows user to manipulate the position and size of elements in the sketch.
- The **Model menu** provides access to the simulation control and the time bounds dialogs, the model checking features, and importing and exporting datasets.
- The **Tools menu** sets Vensim's global options and allows the user to manipulate analysis tools and sketch tools as well as to set global options.
- The **Windows** menu enables the user to switch among different open windows.
- The **Help** menu provides access to the on-line help system.

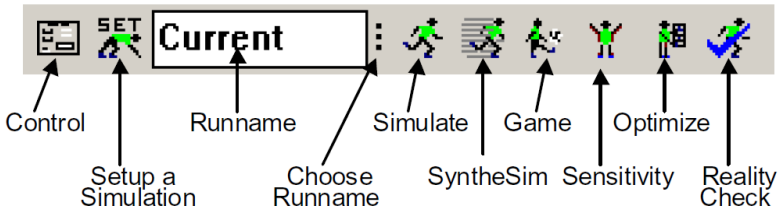
Menus are context sensitive and the commands apply to whichever window currently is active. The most commonly used menu commands also have shortcut keys and can be performed from the toolbar described below.

2.2.2 Toolbar

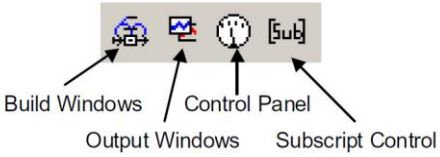
The toolbar provides buttons for some of the most commonly used menu items and simulation features. The first set of buttons access 'File' and 'Edit' menu items.



The next several buttons and the Runname editing box are used for model simulation.



The last few buttons access the window classes. User may need to click on a button to bring forward that type of window or circulate through windows of that type.

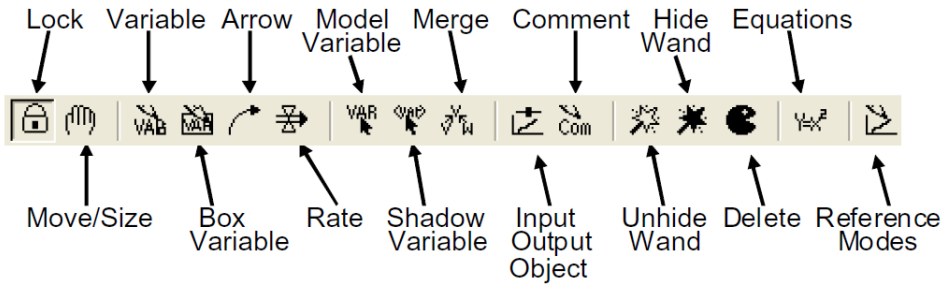


2.2.3 The Build Window

Build window is used to create model in Vensim. By default, the window opens with the sketch tools for sketching the structure of the model and for writing equations. The status bar provides buttons for modifying the sketch. Each sketch view shows a part of the model, much like each page in a book tells part of a story. In Vensim Professional and DSS, the build window can be switched to a text editor for building and editing text-based models.

2.2.4 Sketch Tools

Sketch tools are grouped into a sketch toolset. Customized toolsets can be saved to files and reopened for later use. The built in sketch toolset (default.sts) contains most of the sketch tools needed for building models.



Vensim PLE and PLE Plus do not contain the Model Variable, Merge, Unhide Wand or Hide Wand tools. The sketch tools in the built in sketch toolset are:

- **Lock** — sketch is locked. Pointer can select sketch objects and the Workbench Variable but cannot move sketch objects.
- **Move/Size —** move, sizes and selects sketch objects: variables, arrows, etc.
- **Variable —** creates variables (Constants, Auxiliaries and Data).
- **Box Variable —** create variables with a box shape (used for Levels or Stocks).
- **Arrow** — creates straight or curved arrows.
- **Rate** — creates Rate (or flow) construct, consisting of perpendicular arrows, a valve and, if necessary, sources and sinks (clouds).
- **Model Variable** — adds an existing model variable and the causes of that variable to the sketch view.
- **Shadow Variable** — adds an existing model variable to the sketch view as a shadow variable (without adding its causes).
- **Merge** — merges two variables into a single variable, merges Levels onto existing clouds, merges Arrows onto a variable to split an Arrow, and performs other operations.
- **Input Output Object** — adds input sliders and output graphs and tables to the sketch.
- **Sketch Comment** — adds comments and pictures to the sketch.
- **Unhide Wand** — unhide (makes visible) variables in a sketch view.
- **Hide Wand** — hides variables in a sketch view.
- **Delete** — deletes structure, variables in the model, and comments in a sketch.
- **Equations —** create and edit model equations using the Equation Editor.

2.2.5 Status Bar

The status bar shows the state of the sketch and objects in the sketch. The status bar contains buttons for changing the state of selected objects, and moving to another view.

A number of sketch attributes can be controlled from the status bar, including:

- Change characteristics on selected variables; font type, size, bold, italic, underline, strikethrough.
- Set the hide level.
- Variable colors, box color, surround shape, text position, arrow color, arrow width, arrow polarity, and etc.
- When using the 'Text Editor' (Vensim Professional and DSS), the Status Bar changes to reflect text editing operations.

2.2.6 Output Windows

'Output Windows, are generated by clicking on the 'Analysis Tool'. The analysis tool gathers information from the model and displays the information in a window as a diagram, graph, or text, depending on the particular tool. Dozens of these windows can be open simultaneously, and a particular window can be closed individually by clicking the Close button in the top left or top right corner, or all windows can be closed at once using the menu item *Windows>Close All Output.*

2.2.7 Analysis Tool

The analysis tool is used to show information about the 'Workbench' variable, either its place or value in the model, or its behaviour from the simulation datasets. Analysis tools are grouped into toolsets. To configure a tool, user needs to click on the tool with the right mouse button and change its options. Tools can also be added to a toolset. As with 'Sketch' toolsets, if the user makes changes he/she will be

prompted to save the toolset when exiting Vensim. Several different analysis toolsets are supplied with Vensim, and can be opened from the menu *Tools>Analysis Toolset>Open*.

The following toolsets (**Figure 2.4**) are built-in.

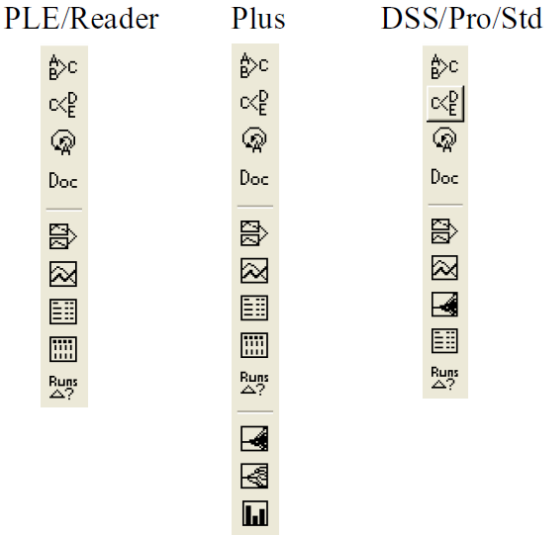


Figure 2.4: Vensim built-in toolsets

A description of the functions of toolsets follows below.

2.2.8 Structural Analysis Tools

Causes Tree — creates a tree-type graphical representation showing the causes of the Workbench Variable.

Uses Tree — creates a tree-type graphical representation showing the uses of the Workbench Variable.

Loops — displays a list of all feedback loops passing through the Workbench Variable.

Document — reviews equations, definitions, units of measure, and selected values for the Workbench Variable.

2.2.9 Dataset Analysis Tools

 **Causes Strip Graph —** displays simple graphs in a strip, allowing the user to trace causality by showing the direct causes (as shown) of the Workbench Variable.

 **Graph —** displays behaviour in a larger graph than the Strip Graph, and contains different options for output than the Strip Graph.

 **Sensitivity Graph —** creates a sensitivity graph of one variable and its range of uncertainty generated from sensitivity testing.

 **Bar Graph —** creates a bar graph of a variable at a specific time, or displays a histogram of variables over all times or across sensitivity simulations at a time.

 **Table —** generates a table of values for the Workbench Variable.

 **Table Running Down —** table with time running down.

 **Runs Compare —** compares all Lookups and Constants in the first loaded dataset to those in the second loaded dataset.

 **Statistics —** provides summary statistics on the Workbench Variable and its causes or uses.

2.2.10 Other Tools

 **Units Check** — provides an alternative way to access the units check feature.

 **Equation Editor** — provides an alternative way to access the equation for the Workbench Variable.

 **Venapp Editor —** supports the visual editing of Venapps.

 **Text Editor —** a general purpose text editor.

Further details about model 'views' are available in the Vensim User's Guide, version10 (Ventana Systems, 2010), which is distributed with the software.

2.3 Numerical Integration Technique

The integration technique is the method that Vensim uses to advance a model in time. In software package like Vensim DSS, actual computation of simulation requires numerical integration. Several different types of numerical integration are available: Euler, Diff, Runge-Kutta4 auto, Runge-Kutta4 fixed, Runge-Kutta2 auto, and Runge-Kutta2 fixed techniques (Ventana Systems, 2010). Euler integration is the simplest and fastest numerical method, but is less accurate than the Runge-Kutta method. Diff performs Euler integration but stores the values for Auxiliaries computed at the previous save time. Regular Euler integration stores the values of Auxiliaries computed at the current save time. Diff, as its name suggests, is intended primarily for difference equations where this reporting convention is often used. Runge-Kutta is modification of Euler integration that improves accuracy substantially by checking derivatives between the set time-intervals, without imposing a heavy computational burden. Several different Runge-Kutta intervals can be chosen in Vensim: fixed step size of one-half (fixed RK2) and one-quarter (fixed RK4), as well as automatic adjustments of step size, (RK2 auto and RK4 auto). RK4 Auto performs fourth order Runge-Kutta integration with automatic adjustment of the step size to ensure accuracy. This is the best choice, if the user wants an accurate answer quickly, but requires significantly more computational effort than the other forms. Therefore, RK4 auto is the slowest of the numerical integration techniques. RK4 Fixed performs fourth order Runge-Kutta integration with a fixed step size specified by TIME_STEP. This is usually very accurate, but does not detect own inaccuracies. RK2 Auto which performs second order Runge-Kutta integration with automatic adjustment of the step size. This

is less accurate, but sometimes faster than RK4 auto. It is not recommended unless user feels there is a special reason to use it. RK2 Fixed performs second order Runge-Kutta integration with a fixed step size. This is faster than RK4 but more accurate than Euler. It is useful when both speed and accuracy are important and difficult to achieve.

In the use of ANEMI model, user should avoid Runge-Kutta2 auto or Runge-Kutta4 auto, as the model setup requires predefined time-step. Even though, ANEMI model is mostly build using system dynamic based Vensim platform, still it has a dynamic link with outside computational environment (MATLAB). In each time-step Vensim sends some information to MATLAB, to get a new set of parameters for the next time step. Therefore it is essential to maintain same calculation time step for both programs. However, if it seems time consuming to use the same time step then a predefined computational time step (in such a case, the maximum computational time step between Vensim and MATLAB will work) should be selected.

All numerical integration techniques require the selection of a discrete, finite 'time-step', at which solutions are calculated for each simulated variable. This time step has a significant effect on model behaviour, so its value must be chosen carefully to avoid the introduction of *integration error* into the simulated values. Since integration error depends on the rate at which flows change relative to the selected time step, faster rates of change in flows demand shorter time steps. The practical advice for selection of an appropriate time step for system dynamics model is:

- Time steps should be divisible by 2, so that possible time step values are 1, 0.5, 0.25, 0.125, and so on;
- Time steps should be roughly one-quarter to one-tenth the size of the smallest time constant in the model.

To test the suitability of the chosen time step, user needs to run a model simulation and check its behaviour. When using Euler integration the improvement in the results is obtained by cutting the integration period in half, and evaluationg if the result changes (Ventana Systems, 2010) – for example, change the time step from 0.03125 to 0.015625. If the model behaviour matches between the two simulations, the original time step is acceptable; however, if there is any change in behaviour then the integration step should be cut further in half (0.0078128) and so on. If after using a small time step simulation results mismatch then the user is advised to switch to RK4.

2.4 An Example

This section will illustrate how a system dynamics based simulation model can be developed with Vensim software.

2.4.1 Problem Description and Solution

Problem:

Consider a small subdivision of London that is growing in population. Land available for housing development is obtained by converting the agricultural land into urban. The total available agricultural land is limited and can support the growth up to a certain level. With more potential home customers in the subdivision, land conversion from the available agricultural land will increase. With more land converted, the more actual home customers there will be. However, the higher land conversion brings awareness that the available agricultural land is limited, and that inversely affects potential home customers. The more land converted reduces the available agricultural land and makes less urban land available for new homes.

Subdivision has 100 potential home customers; if the land for development is available 2.5% of potential customers each month may decide to move to the subdivision and become actual customers (assume that units for land conversion are expressed using number of customers – one customer is equal to one home plot of land); total agricultural land available is sufficient for 85 customers.

The solution of the problem follows the procedure as outlined:

(a) Development of a causal diagram for the problem;

(b) Development of the corresponding stock and flow diagram;

(c) Development of the Vensim model for the problem;

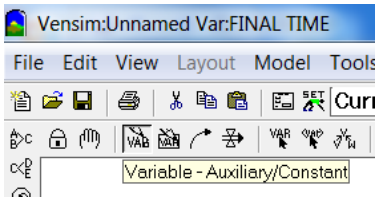
(d) Simulation of the Vensim model.

Solution:

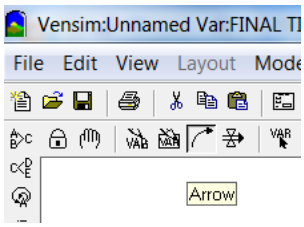
(a)

1. Start the Vensim program from the Start Menu, and draw the causal loop diagram;

2. After opening the program, select 'variable' button (Auxiliary/Constant) and then click on the workspace area to identify all the variables;



3. Select the arrow button to connect the appropriate variables in such a way that the arrow starts from a cause and ends with a result, like; if number of 'potential customers' increases then the land conversion rate should follow. In such a case user should start from the 'Potential customer' and connect towards 'Land conversion' to keep arrow head towards in the right direction. In the case of positive causality, the arrow head should be marked with '+' sign;



After successfully connecting all the variables, the causal-loop diagram as in Figure 2.5 should be obtained. Polarity of causal relationships determines the sign of the feedback loop (Sterman, 2000).

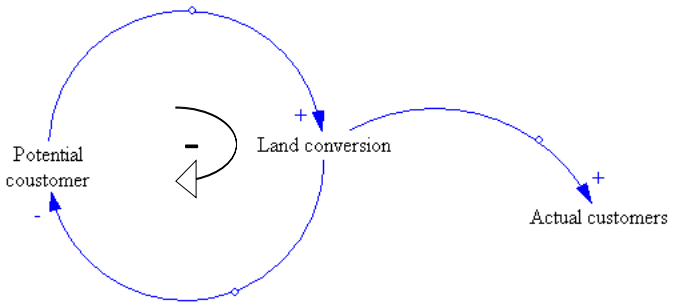


Figure 2.5: Causal-loop diagram (the negative feedback loop)

(b)

1. Model development in Vensim. Before going further, the user should be able to distinguish between 'stock' and 'flow' variables (detailed description is available in Ventana Systems, 2010; and Sterman, 2000);

2. For the development of simulation model (stock and flow diagram), it's better to start with a new model, as casual loop diagram is not a simulation model. It only helps to formulate the model structure. If the casual loop diagram is mixed with the model simulation file, the error message could appear;

3. Select the model setting window to define the computational time step and simulation time horizon (**Figure 2.6**)

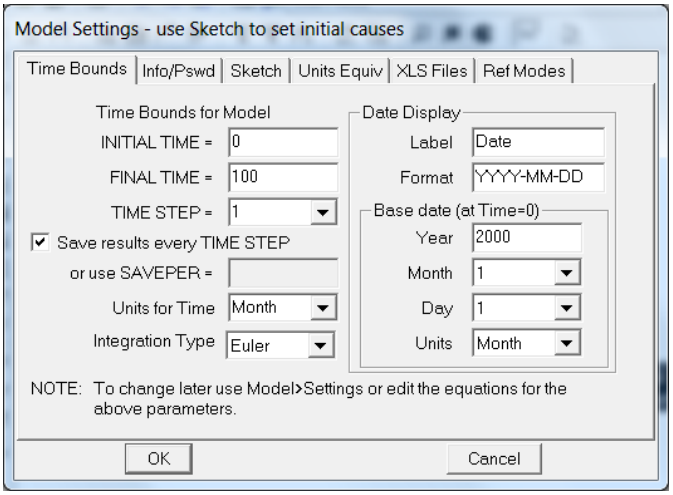
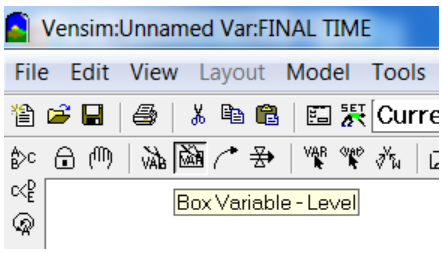
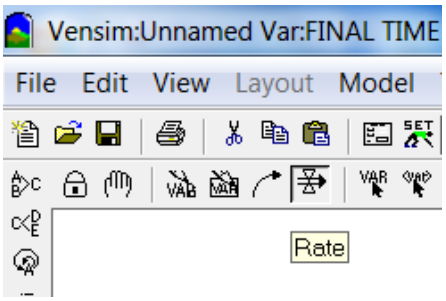


Figure 2.6: Vensim model setting window

4. Select the 'Box Variable' button before drawing the variables in the workspace. User also needs to select the 'Rate' button to make connection with the 'stock' variable through 'flow rate'.





5. After the completion of all the required connections the stock and flow diagram of the model should be like the diagram in **Figure 2.7**, where 'Potential Customer' and 'Actual Customer' are stocks representing number of customers. 'Land conversion' is working as a flow by transforming 'Potential Customer' to 'Actual Customer'.

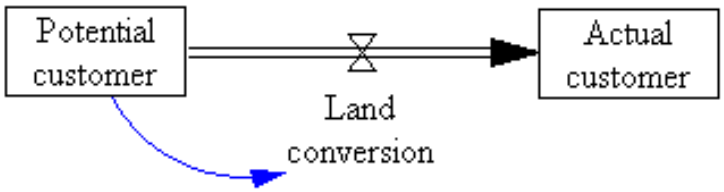


Figure 2.7: Stock and flow diagram

(c)

1. To incorporate the mathematical equations, the user needs to select the equation button before clicking on any variable. After that, user will be able to edit the equation or incorporate equation in the designated area (Figure 2.8).

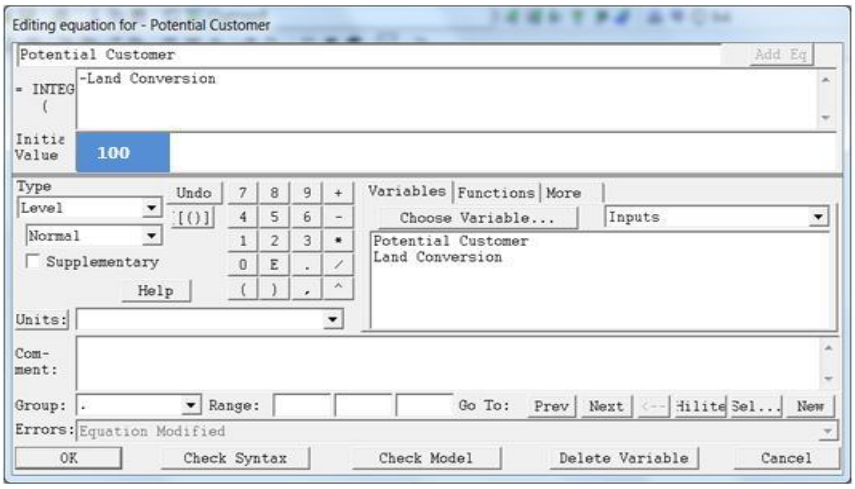


Figure 2.8: Equation editor window

2. Define the initial conditions for the model two stocks. Insert '100' and '0' value for 'Potential Customer' and 'Actual Customer' respectively. In this case at the beginning of the simulation period, all of the customers (100) were potential customer as there was no home to handover, which leads to zero number of actual customer.

3. In the problem description, it is mentioned that the project progress rate is aimed to transform 2.5% of potential customers to actual customer in each month. So the land conversion rate can be defined as:

   *Land conversion = Potential customer*0.025*

4. Vensim also allows user to visualize all the embedded equations under the diagram in the text format, which looks as:

Actual customer= INTEG (

Land conversion,

0)

~ number of customer

~ |

Land conversion=

*Potential customer*0.025*

~ number of customer

~ |

Potential customer= INTEG (

-Land conversion,

100)

~ number of customer

~ |

****

.Control

**********~

Simulation Control Parameters

FINAL TIME = 100

~ Month

~ The final time for the simulation.

|

INITIAL TIME = 0

~ Month

~ The initial time for the simulation.

|

SAVEPER =

TIME STEP

~ Month [0,?]

~ The frequency with which output is stored.

|

TIME STEP = 1

~ Month [0,?]

~ The time step for the simulation.

(d)

As the last step, model simulation is initiated by pressing 'Run' button from the Tool Bar. After completion of the simulation, the user can visualize or extract the results file, both in graphical and numerical format.

In the problem description, it is mentioned that the total land available is sufficient for 85 customers. So, from the graph of actual customers (Figure 2.9), it can be seen that 75 months would be sufficient to sell all the properties within the subdivision.

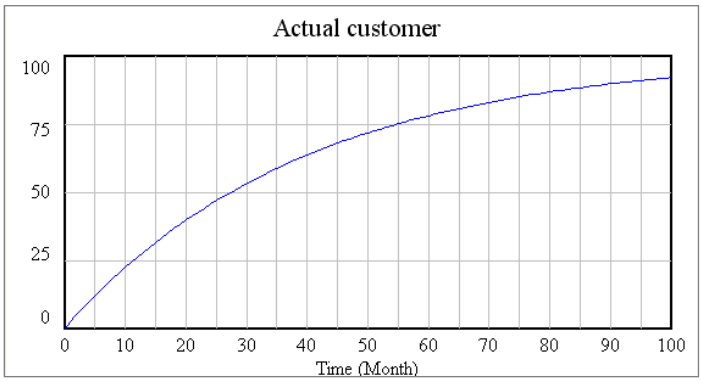


Figure 2.9: Time series plot of the number of actual customers

3 ANEMI MODEL

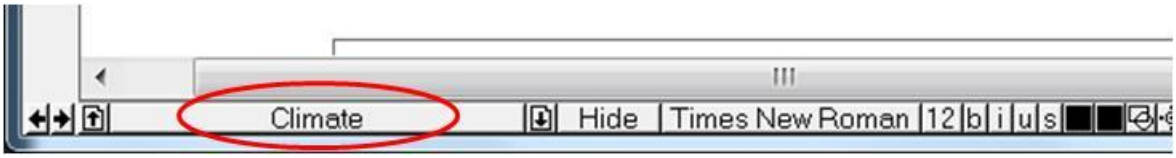
3.1 Model Organization and Mathematical Basis

The ANEMI version 2 model captures interconnections between main elements of the complex society-biosphere-climate-economy-energy system like global surface temperature, global CO_2 concentration, average annual surface flow, population growth, economic output, energy consumption, wastewater volume, and others (Akhtar et al, 2011).

The system dynamics models include two levels of model representation: (i) a diagrammatic representation of the causal connections that constitute the system under study, and (ii) the mathematical basis of those connections in the form of equations.

Vensim allows the user to separate the model in many ways at the diagrammatic level. This unique facility supports the ANEMI model structure – nine model sectors are developed using multiple system dynamics diagrams. Conceptually, the sectoral view helps the user to focus on any specific sector by drawing boundaries around the processes of importance in that part of the model. While looking at the integrated modelling structure it is not uncommon that the majority of variables in one sector are not relevant to the rest of the model, and their number within an individual sector is generally significantly higher than the number of equations that connect different sectors. Finally, model division into subsystems separates the relevant from the irrelevant variables, so that only key variables – those involved in intersectoral feedbacks – are visible to the rest of the model.

The global version of ANEMI model is divided into fourteen subsystem views, which in most cases correspond to model sectors. Those subsystems, which are not treated as sectors, are mainly introduced to make the visual representation more tidy and convenient for the model user. These fourteen views of nine ANEMI sectors are introduced in the Vensim DSS model version through the 'view selector' located at the bottom of the main screen or by pressing the 'page up' and 'page down' key.



The model views are presented below in the following order (from Figure 3.1 through Figure 3.14): carbon, other gasses, climate, climate_Nordhaus, land-use, food production, hydrologic cycle (water quantity), water demand, water quality, water stress, population, emission, energy-economy, and sea-level rise.

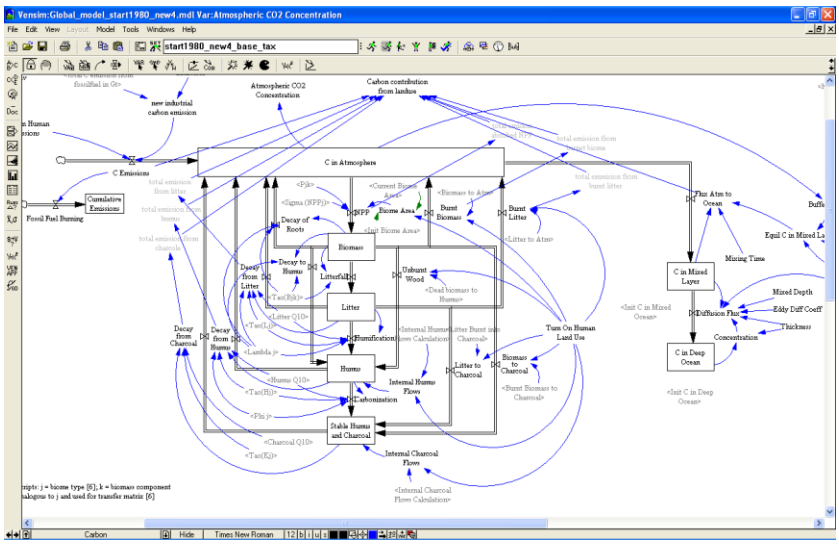


Figure 3.1: View of the 'carbon' sector

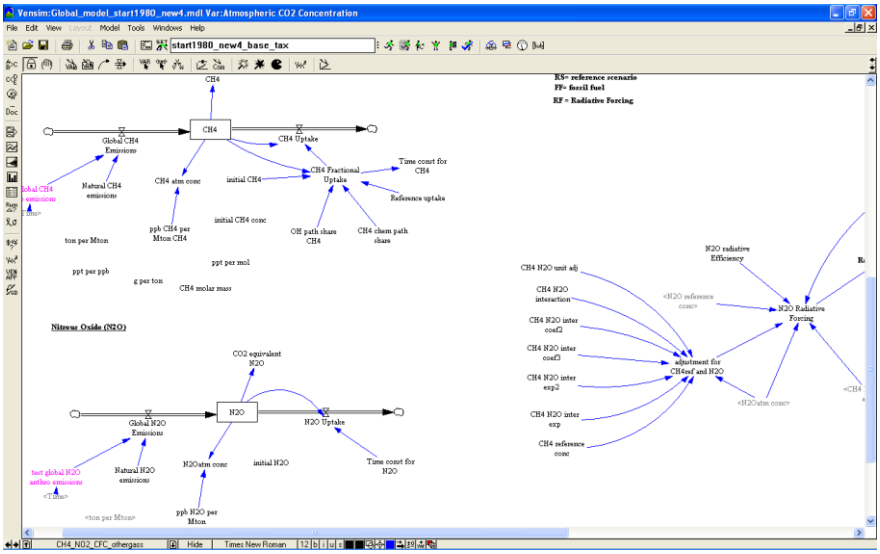


Figure 3.2: View of the 'other gasses' subsystem

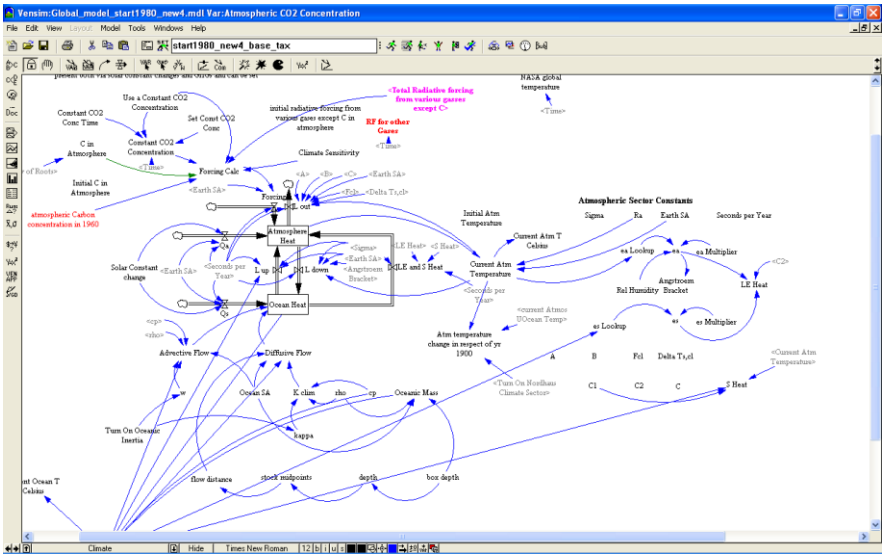


Figure 3.3: View of the 'climate' sector

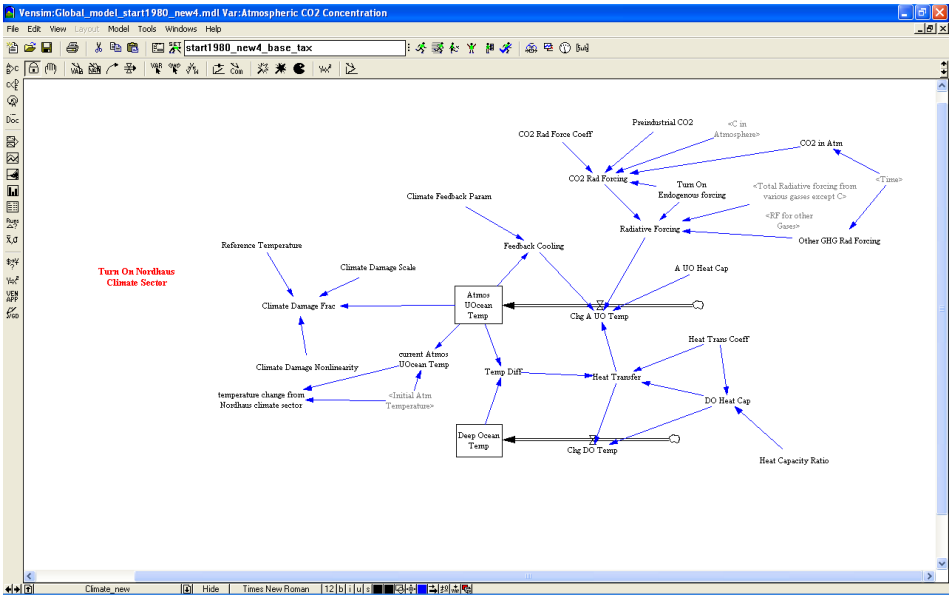


Figure 3.4: View of the 'climate_Nordhause' subsystem

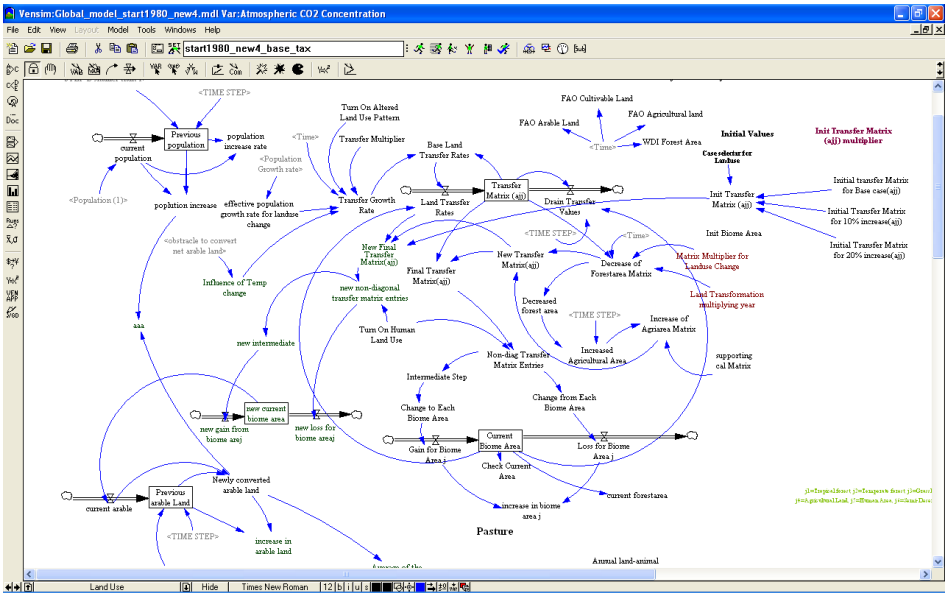


Figure 3.5: View of the 'land-use' sector

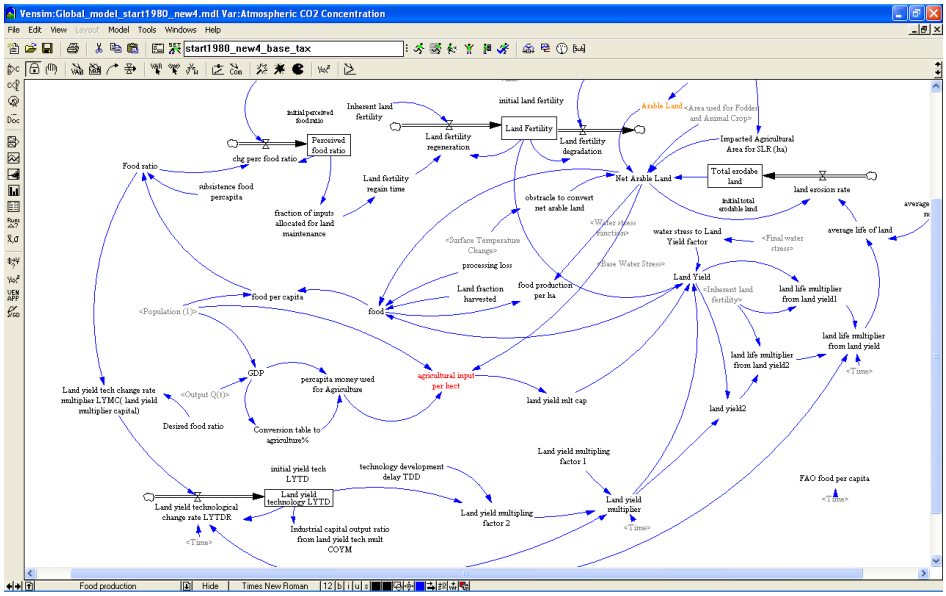


Figure 3.6: View of the 'food production' sector

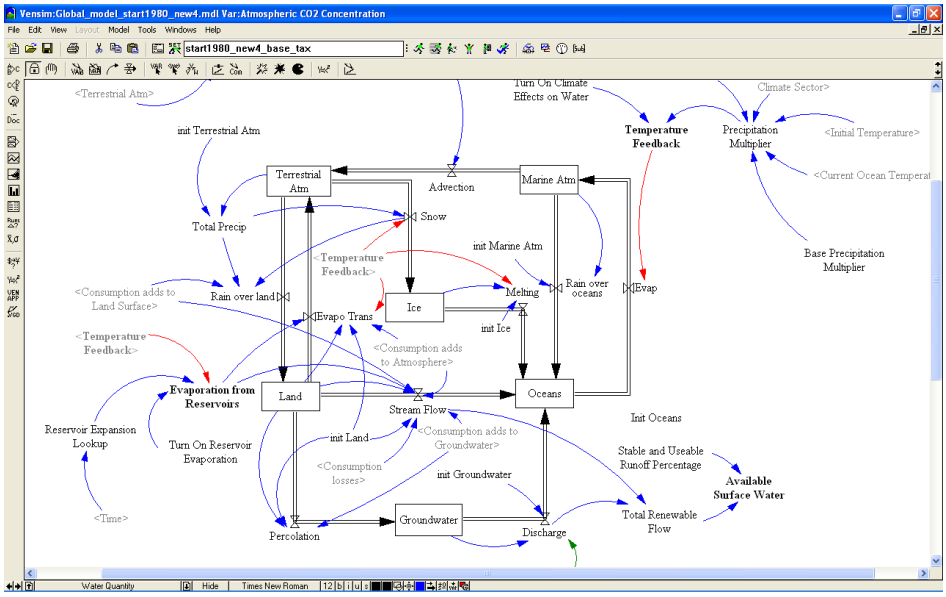


Figure 3.7: View of the 'hydrologic cycle' sector

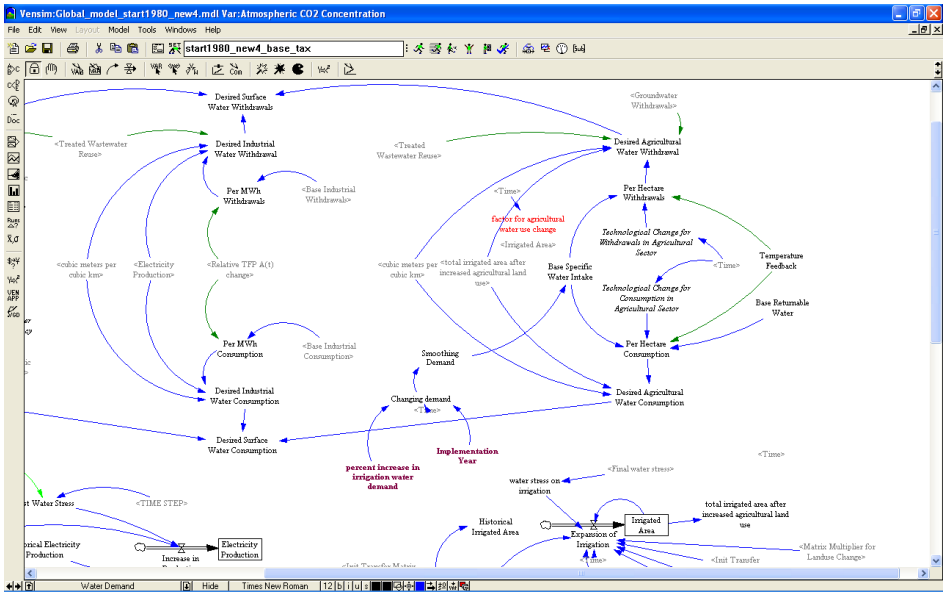


Figure 3.8: View of the 'water demand' sector

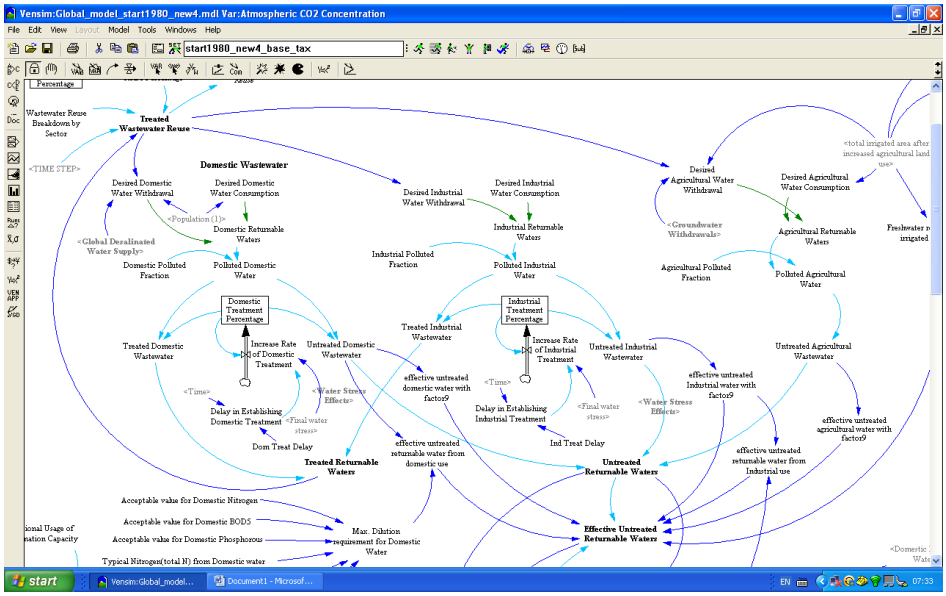


Figure 3.9: View of the 'water quality' sector

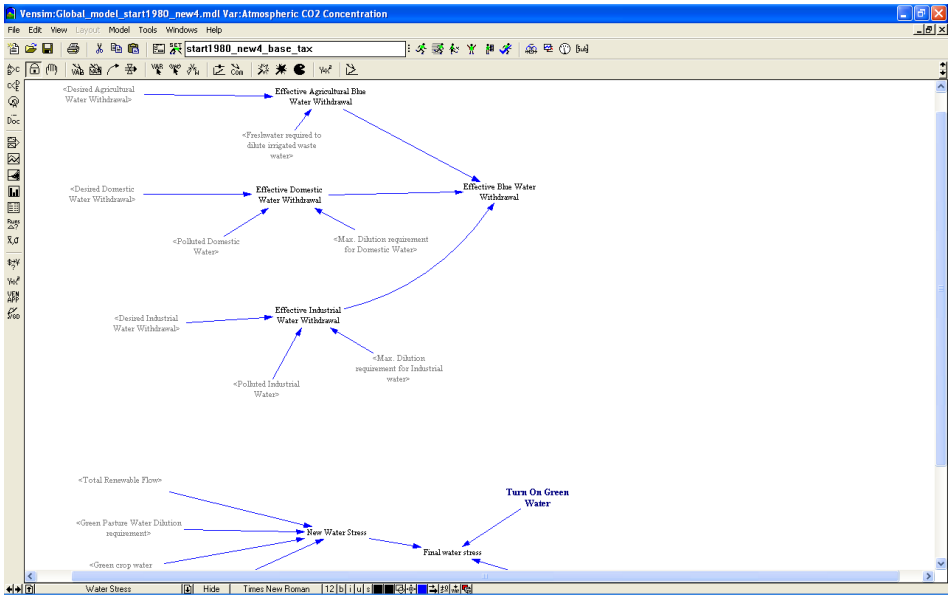


Figure 3.10: View of the 'water stress' subsystem

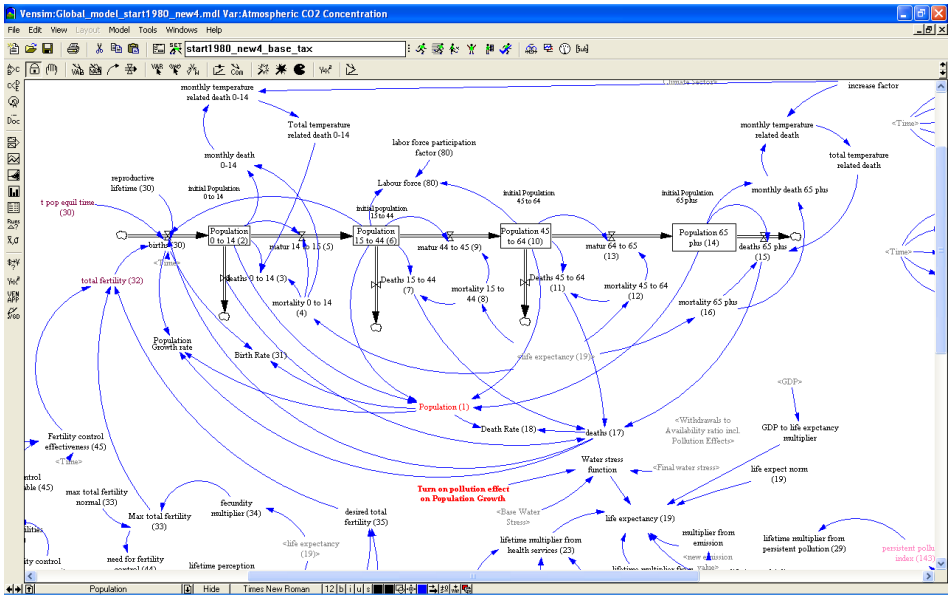


Figure 3.11: View of the 'population' sector

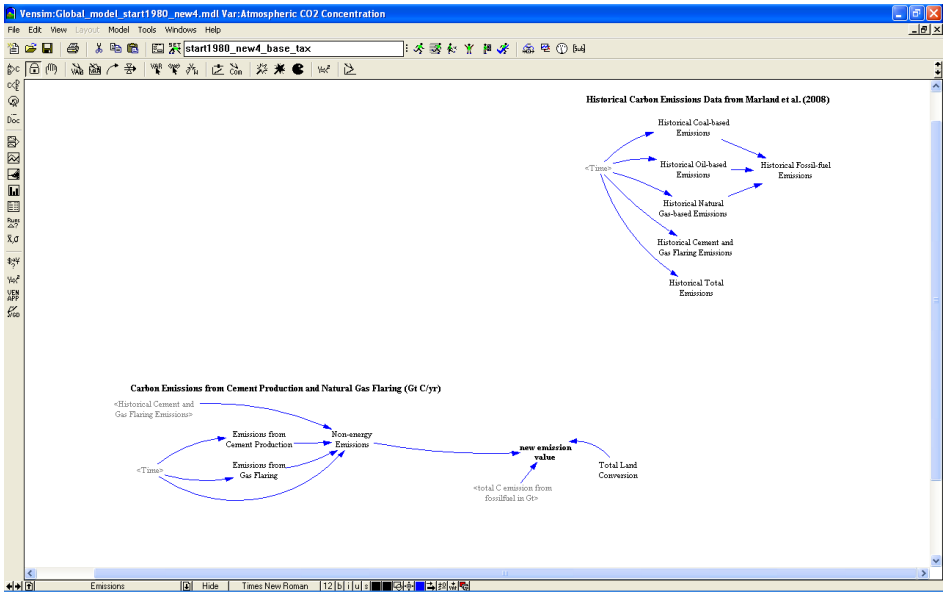


Figure 3.12: View of the 'emission' subsystem

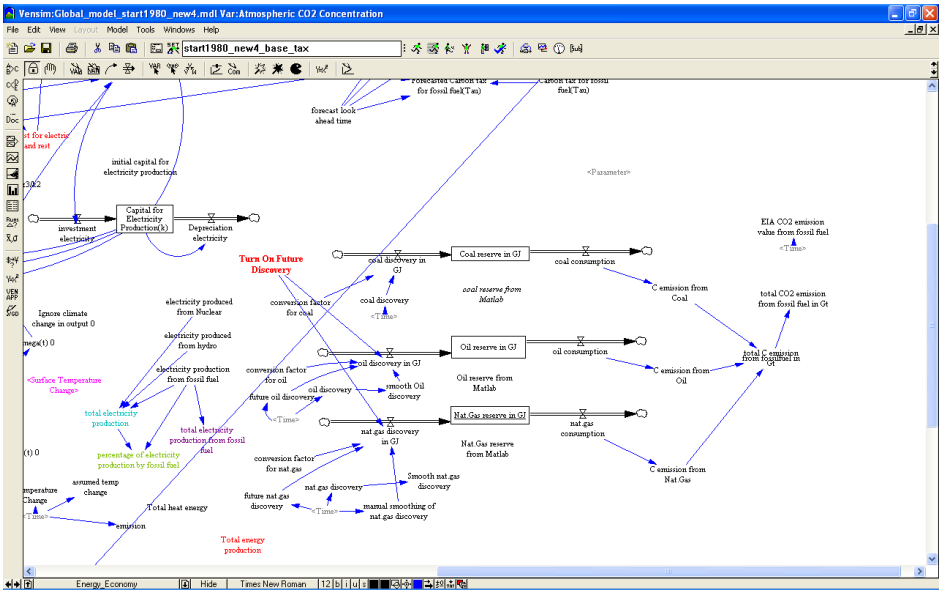


Figure 3.13 : View of the 'energy-economy' sector

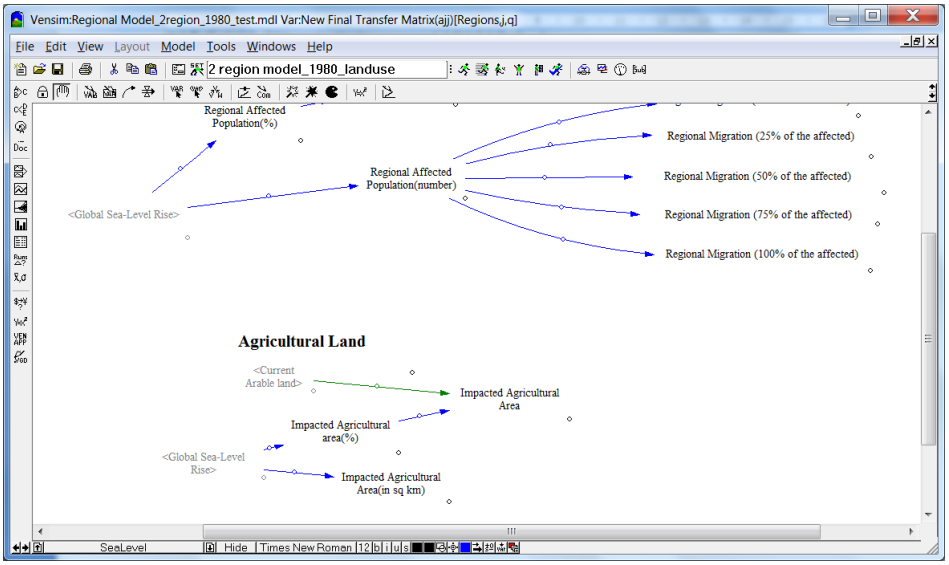


Figure 3.14: View of the 'sea-level' subsystem

All the variables, constants and parameters shown in Figures 3.2 to 3.14 are representing stocks or flows or auxiliary variables in the ANEMI stock and flow diagrams.

3.2 ANEMI Model Simulations

The ANEMI system dynamics modelling follows a structural approach of modelling, so that each individual sector is based on the best understanding of the real-world. Here the structural approach means that equations used to drive the model are not only based on a mathematical expressions and matching data, but also on the current level of scientific understanding and judgment to appropriately represent the physical processes occurring within the complex system. Therefore, it is often observed that the ANEMI model fails to exhibit excellent match with the actual data. At the same time, the model is capable of avoiding data overfitting problem.

The greatest strength of the system dynamics model like ANEMI is its structure rather than the set of equations that provides the best-fit to the data. So manipulation of the calibration parameters is not the primary and only modeling objective. The calibration procedure concentrates primarily on the manipulation of uncertain structural elements through alterations to stocks and flows and feedback structures, whereas parameter tuning constitutes a minor part of the model calibration and verification process.

The ANEMI version 2 model is tested following the three basic steps:

i) Validation;

ii) Checking the model behaviour by functional analysis; and

iii) Checking the impact of feedback structure.

The ANEMI model is fully tested and above mentioned steps may be repeated only if the modifications are made to the model structure. The main mode of model use by the user is through the implementation of various policy options ('what if' scenarios) that can be created by changing /choosing model input parameters. Implementation of the carbon tax scenario could be a good example for the illustration of this process. The user could easily modify the parameter of carbon tax policy in this model and track the consequences within few minutes after a successful model run. User needs not to be restricted to simulation results within the energy-economy sector, but can analyze the behaviour of any variable within the model structure including all model sectors.

3.3 Policy Development

The ANEMI model can be used to analyze the consequences of different policy scenarios. The policy could be related to energy price, energy consumption, water use, water quality, irrigation practice, population dynamics, land-use change and much more issues, which can be addressed by the analyses of nine model sectors. ANEMI model structure allows for single or combined policy scenarios.

The following is description of policy development process and the implementation of a particular policy with the ANEMI model.

3.3.1 Scenario 1 - Increase in Water Use

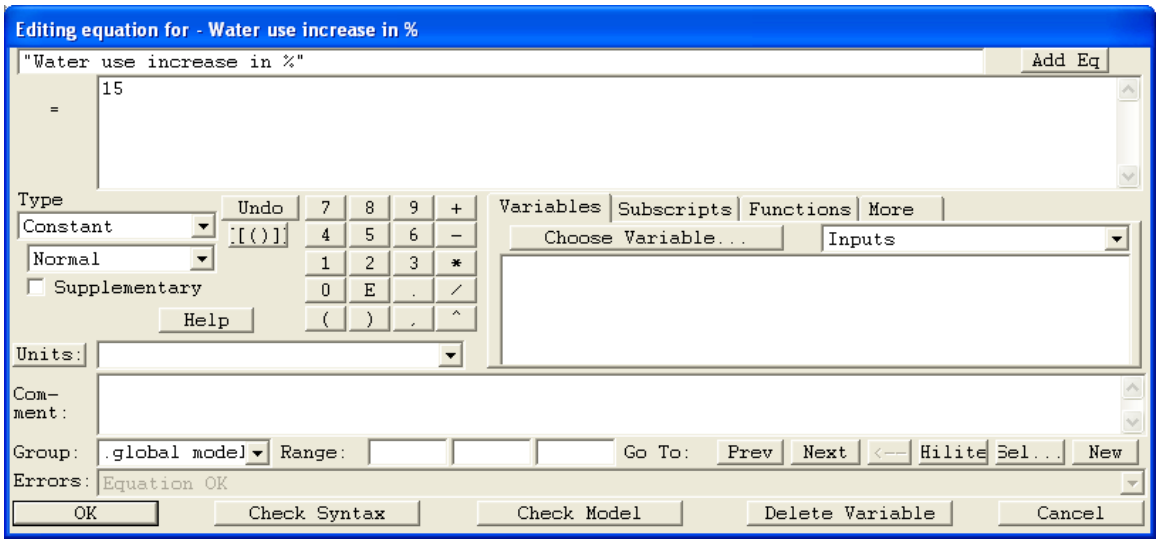
Key Question: What are the impacts from increase in water use?

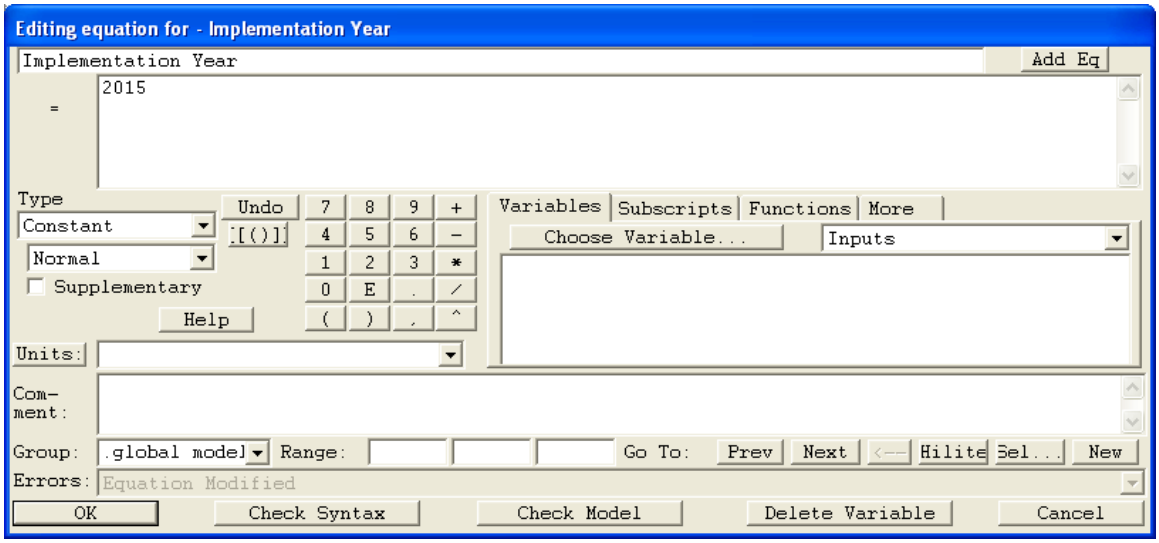
The key question is converted into 'what if' scenario of maintaining current irrigation practices, and whether such practices (and consequently agricultural output) can be sustained in case of increased water stress. This scenario is examined with the global and regional version (focusing on Canada) of the ANEMI model. As the food production sector is not only dependent on land-use, it is also possible to assess the interaction between the food production and the changes in water population and variables of the energy-economy sector. This scenario looks more broadly to several sectors including: hydrologic cycle, water quality, energy-economy, population, climate, carbon, and food production. A 15% increase in water use is considered under this scenario to meet future water demand.

In the ANEMI model the Scenario 1 is created by assigning the two input variables: 'Water use increase in %', and 'Implementation year'. In this case we decided to implement our scenario 1, from the year 2015. So the following modifications are required to implement the scenario 1 (Figures 3....and 3...):

'Water use increase in %' = 15

'Implementation year' = 2015





3.3.2 Scenario 2 – Increase in Food Production

Key Questions: What are the impacts from increased conversion rate of forest land into agricultural land?

This scenario is closely related to the previous one. The scenario 2 tests the impact of changing the land-use by converting one land form into another – forest into agricultural land. In this scenario, 15% increase in land conversion from forest to agricultural is implemented from the year 2015.

In the ANEMI model the Scenario 2 is created by assigning the following values to different input variables: 'Land transformation multiplying year' stands for the increased land transformation start year, and 'Matrix Multiplier for Land Use Change' denotes increase percent of deforestation for agricultural use. Therefore the following modifications are required to implement the scenario 2 (Figures 3….and 3…):

'Land transformation multiplying year' =2015

'Matrix Multiplier for Land Use Change' = -0.15 in place of j1q1

here, *j1q1* is the increased transfer rate of forest out of 1 (value in percent/100) and the sign determines whether it's in losing side or gaining side. In this case as the forest area is decreasing so j1q1 should be negative.

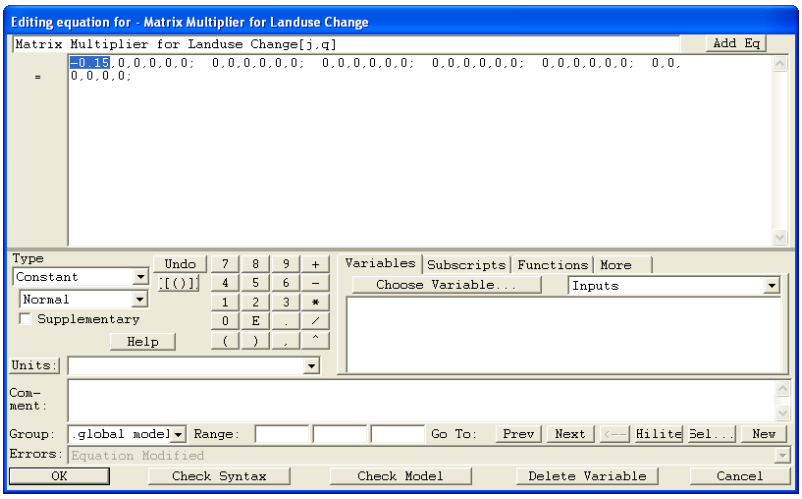


Figure 3.15: Option view to choose land transformation rate

3.3.3 Scenario 3 - Carbon Tax

Key Questions: What are the impacts from implementing the carbon tax policy?

In the ANEMI energy-economy sector, the carbon tax is implemented as a tax per unit of CO_2 emissions, effectively raising the price of fossil fuel. Under this experimentation, the carbon tax policy is implemented in 2012 and then slowly ramped up to $100 per tonne of CO_2 over next 30years.

In the ANEMI model the Scenario 3 is created by assigning the following values to different input variables (Figures 3....to 3....) :

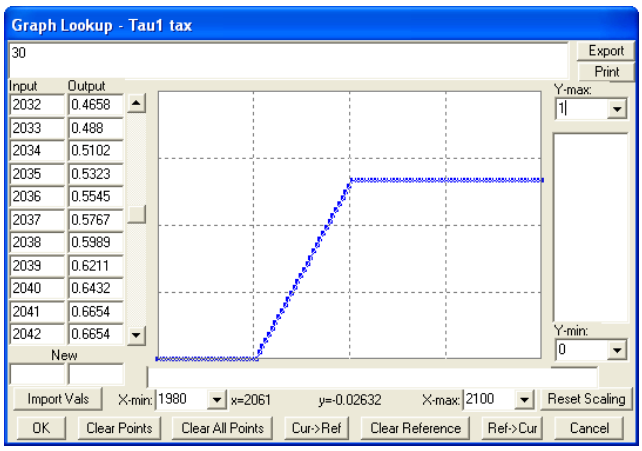
'Carbon Tax ON' =1;

'Tau1 tax'= Starts from the year 2012 with an increment rate of 0.02218 until it reaches to 0.6654 in the year 2041 and then continues with the same fixed value which is $100 per tonne of CO_2.

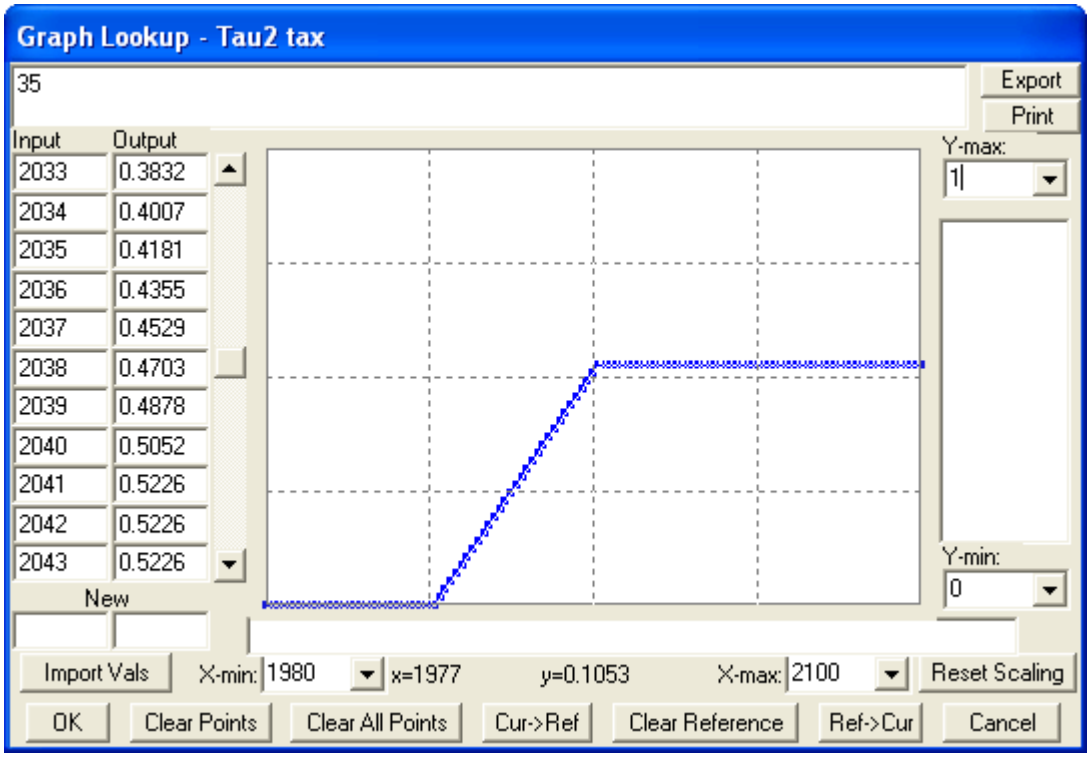
'Tau 2 tax'= Starts from the year 2012 with an increment rate of 0.01742 until it reaches to 0.5226 in the year 2041 and then continues.

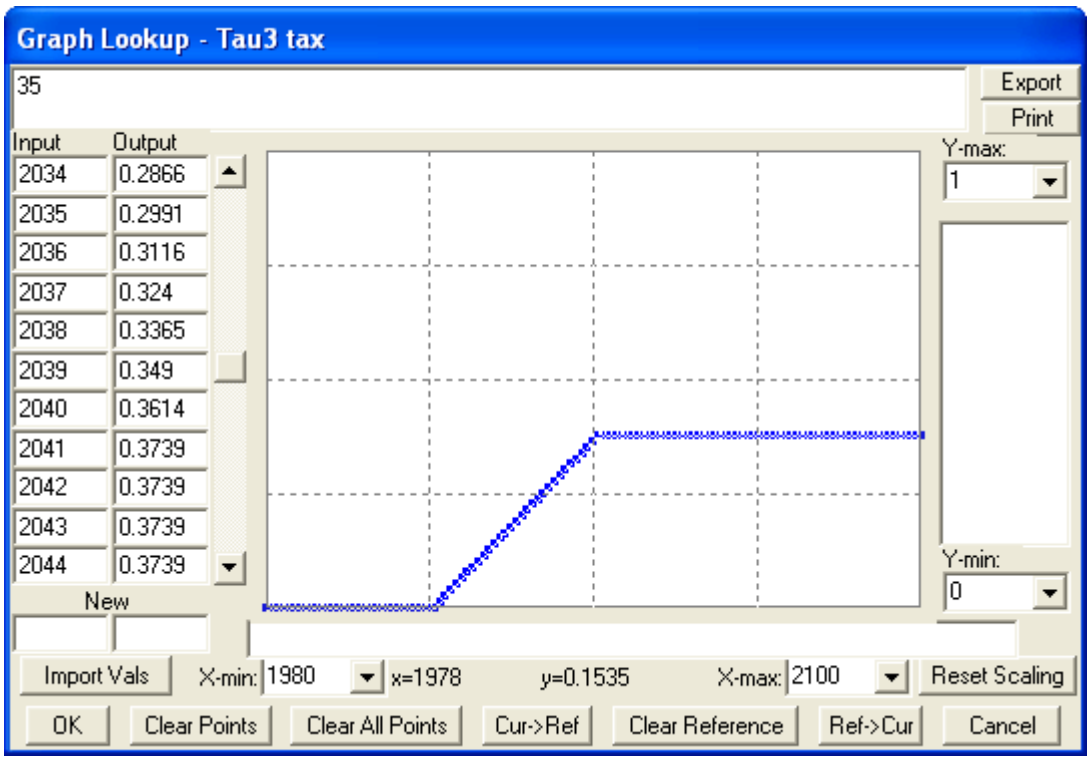
'Tau3 tax' = Starts from the year 2012 with an increment rate of 0.01246 until it reaches to 0.3739 in the year 2041 and then continues.

Select values for 'Tau1 tax', 'Tau2 tax', and 'Tau3 tax', as they represent the carbon tax for 'Coal', 'Oil' and 'NaturalGas' respectively (In this demonstration, equivalent amount of tax is implemented based on the emission intensity from each unit of fossil fuel. However, user can implement any type of tax policy.



Look-up table for coal based carbon tax rate input





4 OTHER SOFTWARE TOOLS

The ANEMI version 2 model is developed in Vensim system dynamics simulation environment. Vensim has a limited capability in handling optimization. In order to accommodate the structure of the economy-energy sector of the model optimization capability had to be introduced with thin the simulation model. The MATLAB computer package (MathWorks, 2007) is integrated with Vensim to provide the optimization capability to the ANEMI model. However, other computer tools like Visual Studio (Microsoft, 2008), and Microsoft Excel are also used to facilitate the dynamic data exchange procedure between Vensim and MATLAB.

4.1 MATLAB Computer Package

For the optimization of the energy-economy sector, the ANEMI model needs the interaction between Vensim and MATLAB software in every simulation time step. This section presents the MATLAB installation procedure.

4.1.1 MATLAB Installation

1. Obtain the Personal License Password (PLP) that is required for the installation of MATLAB package.

2. Use the installation DVD and follow the MathWorks Installer dialogue (**Error! Reference source not found.**).

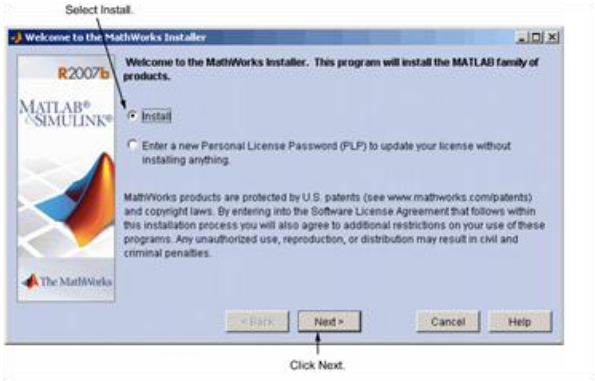


Figure 4.1: MATLAB installation option view

3. Enter the user name, organization name, and Personal License Password (PLP) in the license information dialog box and select 'Next' to continue.

4. In the 'Installation Type' dialog box, select between 'Typical' or 'Custom' installation and then click 'Next' to continue.

5. When the 'MathWorks Installer' finishes the whole installation process, it displays the 'Setup Complete' dialog box (Figure 4.2).

Figure 4.2: MATLAB setup completion message view

4.2 Visual Studio

The ANEMI model requires a number of functions that are not available in Vensim software. They can be programmed externally using any programming language (usually C or C++) and then compiled into a dynamic link library (DLL) which can be loaded by Vensim.

There are number of options for communication with Vensim, starting with the clipboard. Vensim can also easily import or export data and constants from other sources. For dynamic control of Vensim's behaviour, the Vensim DLL allows the user to control Vensim from Visual Basic, Delphi or any other programming language. For the development of ANEMI model, the Visual studio package (Microsoft, 2008) is found to be the most suitable. For those ANEMI model users who will be modifying the model structure familiarity with creation of DLL files to exchange data/information with Vensim is required.

4.2.1 Visual Studio Installation

1. As pre requirement, prior to the Visual Studio installation, system needs to be checked and verified by the setup wizard. Execute Visual Studio installer.

2. Read the 'readme' information. Click the Install Visual Studio 2008 link to start the installation (Figure 4.3) process.

Figure 4.3: Installation option view of the Visual Studio

3. At this stage, the setup wizard transfers needed files into a temporary folder (Figure 4.4);

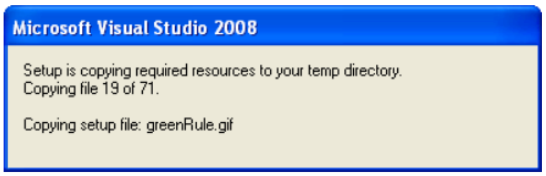


Figure 4.4: View of 'copying setup file'

4. Follow the 'Welcome Setup Wizard' and wait for the wizard to load the installation components (Figure 4.5).

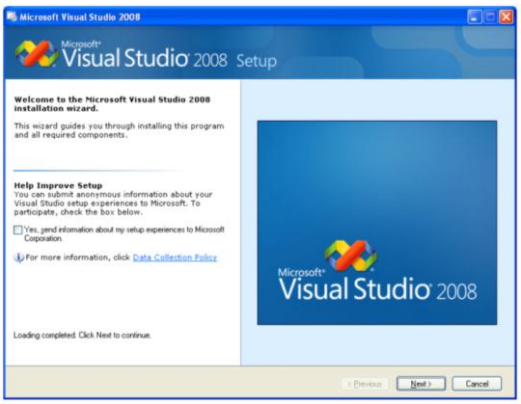


Figure 4.5: Option view to share Visual Studio setup experience

5. Notice that, VS 2008 (version 8.x) needs .NET Framework version 3.5, where user needs to provide the product key information and accept the license terms.

6. Proceed with the selection of installation choice between Default, Full or Custom.

7. Select the 'Install' button and follow the step-by-step auto installation process (Figure 4.6).

Figure 4.6: View of the installation process

4.3 Integration of External Functions With Vensim Software

A dynamic link library (DLL) is a collection of small programs, which can be called upon when needed by the executable program (EXE) that is running. The DLL lets the executable use a particular functions. Introduction of the optimization with the ANEMI model requires a few specialized functions such as: reading from an external file, writing to an external file, and so on. Vensim DSS allows use of external functions by Vensim software through a Dynamic Link Library (DLL). Such external functions can later be used in Vensim, same as a built-in Vensim function.

4.3.1 Steps for DLL file compilation

1. Copy 'TestDll' folder from the supplied DVD (supplied with ANEMI model) and paste it in the desired location.

2. Open Visual Studio program and select ‘File’ menu to open ‘TestDLL.sln’ file, using navigation buttons (Figure 4.7).

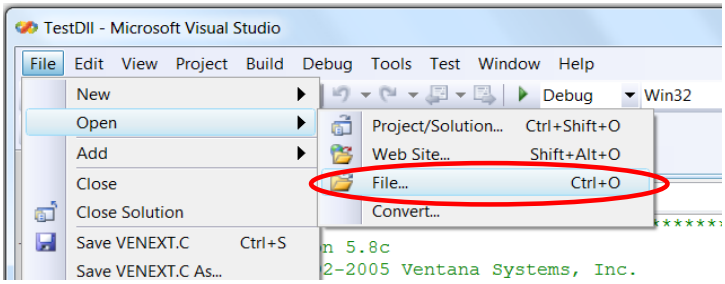


Figure 4.7: Option view to import a file in Visual Studio

3. Find the ‘Solution Explorer’ window and double click on VENEXT.C file (Figure 4.8).

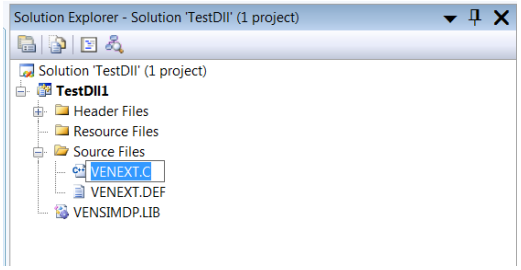


Figure 4.8: Solution explorer window

4. Select the ‘TestDLL1’ folder from the ‘Solution Explorer’ window and then right click to select the ‘properties’ (Figure 4.9).

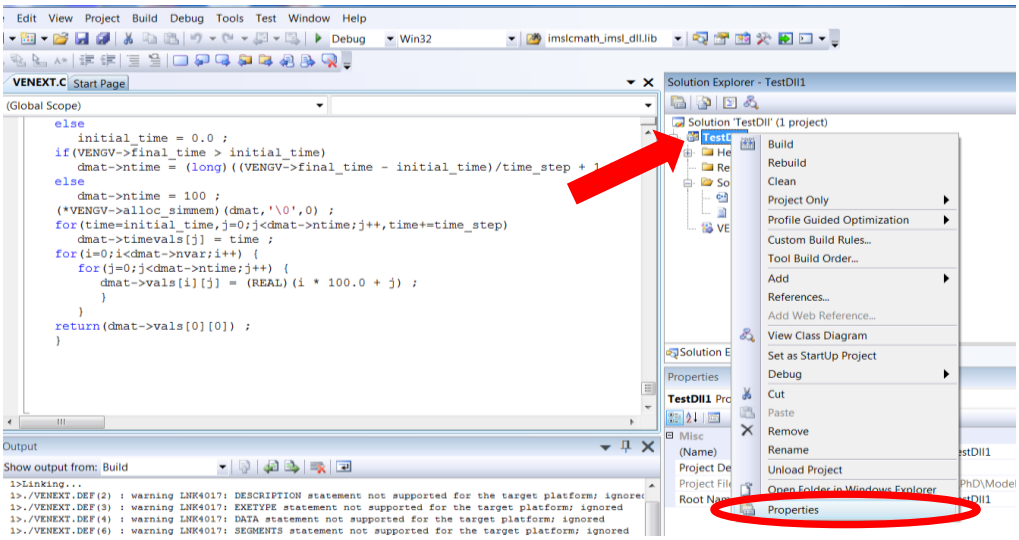


Figure 4.9: General options under solution explorer

5. From 'TestDLL1' Property Page, define the destination path of the DLL file (name could be VENSIM.DLL) under 'General' option (Figure 4.10).

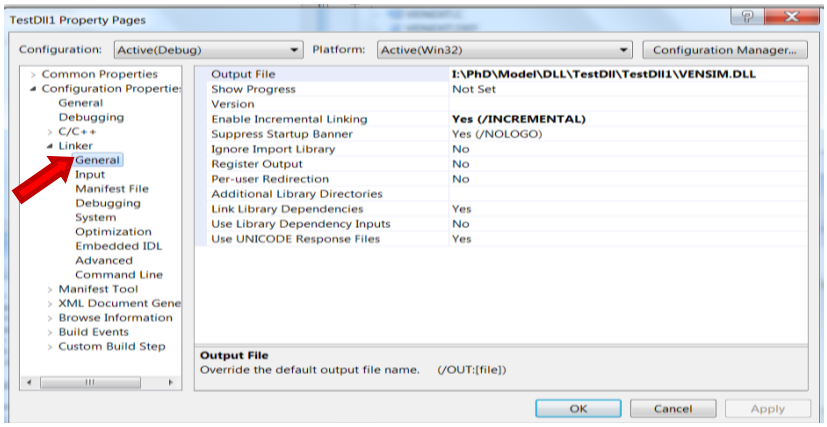


Figure 4.10: View of 'Linker option'

6. Provide required files name (VENSIMDP.LIB and VENEXT.DFF, which are shipped with Vensim software package) under 'Input' option and then press 'OK' (Figure 4.11) to continue.

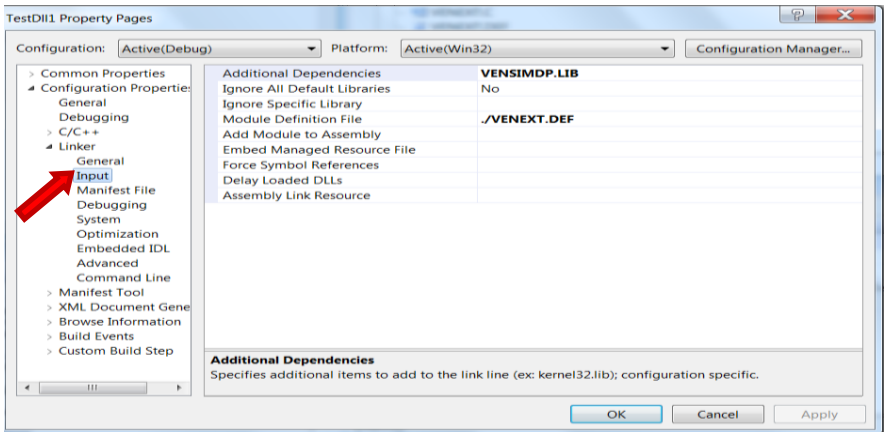


Figure 4.11: Definition file extraction window

7. Create the expected DLL file (VENSIM.DLL). Press 'Debug' button (Debug) and wait for the result, which will appear in the 'Output' window (Figure 4.12).

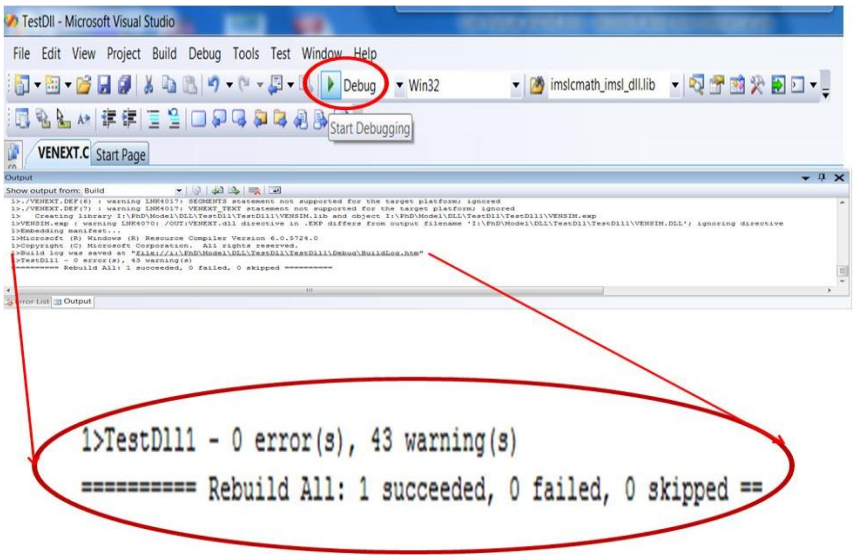


Figure 4.12: Output window

8. After successfully creating the DLL file, link that file (VENSIM.DLL) with Vensim. To do so, open Vensim model and press 'Option' under the 'Tools' menu (Figure 4.13). 'The global option setting' window will pop up and user needs to select 'startup' option before proceeding further (Figure 4.14). Lastly, user should locate the DLL file (VENSIM.DLL), using the 'Browse' button located beside the 'External function Library'.

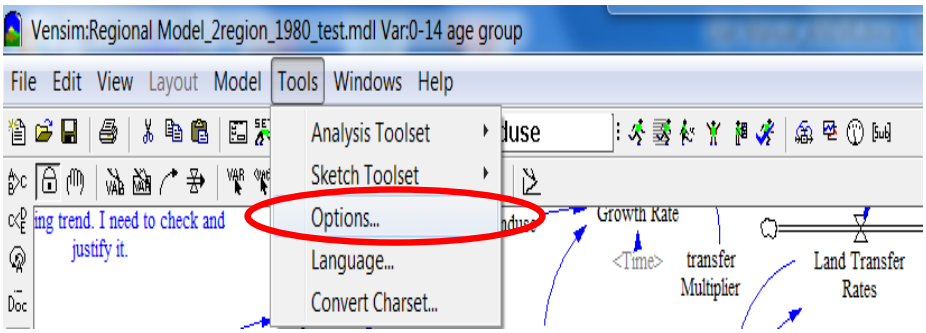


Figure 4.13: Option view of Vensim

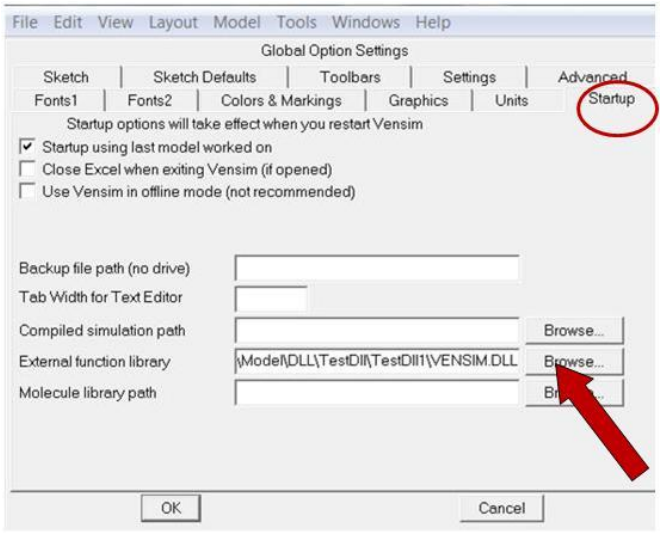


Figure 4.14: Option view of 'External function library'

9. Press 'OK' to complete the process.

4.3.2 Running Vensim and MATLAB Together

The whole 'Model' folder should be copied from the DVD supplied with the ANEMI model. As Vensim and MATLAB are shearing some common files, it is suggested to carry out the simulation and optimization work from the same folder. In the model folder supplied with the ANEMI model the user will find all the required files (text files, Microsoft Excel files, Vensim files and MATLAB files). Modification of these files is not allowed. The ANEMI model developers used a very specific way to set up the simulation-optimization process, which requires exact procedure to be, followed (Figure 4.15):

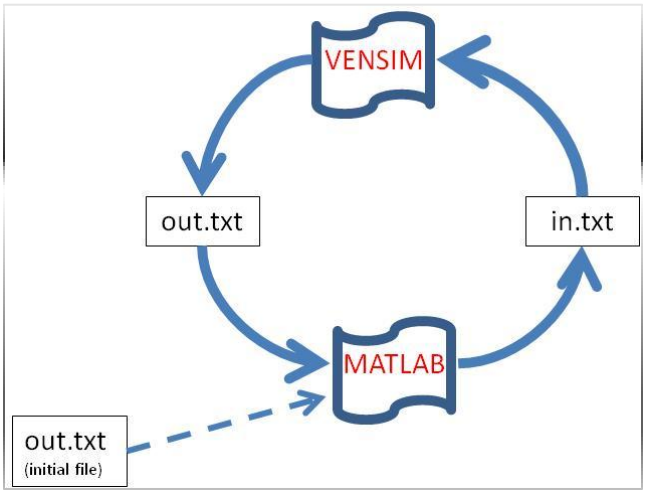


Figure 4.15: Flow diagram of the file exchange process between Vensim and MATLAB

Global Version of the ANEMI Model

1. Open 'out_back.txt' file and save it as 'out.txt'. This step needs to be carried out always at the beginning of each simulation, as all the initial values for the optimization scheme are kept in the 'out_back.txt' file.

2. Start MATLAB program first and then select 'Open' from the File menu (Figure 4.16).

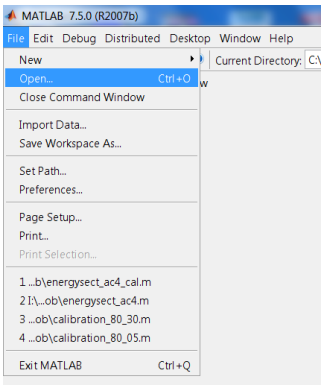


Figure 4.16: View of the 'File Menu' in MATLAB

3. Navigate through newly created folder (where all files supplied on the DVD are kept) and select 'ensect_solve_glb.m' file.

4. Define the path to the working folder (where all files from the DVD are stored) in MATLAB environment (Figure 4.17).

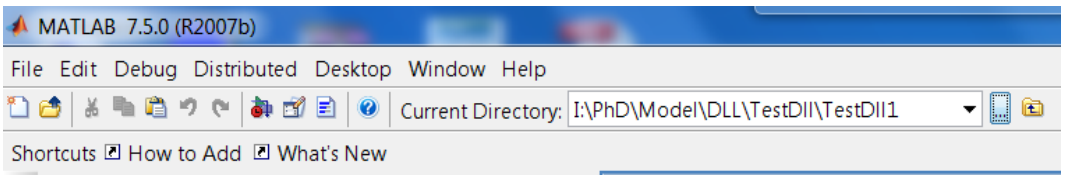


Figure 4.17: Place to define current directory path

5. Activate the 'Editor' window where, 'ensect_solve_glb.m' is loaded. To start the optimization, press the 'Run' ( ) button from the 'Editor' window (Figure 4.18). If the optimization for the initial time step works, then MATLAB will create an 'in.txt' file for the Vensim model.

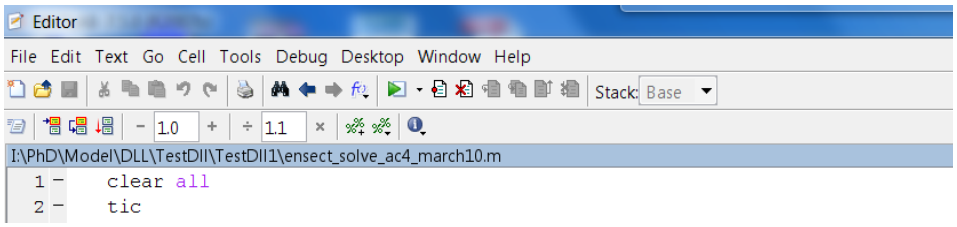


Figure 4.18: MATLAB 'Editor' window

6. Check the accuracy of the optimization by looking at the MATLAB 'Command Window' (Figure 4.19).

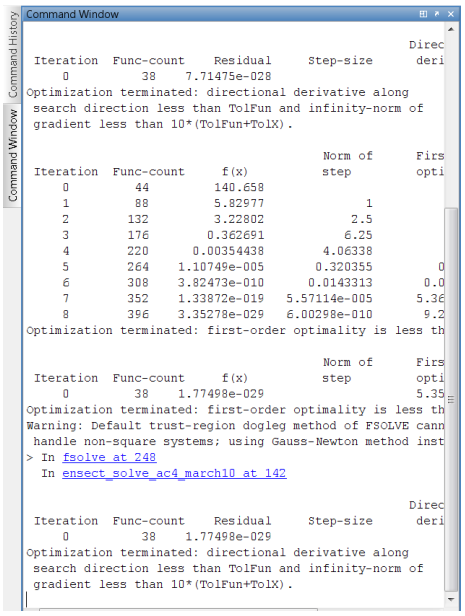


Figure 4.19: View of the MATLAB 'Command Window'

7. Open the Vensim model from the 'Start' menu (Figure 4.20).

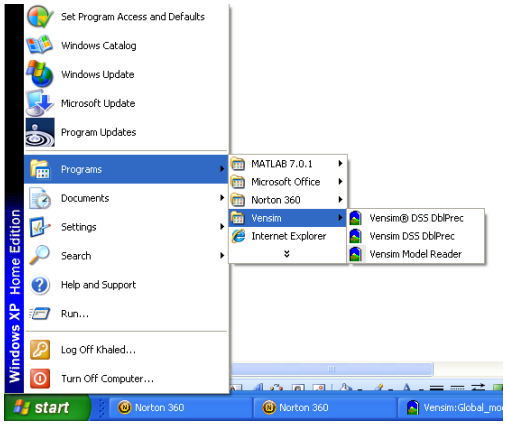


Figure 4.20: View of the 'Start Vensim'

8. Select 'Open Model' from the 'File' menu. Choose 'Global_model.mdl' file (Figure 4.21).

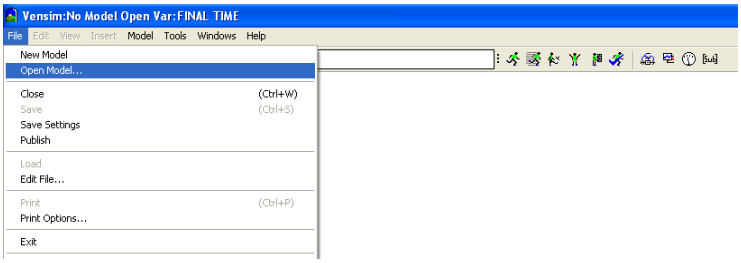


Figure 4.21: File menu of Vensim

9. From the 'Model' menu select 'Setting' option, to setup the 'Model Setting' option (Figure 4.22). This setup is required to define the simulation horizon as well as the computational time step (Figure 4.23). Press 'OK' to proceed further.

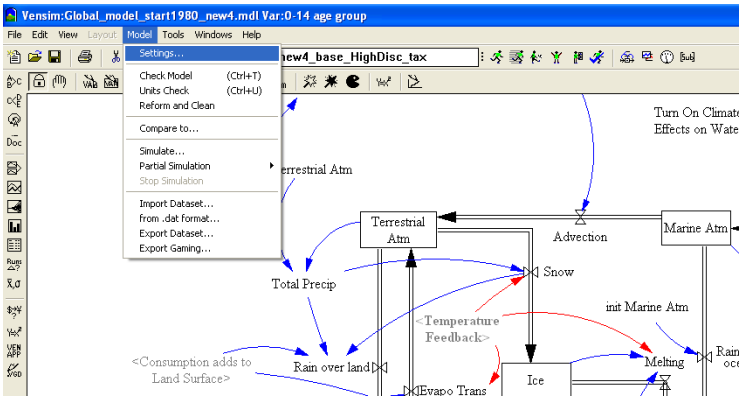


Figure 4.22: Model setting option of Vensim

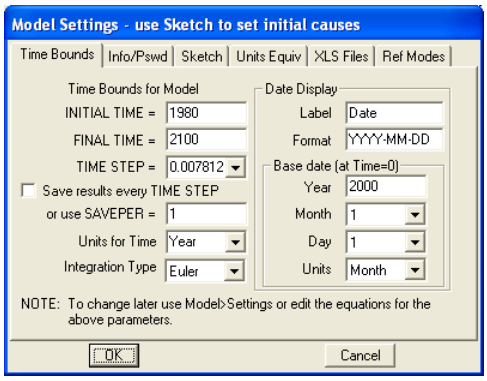


Figure 4.23: View of the 'Time bound option' under model setup option in Vensim

10. Check any specific parameter value or the model equation by using the equation button ( ). Select any parameter/variable/stock that maybe modified;

11. Before experimenting with the scenarios run a 'base run' to replicate the past and present observations, without the implementation of any new policy.

12. Enter the name for the base model run - for example 'Base' (Figure 4.24).

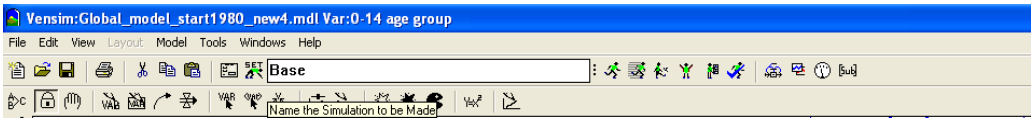


Figure 4.24: Option view to define the name of the simulation output file

13. Press the 'Run a Simulation' button ( ) to start the computation (Figure 4.25); and

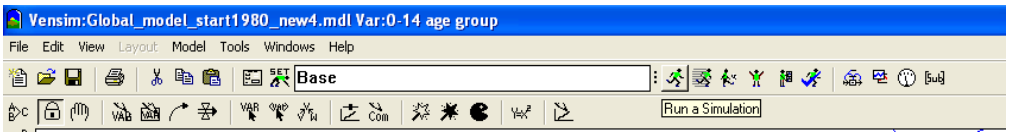


Figure 4.25: View of the 'Run a Simulation' option

14. After successful completion of a model simulation, the results can be reviewed by selecting a particulate variable from the 'Dataset Analysis Tools' menu bar (Figure 4.26). If the user wants to see the graphical view of a variable then the 'Graph' button should be selected. In the same way the numerical values can be obtained by selecting the 'Table' button.

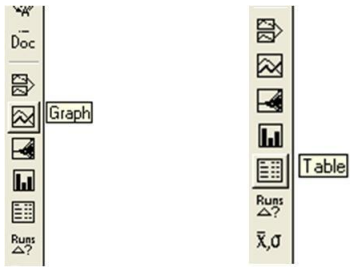


Figure 4.26: View of the dataset analysis tools

Regional Version of the ANEMI Model

1. For the regional model, access 'Regional' folder before carrying out the start of simulation process;

2. Open 'out_back.txt' file and save it as 'out.txt'.

3. Start MATLAB program first and then select 'Open' from the 'File' menu;

4. Navigate through the newly created folder (where all files copied from the supplied DVD are kept) and select 'ensect_solve_can_apr17_1.m' file.

5. Define the path to the working folder (where all files from the DVD are stored) in MATLAB environment.

6. To start the optimization, press the 'Run' () button in the 'Editor' window of MATLAB. If the optimization for the initial time step works fine then MATLAB will create an 'in.txt' file, which will then be used by Vensim.

7. Open the Vensim model from the 'start' menu.

8. From the 'File' menu select 'Open Model' and select the 'Regional Model.mdl' file.

9. Select 'Setting' option from the 'Model' menu to setup the 'Model Setting' option. This setup is required to define the simulation horizon and the computational time step.

10. Follow the same process from step 9 to step 14, presented for global version of the ANEMI model to complete the simulation.

4.4 Important Remarks

If something goes wrong during the simulation process, user will not be able to stop the Vensim software by only pressing ‘Escape’ key on the keyboard. As per the external function command, Vensim is forced to wait until it gets a new text file (in.txt). In such a situation, press ‘Escape’ key first and then open ‘b_in.txt’ file and save it as ‘in.txt’. Now, the decision can be made whether the result should be saved or not. The user can also choose to continue the simulation but the chance of having erroneous result is very high.

5 SIMULATIONS OF POLICY SCENARIOS

5.1 Scenario 1 – Increase in Water Use

The introduction of Scenario 1 is presented in Section 3.3.1 of this Manual. Here we present the procedure for implementing Scenario 1 in ANEMI simulations.

5.1.1 Scenario 1 Analysis With Global ANEMI Model

1. Open the ANEMI model (Global_model.mdl) using Vensim software;

2. Select the 'Water Demand' sector view (Figure 5.1), to implement the scenario by pressing 'page up' or 'Page Down' key of the key board;

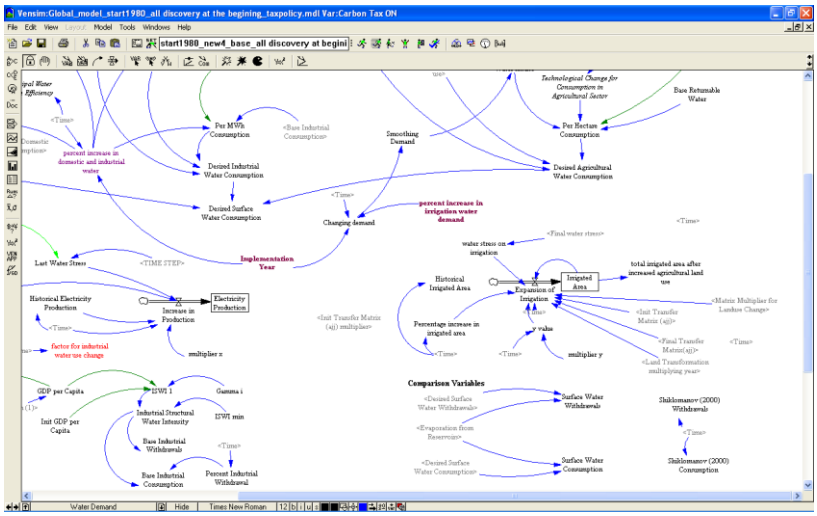


Figure 5.1: View of the 'water demand' sector

3. Select equation button ( ) first and then click on the 'percent increase in water demand' parameter to insert 15. Experimentation can be done by selecting other values too.

4. Select the starting year for this policy scenario in 'Implementation Year' option. For the purpose of this demonstration select 2015 as the 'Implementation Year'.

5. Save the model with a suitable name and close the Vensim program; and

6. Follow steps presented in Section 4.3.2 for running ANEMI global model to complete the simulation of Scenario 1.

5.1.2 Scenario 1 Analysis With ANEMI Regional Model

Regional version of ANEMI is focused on Canada and the detailed description is in Akhtar et al, 2011. Regional version of the ANEMI model has a close links with the rest of the world through climate, water, and energy-economy sectors. Therefore, some of the simulation results obtained from the implementation of global model are necessary for the simulation of the regional model.

1. Open the Global version of ANEMI model Scenario 1, to copy the 'Price of fossil fuel' from the 'Energy-Economy' sector. Select the 'price of fossil fuel' variable and then press on 'Table' button.

2. Export the content from the tabular view and 'paste' it in Microsoft Excel.

3. Open the 'Energy-Economy' view of the regional version of the ANEMI model (Regional Model.mdl).

4. Import the respective fossil fuel price from the Excel file containing global fuel price for Coal, Oil, and NaturalGas (Figure 5.2).

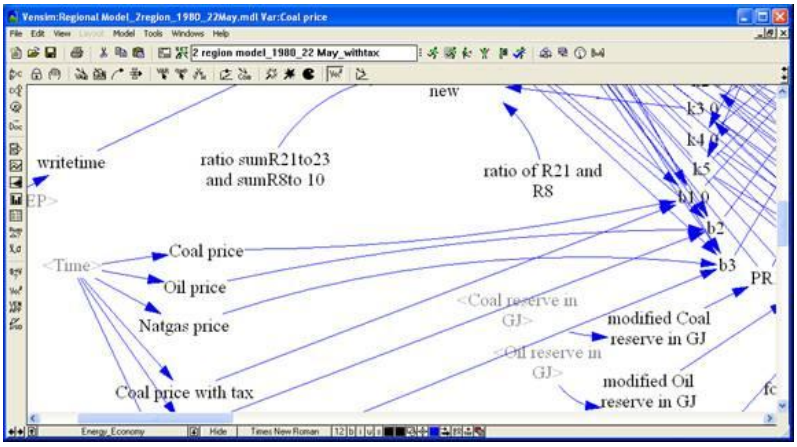


Figure 5.2: View of the 'energy-economy' sector, focusing on fossil fuel price

5. In the same way, export 'new industrial carbon emission', and 'GDP1' value from the 'Carbon' sector and 'Energy-Economy' sector of the global model, respectively.

6. Transfer extracted values as the 'Total Industrial Carbon emission' and 'Global GDP in trillion' in the regional version of the ANEMI model.

7. Select the 'Water Demand' sector view of the regional model to implement the Scenario 1 using 'Page Up' or 'Page Down' key (**Error! Reference source not found.**).

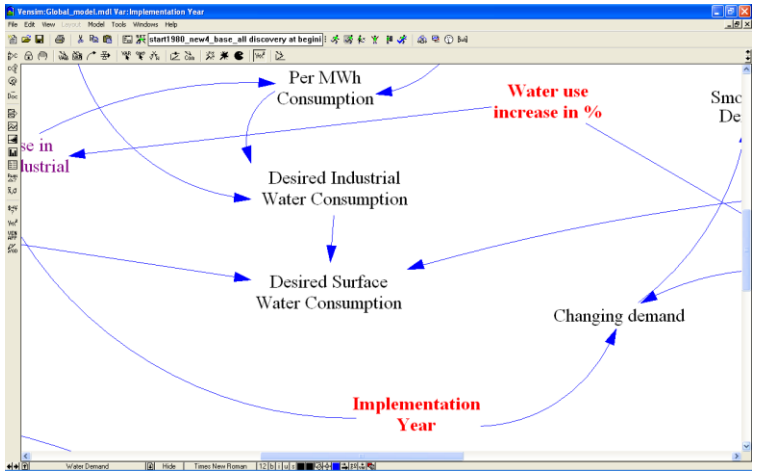


Figure 5.3: Parameters to implement Scenario 1 policy

7. Select equation button ( ) first and then click on the 'percent increase in water demand' to insert 15.

8. Choose the starting year for this policy implementation in the 'Implementation Year'.

9. Save the model with a suitable name and close the Vensim program; and

10. Follow the procedures from Section 4.3.2 for simulating the regional ANEMI model.

5.2 Scenario 2 – Increase in Food Production

The introduction of Scenario 2 is presented in Section 3.3.2 of the Manual. In this section the instructions are presented for simulating this scenario 2 with the ANEMI model.

5.2.1 Scenario 2 Analysis With Global ANEMI Model

1. Select the 'Land-Use' view (Figure 5.4), to implement Scenario 2.

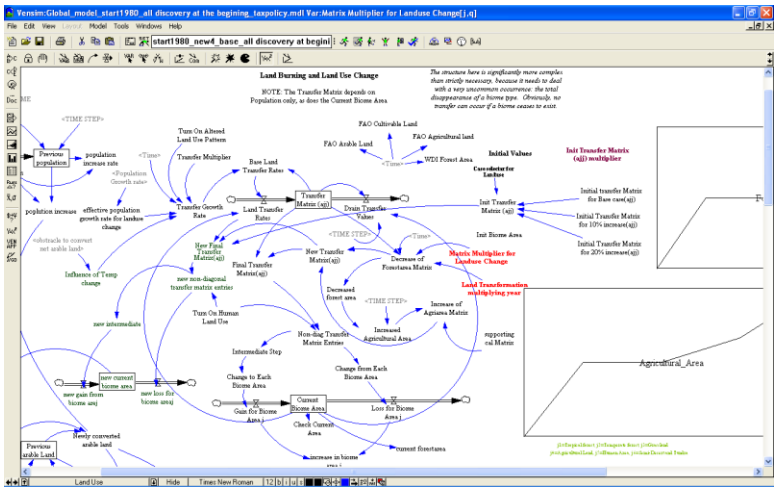


Figure 5.4: View of the 'Land-Use' sector

2. Select equation button ( ) first and then click on the 'Matrix Multiplier for Land use Change'.

3. Change the value of j1q1 to -0.15, which represents the additional land conversion from forest to agricultural land by 15% (Figure 5.5).

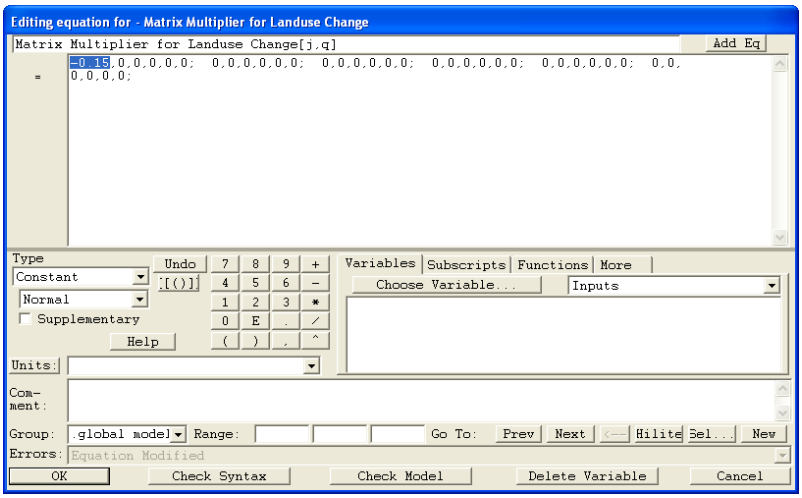


Figure 5.5: Option view to choose land transformation rate

4. Modify ‘Land transformation multiplying year’. For the purpose of this demonstration year 2015 in ‘Land transformation multiplying year’ is selected as the policy implementation year.

5. Save the model with a suitable name and close the Vensim program.

6. Carry out the simulation following the procedure presented in Section 4.3.2 for simulating the global version of ANEMI model.

5.2.2 Scenario 2 Analysis With Regional ANEMI Model

1. Open the Global version of ANEMI model which runs Scenario 2, to copy the simulated results of ‘Price of fossil fuel’ from the ‘Energy-Economy’ sector.

2. Export the values of ‘Price of fossil fuel’ variable to Microsoft Excel.

3. Open the ‘Energy-Economy’ view of the regional version of the ANEMI model.

4. Import the fossil fuel price from the Excel file with global fuel price for Coal, Oil, and NaturalGas (Figure 5.6).

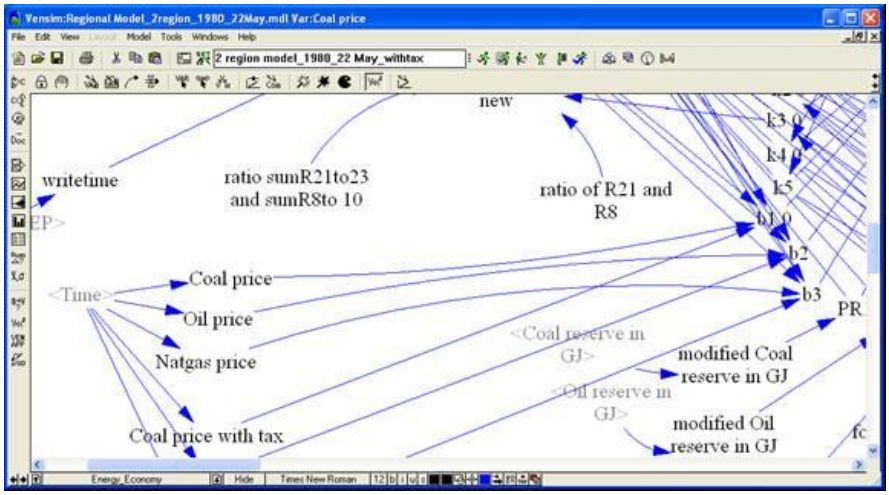


Figure 5.6: Fossil fuel price to be imported in the regional version of the ANEMI model

5. Export ‘New industrial Carbon Emission’, and ‘GDP1’ value from the ‘Carbon Sector’ and ‘Energy-Economy’ sector of the global model, respectively.

6. Transfer exported values to ‘Total Industrial Carbon Emission’ and ‘Global GDP in trillion’ of the regional version of the ANEMI model.

7. Open ‘Land-Use’ view (Figure 5.7), to implement the Scenario 2.

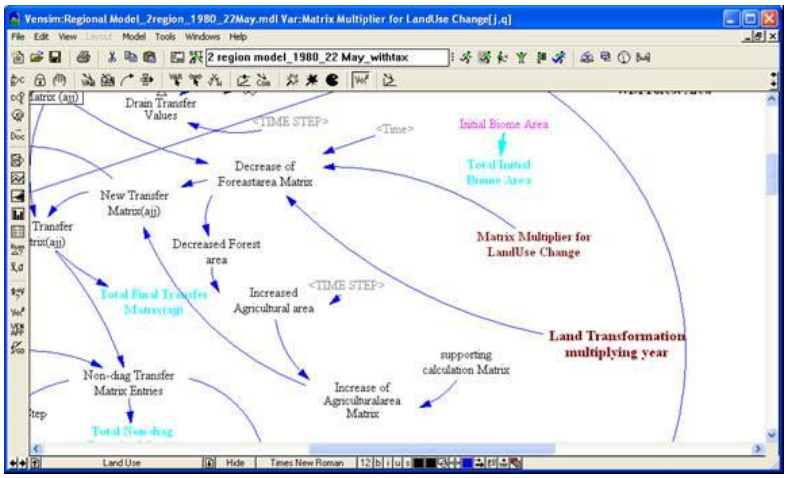


Figure 5.7: Parameters to implement with Scenario 2

8. Select equation button ( ) first and then click on the ‘Matrix Multiplier for Land-Use Change’.

9. In the ‘Matrix multiplier for land use change’ change the value of ‘j1q1’ to -0.15, (Figure 5.8).

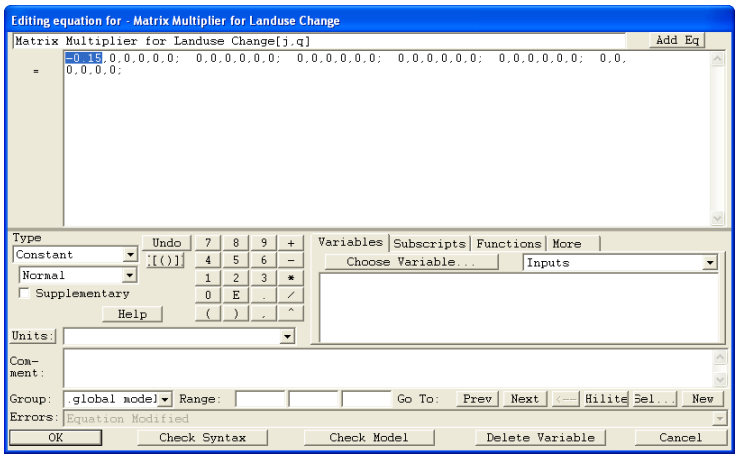


Figure 5.8: Option view to choose land use transformation rate (regional ANEMI model)

10. Change the ‘Land transformation multiplying year’.

11. Save the model with a suitable name and close the Vensim program.

12. Simulate Scenario 2 using procedure from the Section 4.3.2 for regional ANEMI model.

5.3 Scenario 3 - Carbon

The introduction of the carbon tax scenario is presented in Section 3.3.3 of this Manual. Here are the instructions for the implementation of the carbon tax scenario with the ANEMI model.

5.3.1 Scenario 3 Analysis With Global ANEMI Model

1. Select the ‘Energy-Economy’ view (Figure 5.9), to implement the scenario;

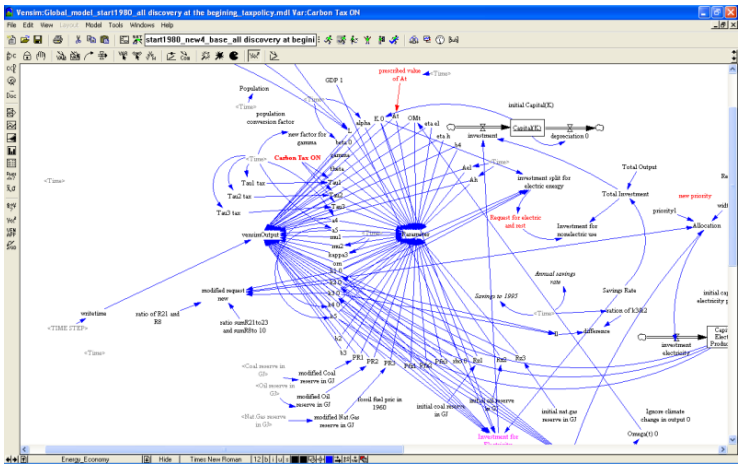


Figure 5.9: View of the 'Energy-Economy' sector

2. Select the equation button ( ) first and then click on the 'Carbon Tax ON' and replace '0' by '1' to activate the carbon tax policy (Figure 5.10);

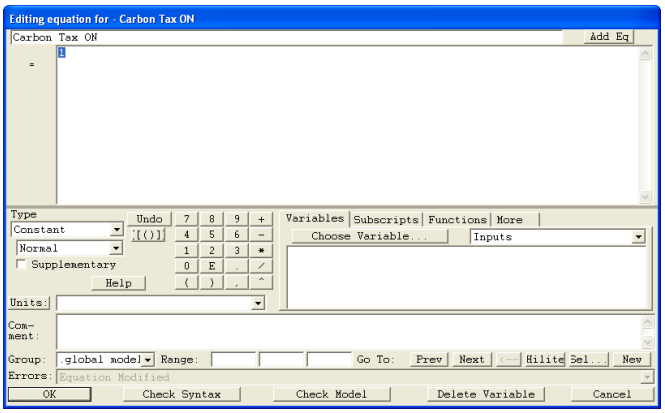


Figure 5.10: Option view to turn ON carbon tax policy

3. Select values for 'Tau1 tax', 'Tau2 tax', and 'Tau3 tax', as they represent the carbon tax for 'Coal', 'Oil' and 'NaturalGas' respectively (Figure 5.11). In this demonstration, equivalent amount of tax is implemented based on the emission intensity from each unit of fossil fuel. However, user can implement any type of tax policy.

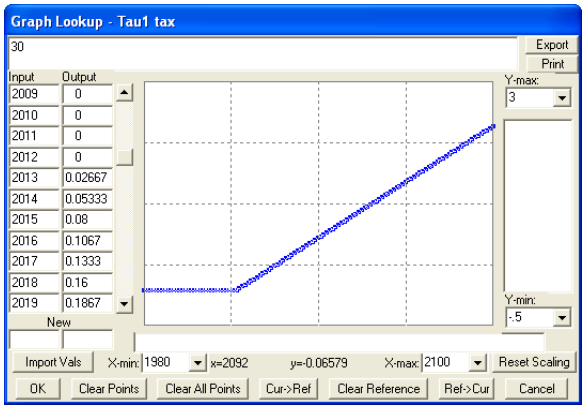


Figure 5.11: Look-up table for carbon tax rate input

4. Save the model with a suitable name and close the Vensim program; and

5. Complete the simulation using the procedure presented in Section 4.3.2 for global ANEMI model.

5.3.2 Scenario 3 Analysis With Regional ANEMI Model

1. Open the Global version of ANEMI model which runs Scenario 3, and copy the 'Price of Fossil Fuel' from the 'Energy-Economy' sector. Select the 'Price of Fossil Fuel' variable and then press the 'Table' button;

2. Copy the global fossil fuel price in Microsoft Excel;

3. Open the 'Energy-Economy' view of the regional version of the ANEMI model;

4. Import the respective fossil fuel price from the Excel file containing global fuel price with tax for Coal, Oil, and NaturalGas (Figure 5.12);

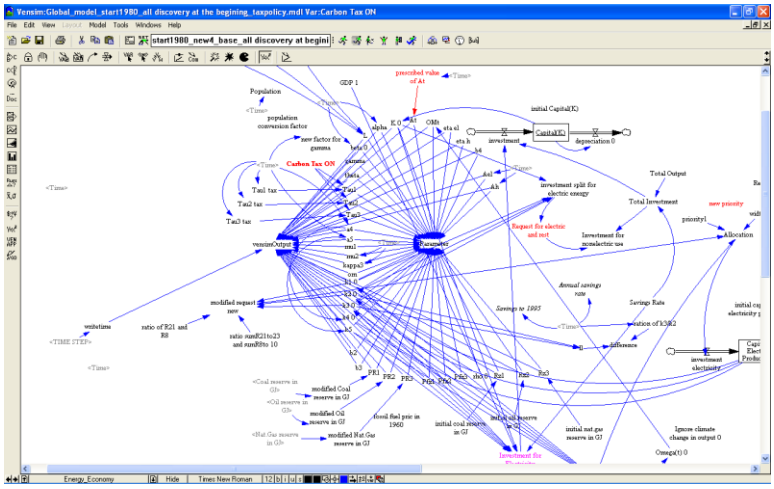


Figure 5.12: View of the regional 'Energy-Economy' sector

5. Select equation button ( ) and then click on the 'Carbon Tax ON' and replace '0' by '1' to activate the carbon tax policy (Figure 5.13);

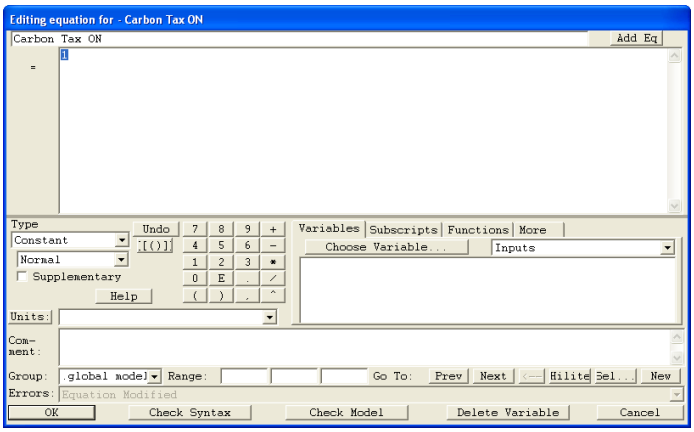


Figure 5.13: Option window to turn ON carbon tax for the regional version of ANEMI model

6. Review/modify 'Tau1 tax', 'Tau2 tax', and 'Tau3 tax' (Figure 5.14), as they represent the carbon tax for 'Coal', 'Oil' and 'NaturalGas' respectively. It is advised to use the same tax policy with global and regional versions of the ANEMI model. In this experiment equivalent amount of tax is implemented based on the emission intensity from each unit of fossil fuel. Any other tax policy can be implemented.

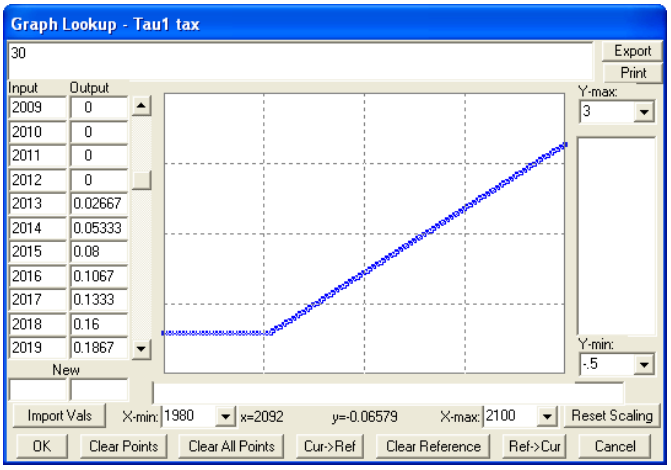


Figure 5.14: Look-up table for 'Carbon Tax' rate input in the regional version of ANEMI model

7. Export 'Total Industrial Emission' and 'GDP' values into the regional ANEMI model.

8. Save the model with a suitable name and close the Vensim program.

9. Complete the simulation using procedure from the Section 4.3.2 for simulation of regional ANEMI model.

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APPENDIX A: ANEMI MODEL CODE (MATLAB)

Global ANEMI Model

List of Variables

Y	Total output
E	Aggregate energy services
Eh	Heat energy services
El	Electric energy services
Fh1	Coal used in heat energy production (GJ)
Fh2	Oil used in heat energy production (GJ)
Fh3	Natural gas used in heat energy production (GJ)
Fe1	Coal used in electricity production (GJ)
Fe2	Oil used in electricity production (GJ)
Fe3	Natural gas used in electricity production (GJ)
r	Gross interest rate
w	Wage rate
Pe	Price of aggregate energy services
Ph	Price of heat energy services
Pel	Price of electricity services
e4	electricity produced from nuclear power
e5	electricity produced from hydro power
FC1	Price of coal
FC2	Price of oil
FC3	Price of natural gas
TCe1	Total cost of electricity produced from coal

TCe2	Total cost of electricity produced from oil
TCe3	Total cost of electricity produced from natural gas
TCh1	Total cost of heat energy produced from coal
TCh2	Total cost of heat energy produced from oil
TCh3	Total cost of heat energy produced from natural gas
a1	CES weight for coal
a2	CES weight for oil
a3	CES weigth for natural gas
a1p	Short hand term for CES weight calculation for coal
a2p	Short hand term for CES weight calculation for oil
a3p	Short hand term for CES weight calculation for natural gas
Fh4	Alternative heat energy (GJ)
FC4	Price of alternatie heat energy
TCh4	Total cost of heat energy produced from alternative energy
short_El	Short hand term for electricity calculations
short_H	Short hand term for heat energy calculations

List of Parameters

gam1	Parameter for CES weight function for coal
gam2	Parameter for CES weight function for oil
gam3	Parameter for CES weight function for natural gas
b1	CES weight for coal
b2	CES weight for oil
b3	CES weight for natural gas
b4	CES weight for alternative heat energy
Pfz1	Base year price for coal
Pfz2	Base year price for oil
Pfz3	Base year price for natural gas
PR1	Current reserve value for coal
PR2	Current reserve value for oil
PR3	Current reserve value for natural gas
Rz1	Base year reserve value for coal
Rz2	Base year reserve value for oil
Rz3	Base year reserve value for natural gas
alpha	Capital's share
beta	Labour's share
gamma	Share parameter for energy aggregation
rho	Elasticity parameter for fossil fuel price function
theta	Elasticity parameter for energy aggregation
At	Total Factor Productivity
OMt	Nordhaus damage coefficient
L	Labour force

a4	Prescribed nuclear energy
a5	Prescribed hydro power
mu1	Parameter for alternative heat energy price function
mu2	Parameter for alternative heat energy price function
eta_e	Elasticity parameter for electricity production
eta_h	Elasticity paramater for heat energy production
om	Scale parameter for CES weights in electricity production
Ael	Electricity specific productivity term
Ah	Heat energy specific productivity term
tau1	Carbon tax rate for coal
tau2	Carbon tax rate for oil
tau3	Carbon tax rate for natural gas
nh_weight	CES weight for nuclear and hydro power

Solver File

This file is the primary 'solver file' used for the global ANEMI model. It takes inputs from Vensim, calls the appropriate function, and produces the solution to the one-period energy-economy model.

```
clear all

tic

 options1=optimset('FunValCheck','on', 'TolX',1.0e-9, 'TolFun',1.0e-9, 'MaxFunEvals',1.0e+9, ...

   'MaxIter',0.100e+3, 'Display', 'iter', 'NonlEqnAlgorithm','dogleg');

 options2=optimset('FunValCheck','on', 'TolX',1.0e-12, 'TolFun',1.0e-12, 'MaxFunEvals',1.0e+12, ...

   'MaxIter',0.501e+3, 'Display', 'iter', 'NonlEqnAlgorithm','lm');


n=121;

time = linspace(1,n,121);

flag_vect = zeros(1,n);

par_check = zeros(37,n);

count2 = 1;

 par_mat = xlsread('par_values_1.xls');

eng_mat = xlsread('eng_values.xls');

 x0_cal = [2.91358474058133,2.06326283606995,1.62053847133827,4.11331109535488,-
0.301549557940114,0.194442342794547,-0.571260880029906,-2.17853176565763,-3.05841668528190,-3.90908781731049,-
1.85915914556616,1.48589400409797,-1.73994526093445,-1.62394359422644,-5.06755448357096,-3.71373791361643,-
2.71449037441833,-1.43801570954409,-0.533396790576313,-1.66283102760545,-2.04851166542617,-2.86752553959320,-
4.11858835525487,-1.73956526748421,-0.338954447781766,-
2.23409190763535,2.28985770205577,3.60298287203739,3.40364624800653,2.68549220816011,4.43877201412756,4.66470
844434739,-4.25209931331017,-2.31939186808372,-6.57149118139387,2.05665554767744,-
0.341023310827887,5.50885453934179,6.82192669034317,6.62260568833010,-1.58600226800754,-0.987779581613031,-
1.83169529110752];

cap = [35,0.655,0.188,0.080,0.352,0.823];

eng = eng_mat(1,:);

par = par_mat(1,:);

 [xout_cal, fval, flag] = fsolve('energysect_glb_cal', x0_cal, options1, par, cap, eng);

if flag ~= 1

[xout_cal, fval, flag2] = fsolve('energysect_glb_cal', xout_cal, options2, par, cap, eng);

end

 y = exp(xout_cal);
```

```
x0 = xout_cal(1,1:37);

x0_cal  = xout_cal;

outmat(:,1) = y;

par_check(:,1) = par;

x0_zo = x0_cal(1,1:37);

par_ff = [y(1,9), y(1,28),y(1,31)];

par(1,1:6) = exp(x0_cal(1,38:43));

[xt_zo, fval, flag] = fsolve('energysect_glb_zo', x0_zo, options1, par, par_ff, cap);

if flag ~= 1

[xt_zo, fval, flag] = fsolve('energysect_glb_zo', x0_zo, options2, par, par_ff, cap);

end

x0_zo=xt_zo;

 for i=1:n

    filename ='out.txt';

   mmfile = -1;

   while(mmfile == -1)

      pause(5);

      mmfile = fopen(filename,'r');

   end

    par=fscanf(mmfile,'%e',[1 34]);

   cap=fscanf(mmfile,'%e',[1 6]);

   fclose(mmfile);

   delete('out.txt');

    eng = eng_mat(i,:);

   par(1,35:37) = par(1,1:3);

  if i<26

      [xout_cal, fval, flag] = fsolve('energysect_glb_cal', x0_cal, options1, par, cap, eng);

      if flag ~= 1

      [xout_cal, fval, flag2] = fsolve('energysect_glb_cal', xout_cal, options2, par, cap, eng);

      end

       y = exp(xout_cal);
```

```
    x0_cal=xout_cal;
    x0 = x0_cal(1,1:37);
    outmat(:,i) = y;
end
if i<26
    par(1,1:6) = outmat(38:43,i);
else
    par(1,1:6) = outmat(38:43,i-1).*(1 + 0.95*(outmat(38:43,i-1)-outmat(38:43,i-2))./outmat(38:43,i-2));
end
par_check(:,i) = par;
cap_check(:,i) = cap;
if  count2 > 1 || exp(x0(1,9)) < 0.015
    par_ff(1,1) = 0.015;
    par_ff(1,2) = outmat(28,i-1);
    par_ff(1,3) = outmat(31,i-1);
    [xt, fval, flag] = fsolve('energysect_glb_zo', x0, options1, par, par_ff, cap);
    if flag ~= 1
    [xt, fval, flag] = fsolve('energysect_glb_zo', x0, options2, par, par_ff, cap);
    end
    x0=xt;
    y=exp(xt);
    outmat(1:37,i) = y;
    outmat(38:43,i) = par(1,1:6);
    count2 = count2+1;
else

    x0_mat(:,i) = x0;
    [xout, fval, flag] = fsolve('energysect_glb', x0, options1, par, cap);
    if flag ~= 1
    [xout, fval, flag] = fsolve('energysect_glb', xout, options2, par, cap);
    end
```

```
    y=exp(xout);
    x0=xout;
    x0 = x0_mat(:,i)';
    par_ff = [y(1,9), y(1,28), y(1,31)];
    [xt, fval, flag] = fsolve('energysect_glb_zo', x0, options1, par, par_ff, cap);
    if flag ~= 1
    [xt, fval, flag] = fsolve('energysect_glb_zo', xt, options2, par, par_ff, cap);
    end
    x0=xt;
    yt=exp(xt);
    outmat(1:37,i) = yt;
    outmat(38:43,i) = par(1,1:6);
end

flag_vect(1,i) = flag;
fval_vect(1,i) = mean(abs(fval));
fval_mat(:,i) = fval;
y = outmat(1:37,i);
filename ='in.txt';
mmfile = fopen(filename,'w');
if ( mmfile == -1 )
    disp(filename);
    error('File not found');
end;
aa =fprintf(mmfile,'%e\n', y);
fclose(mmfile);
filename ='b_in.txt';
mmfile = fopen(filename,'w');
if ( mmfile == -1 )
    disp(filename);
    error('File not found');
```

```
    end;
    aa =fprintf(mmfile,'%e\n', y);
    fclose(mmfile);
end

toc
```

Main Function File

The main function file for MATLAB solves the one-period problem for the global model. It is a non-linear system of 37 equations and variables.

```
function z = energysect_glb(y,par,cap)
 %variables
Y = y(1,1);
E = y(1,2);
Eh = y(1,3);
El = y(1,4);
Fh1 = y(1,5);
Fh2 = y(1,6);
Fh3 = y(1,7);
Fe1 = y(1,8);
Fe2 = y(1,9);
Fe3 = y(1,10);
r = y(1,11);
w = y(1,12);
Pe = y(1,13);
Ph = y(1,14);
Pel = y(1,15);
e4 = y(1,16);
e5 = y(1,17);
FC1 = y(1,18);
FC2 = y(1,19);
FC3 = y(1,20);
TCe1 = y(1,21);
TCe2 = y(1,22);
```

```
TCe3 = y(1,23);

TCh1 = y(1,24);

TCh2 = y(1,25);

TCh3 = y(1,26);

a1 = y(1,27);

a2 = y(1,28);

a3 = y(1,29);

a1p = y(1,30);

a2p = y(1,31);

a3p = y(1,32);

Fh4 = y(1,33);

FC4 = y(1,34);

TCh4 = y(1,35);

short_El = y(1,36);

short_H = y(1,37);


 %capital

K = cap(1,1);

k1= cap(1,2);

k2= cap(1,3);

k3= cap(1,4);

k4= cap(1,5);

k5= cap(1,6);


%parameters

gam1 = par(1,1);

gam2 = par(1,2);

gam3 = par(1,3);

b1 = par(1,4);
```

```
b2 = par(1,5);

b3 = par(1,6);

Pfz1 = par(1,7);

Pfz2 = par(1,8);

Pfz3 = par(1,9);

PR1 = par(1,10);

PR2 = par(1,11);

PR3 = par(1,12);

Rz1 = par(1,13);

Rz2 = par(1,14);

Rz3 = par(1,15);

alpha = par(1,16);

beta = par(1,17);

gamma = par(1,18);

rho = par(1,19);

theta = par(1,20);

At  = par(1,21);

OMt = par(1,22);

L = par(1,23);

a4 = par(1,24);

a5 = par(1,25);

b4 = par(1,26);

mu1 = par(1,27);

mu2 = par(1,28);

kap3 = par(1,29);

eta_e = par(1,30);

eta_h = par(1,31);

om = par(1,32);

Ael = par(1,33);
```

```
Ah = par(1,34);

tau1 = par(1,35);

tau2 = par(1,36);

tau3 = par(1,37);

nh_weight = 0.25;


% Energy economy

z(1) = exp(Y) - OMt*At*K.^alpha*L.^beta*exp(E).^(1-alpha-beta);

z(2) = alpha*L*exp(w) - beta*K*exp(r);

z(3) = alpha*exp(E)*exp(Pe) - (1-alpha-beta)*K*exp(r);

z(4) = exp(Y) + tau1*(exp(Fe1) + exp(Fh1)) + tau2*(exp(Fe2) + exp(Fh2)) + tau3*(exp(Fe3) + exp(Fh3)) - exp(r)*(K) - exp(w)*L -
exp(Pe)*exp(E);


% Aggregation of energy services

z(5) = exp(E) - (gamma*exp(Eh).^theta + (1-gamma)*exp(El).^theta).^(1./theta);

z(6) = gamma*exp(Pel)*exp(El)^(1-theta) - (1-gamma)*exp(Ph)*exp(Eh).^(1-theta);

z(7) = exp(Pe)*exp(E) - exp(Ph)*exp(Eh) - exp(Pel)*exp(El);


% Electricity production

z(8) = exp(El) - Ael*(exp(a1)*exp(Fe1).^eta_e + exp(a2)*exp(Fe2).^eta_e + exp(a3)*exp(Fe3).^eta_e +
nh_weight*exp(e4).^eta_e + nh_weight*exp(e5).^eta_e).^(1./eta_e);

z(9) = exp(Pel) - (exp(TCe1) + exp(TCe2) + exp(TCe3) + exp(r)*k4 + exp(r)*k5)./exp(El);

z(10) = ((exp(FC1) - (exp(FC1)-tau1)*exp(Fe1)*rho./(PR1-exp(Fe1)-exp(Fh1)))*(exp(short_El)./exp(a1p)) - exp(TCe1)) ...

    - ((exp(FC2) - (exp(FC2)-tau2)*exp(Fe2)*rho./(PR2-exp(Fe2)-exp(Fh2)))*(exp(short_El)./exp(a2p)) - exp(TCe2));

z(11) = ((exp(FC2) - (exp(FC2)-tau2)*exp(Fe2)*rho./(PR2-exp(Fe2)-exp(Fh2)))*(exp(short_El)./exp(a2p)) - exp(TCe2)) ...

    - ((exp(FC3) - (exp(FC3)-tau3)*exp(Fe3)*rho./(PR3-exp(Fe3)-exp(Fh3)))*(exp(short_El)./exp(a3p)) - exp(TCe3));


% Heat energy production

z(12) = exp(Eh) - Ah*(b1*exp(Fh1).^eta_h + b2*exp(Fh2).^eta_h + b3*exp(Fh3).^eta_h + b4*exp(Fh4).^eta_h).^(1./eta_h);

z(13) = exp(Ph) - (exp(TCh1) + exp(TCh2) + exp(TCh3) +  exp(TCh4))./exp(Eh);
```

```
z(14) = ((exp(FC1) - (exp(FC1)-tau1)*exp(Fh1)*rho./(PR1-exp(Fe1)-exp(Fh1)))*(exp(short_H)./(b1*exp(Fh1).^(eta_h-1))) -
exp(TCh1)) ...

    - ((exp(FC2) - (exp(FC2)-tau2)*exp(Fh2)*rho./(PR2-exp(Fe2)-exp(Fh2)))*(exp(short_H)./(b2*exp(Fh2).^(eta_h-1))) -
exp(TCh2));

z(15) = ((exp(FC2) - (exp(FC2)-tau2)*exp(Fh2)*rho./(PR2-exp(Fe2)-exp(Fh2)))*(exp(short_H)./(b2*exp(Fh2).^(eta_h-1))) -
exp(TCh2)) ...

    - ((exp(FC3) - (exp(FC3)-tau3)*exp(Fh3)*rho./(PR3-exp(Fe3)-exp(Fh3)))*(exp(short_H)./(b3*exp(Fh3).^(eta_h-1))) -
exp(TCh3));

z(16) = ((exp(FC3) - (exp(FC3)-tau3)*exp(Fh3)*rho./(PR3-exp(Fe3)-exp(Fh3)))*(exp(short_H)./(b3*exp(Fh3).^(eta_h-1))) -
exp(TCh3)) ...

    - ((1+mu2)*exp(FC4)*(exp(short_H)./(b4*exp(Fh4).^(eta_h-1))) - exp(TCh4));


% Nuclear and hydro electricity production

z(17) = exp(e4) - a4;

z(18) = exp(e5) - a5;


%Fuel prices

z(19) = exp(FC1) - tau1 - Pfz1*((PR1-exp(Fe1)-exp(Fh1))./Rz1).^rho;

z(20) = exp(FC2) - tau2 - Pfz2*((PR2-exp(Fe2)-exp(Fh2))./Rz2).^rho;

z(21) = exp(FC3) - tau3 - Pfz3*((PR3-exp(Fe3)-exp(Fh3))./Rz3).^rho;


% Total cost functions for electricity

z(22) = exp(TCe1) - exp(r)*k1 - exp(Fe1)*exp(FC1);

z(23) = exp(TCe2) - exp(r)*k2 - exp(Fe2)*exp(FC2);

z(24) = exp(TCe3) - exp(r)*k3 - exp(Fe3)*exp(FC3);


% Total cost functions for heat energy

z(25) = exp(TCh1) - exp(Fh1)*exp(FC1);

z(26) = exp(TCh2) - exp(Fh2)*exp(FC2);

z(27) = exp(TCh3) - exp(Fh3)*exp(FC3);

z(28) = exp(TCh4) - exp(Fh4)*exp(FC4);
```

% CES weights for electricity production

z(29) = exp(a1) - (1./om)*(gam1 - (exp(Fe1)./k1).^2);

z(30) = exp(a2) - (1./om)*(gam2 - (exp(Fe2)./k2).^2);

z(31) = exp(a3) - (1./om)*(gam3 - (exp(Fe3)./k3).^2);

z(32) = exp(Fe1).^(1-eta_e)*exp(a1p) - (exp(a1)*eta_e - (2./om)*(exp(Fe1)./k1).^2);

z(33) = exp(Fe2).^(1-eta_e)*exp(a2p) - (exp(a2)*eta_e - (2./om)*(exp(Fe2)./k2).^2);

z(34) = exp(Fe3).^(1-eta_e)*exp(a3p) - (exp(a3)*eta_e - (2./om)*(exp(Fe3)./k3).^2);

% Alternative Heat Energy Price Function

z(35) = exp(FC4) - mu1 - exp(Fh4).^mu2;

% Short-hand expressions

z(36) = exp(short_El) - (eta_e)*(exp(a1)*exp(Fe1).^eta_e + exp(a2)*exp(Fe2).^eta_e + exp(a3)*exp(Fe3).^eta_e + nh_weight*exp(e4).^eta_e + nh_weight*exp(e5).^eta_e);

z(37) = exp(short_H) - (b1*exp(Fh1).^eta_h + b2*exp(Fh2).^eta_h + b3*exp(Fh3).^eta_h + b4*exp(Fh4).^eta_h);

Calibration Function File

The calibration function file for MATLAB solves the one-period problem for the global model, and matches the historical trend for fossil fuel consumption in heat energy and electricity production.

```
function z = energysect_glb_cal(y,par,cap,eng)
%variables
Y = y(1,1);
E = y(1,2);
Eh = y(1,3);
El = y(1,4);
Fh1 = y(1,5);
Fh2 = y(1,6);
Fh3 = y(1,7);
Fe1 = y(1,8);
Fe2 = y(1,9);
Fe3 = y(1,10);
r = y(1,11);
w = y(1,12);
Pe = y(1,13);
Ph = y(1,14);
Pel = y(1,15);
e4 = y(1,16);
e5 = y(1,17);
FC1 = y(1,18);
FC2 = y(1,19);
FC3 = y(1,20);
TCe1 = y(1,21);
TCe2 = y(1,22);
```

```
TCe3 = y(1,23);

TCh1 = y(1,24);

TCh2 = y(1,25);

TCh3 = y(1,26);

a1 = y(1,27);

a2 = y(1,28);

a3 = y(1,29);

a1p = y(1,30);

a2p = y(1,31);

a3p = y(1,32);

Fh4 = y(1,33);

FC4 = y(1,34);

TCh4 = y(1,35);

short_El = y(1,36);

short_H = y(1,37);

 gam1 = y(1,38);

gam2 = y(1,39);

gam3 = y(1,40);

b1 = y(1,41);

b2 = y(1,42);

b3 = y(1,43);


%capital

K = cap(1,1);

k1= cap(1,2);

k2= cap(1,3);

k3= cap(1,4);

k4= cap(1,5);

k5= cap(1,6);
```

```
%parameters
 Pfz1 = par(1,7);
Pfz2 = par(1,8);
Pfz3 = par(1,9);
PR1 = par(1,10);
PR2 = par(1,11);
PR3 = par(1,12);
Rz1 = par(1,13);
Rz2 = par(1,14);
Rz3 = par(1,15);
alpha = par(1,16);
beta = par(1,17);
gamma = par(1,18);
rho = par(1,19);
theta = par(1,20);
At  = par(1,21);
OMt = par(1,22);
L = par(1,23);
a4 = par(1,24);
a5 = par(1,25);
b4 = par(1,26);
mu1 = par(1,27);
mu2 = par(1,28);
kap3 = par(1,29);
eta_e = par(1,30);
eta_h = par(1,31);
om = par(1,32);
Ael = par(1,33);
Ah = par(1,34);
```

```
tau1 = par(1,35);

tau2 = par(1,36);

tau3 = par(1,37);

e1 = eng(1,1);

e2 = eng(1,2);

e3 = eng(1,3);

share_he1 = eng(1,4);

share_he2 = eng(1,5);

share_he3 = eng(1,6);

nh_weight = 0.25;


% Energy economy

z(1) = exp(Y) - OMt*At*K.^alpha*L.^beta*exp(E).^(1-alpha-beta);

z(2) = alpha*L*exp(w) - beta*K*exp(r);

z(3) = alpha*exp(E)*exp(Pe) - (1-alpha-beta)*K*exp(r);

z(4) = exp(Y) + tau1*(exp(Fe1) + exp(Fh1)) + tau2*(exp(Fe2) + exp(Fh2)) + tau3*(exp(Fe3) + exp(Fh3)) - exp(r)*(K) - exp(w)*L -
exp(Pe)*exp(E);


% Production of energy services

z(5) = exp(E) - (gamma*exp(Eh).^theta + (1-gamma)*exp(El).^theta).^(1./theta);

z(6) = gamma*exp(Pel)*exp(El)^(1-theta) - (1-gamma)*exp(Ph)*exp(Eh).^(1-theta);

z(7) = exp(Pe)*exp(E) - exp(Ph)*exp(Eh) - exp(Pel)*exp(El);


% Electricity production

z(8) = exp(El) - Ael*(exp(a1)*exp(Fe1).^eta_e + exp(a2)*exp(Fe2).^eta_e + exp(a3)*exp(Fe3).^eta_e +
nh_weight*exp(e4).^eta_e + nh_weight*exp(e5).^eta_e).^(1./eta_e);

z(9) = exp(Pel) - (exp(TCe1) + exp(TCe2) + exp(TCe3) + exp(r)*k4 + exp(r)*k5)./exp(El);

z(10) = ((exp(FC1) - (exp(FC1)-tau1)*exp(Fe1)*rho./(PR1-exp(Fe1)-exp(Fh1)))*(exp(short_El)./exp(a1p)) - exp(TCe1)) ...

    - ((exp(FC2) - (exp(FC2)-tau2)*exp(Fe2)*rho./(PR2-exp(Fe2)-exp(Fh2)))*(exp(short_El)./exp(a2p)) - exp(TCe2));

z(11) = ((exp(FC2) - (exp(FC2)-tau2)*exp(Fe2)*rho./(PR2-exp(Fe2)-exp(Fh2)))*(exp(short_El)./exp(a2p)) - exp(TCe2)) ...
```

```
    - ((exp(FC3) - (exp(FC3)-tau3)*exp(Fe3)*rho./(PR3-exp(Fe3)-exp(Fh3)))*(exp(short_El)./exp(a3p)) - exp(TCe3));


% Heat energy production

z(12) = exp(Eh) - Ah*(exp(b1)*exp(Fh1).^eta_h + exp(b2)*exp(Fh2).^eta_h + exp(b3)*exp(Fh3).^eta_h +
b4*exp(Fh4).^eta_h).^(1./eta_h);

z(13) = exp(Ph) - (exp(TCh1) + exp(TCh2) + exp(TCh3) +  exp(TCh4))./exp(Eh);

z(14) = ((exp(FC1) - (exp(FC1)-tau1)*exp(Fh1)*rho./(PR1-exp(Fe1)-exp(Fh1)))*(exp(short_H)./(exp(b1)*exp(Fh1).^(eta_h-1))) -
exp(TCh1)) ...

    - ((exp(FC2) - (exp(FC2)-tau2)*exp(Fh2)*rho./(PR2-exp(Fe2)-exp(Fh2)))*(exp(short_H)./(exp(b2)*exp(Fh2).^(eta_h-1))) -
exp(TCh2));

z(15) = ((exp(FC2) - (exp(FC2)-tau2)*exp(Fh2)*rho./(PR2-exp(Fe2)-exp(Fh2)))*(exp(short_H)./(exp(b2)*exp(Fh2).^(eta_h-1))) -
exp(TCh2)) ...

    - ((exp(FC3) - (exp(FC3)-tau3)*exp(Fh3)*rho./(PR3-exp(Fe3)-exp(Fh3)))*(exp(short_H)./(exp(b3)*exp(Fh3).^(eta_h-1))) -
exp(TCh3));

z(16) = ((exp(FC3) - (exp(FC3)-tau3)*exp(Fh3)*rho./(PR3-exp(Fe3)-exp(Fh3)))*(exp(short_H)./(exp(b3)*exp(Fh3).^(eta_h-1))) -
exp(TCh3)) ...

    - ((1+mu2)*exp(FC4)*(exp(short_H)./(b4*exp(Fh4).^(eta_h-1))) - exp(TCh4));


% Nuclear and hydro electricity production

z(17) = exp(e4) - a4;

z(18) = exp(e5) - a5;


%Fuel prices

z(19) = exp(FC1) - tau1 - Pfz1*((PR1-exp(Fe1)-exp(Fh1))./Rz1).^rho;

z(20) = exp(FC2) - tau2 - Pfz2*((PR2-exp(Fe2)-exp(Fh2))./Rz2).^rho;

z(21) = exp(FC3) - tau3 - Pfz3*((PR3-exp(Fe3)-exp(Fh3))./Rz3).^rho;


% Total cost functions for electricity

z(22) = exp(TCe1) - exp(r)*k1 - exp(Fe1)*exp(FC1);

z(23) = exp(TCe2) - exp(r)*k2 - exp(Fe2)*exp(FC2);

z(24) = exp(TCe3) - exp(r)*k3 - exp(Fe3)*exp(FC3);
```

```
% Total cost functions for heat energy

z(25) = exp(TCh1) - exp(Fh1)*exp(FC1);

z(26) = exp(TCh2) - exp(Fh2)*exp(FC2);

z(27) = exp(TCh3) - exp(Fh3)*exp(FC3);

z(28) = exp(TCh4) - exp(Fh4)*exp(FC4);


% CES weights for electricity production

z(29) = exp(a1) - (1./om)*(exp(gam1) - (exp(Fe1)./k1).^2);

z(30) = exp(a2) - (1./om)*(exp(gam2) - (exp(Fe2)./k2).^2);

z(31) = exp(a3) - (1./om)*(exp(gam3) - (exp(Fe3)./k3).^2);

z(32) = exp(Fe1).^(1-eta_e)*exp(a1p) - (exp(a1)*eta_e - (2./om)*(exp(Fe1)./k1).^2);

z(33) = exp(Fe2).^(1-eta_e)*exp(a2p) - (exp(a2)*eta_e - (2./om)*(exp(Fe2)./k2).^2);

z(34) = exp(Fe3).^(1-eta_e)*exp(a3p) - (exp(a3)*eta_e - (2./om)*(exp(Fe3)./k3).^2);


% Alternative Heat Energy Price Function

z(35) = exp(FC4) - mu1 - exp(Fh4).^mu2;


% Short-Hand Expressions

z(36) = exp(short_El) - (eta_e)*(exp(a1)*exp(Fe1).^eta_e + exp(a2)*exp(Fe2).^eta_e + exp(a3)*exp(Fe3).^eta_e +
nh_weight*exp(e4).^eta_e + nh_weight*exp(e5).^eta_e);

z(37) = exp(short_H) - (exp(b1)*exp(Fh1).^eta_h + exp(b2)*exp(Fh2).^eta_h + exp(b3)*exp(Fh3).^eta_h + b4*exp(Fh4).^eta_h);


% Matching Trend in Fossil Fuels

z(38) = exp(Fe1) - e1;

z(39) = exp(Fe2) - e2;

z(40) = exp(Fe3) - e3;

z(41) = exp(Fh1)./exp(Fe1) - share_he1;

z(42) = exp(Fh2)./exp(Fe2) - share_he2;

z(43) = exp(Fh3)./exp(Fe3) - share_he3;
```

Zero-Oil Condition Function File

The zero-oil function file for MATLAB solves the one-period problem for the global model when a cut-off condition is satisfied. In response to price changes for a fossil fuel type, production of electricity can fall much faster than the depreciation of the capital stock used in production of electricity from that fuel type. As a result, the average total cost may increase very rapidly, and the non-linear equation solver can break down. This event almost always happens to electricity production from oil, and the zero-oil MATLAB function is a fix for that specific problem. When a threshold condition is reached, the value of electricity produced from oil remains fixed at a level close to zero.

```
function z = energysect_glb_zo(y,par, par_ff,cap)

%variables

Y = y(1,1);

E = y(1,2);

Eh = y(1,3);

El = y(1,4);

Fh1 = y(1,5);

Fh2 = y(1,6);

Fh3 = y(1,7);

Fe1 = y(1,8);

Fe2 = y(1,9);

Fe3 = y(1,10);

r = y(1,11);

w = y(1,12);

Pe = y(1,13);

Ph = y(1,14);

Pel = y(1,15);

e4 = y(1,16);

e5 = y(1,17);

FC1 = y(1,18);
```

```
FC2 = y(1,19);

FC3 = y(1,20);

TCe1 = y(1,21);

TCe2 = y(1,22);

TCe3 = y(1,23);

TCh1 = y(1,24);

TCh2 = y(1,25);

TCh3 = y(1,26);

a1 = y(1,27);

a2 = y(1,28);

a3 = y(1,29);

a1p = y(1,30);

a2p = y(1,31);

a3p = y(1,32);

Fh4 = y(1,33);

FC4 = y(1,34);

TCh4 = y(1,35);

short_El = y(1,36);

short_H = y(1,37);


%capital

K = cap(1,1);

k1= cap(1,2);

k2= cap(1,3);

k3= cap(1,4);

k4= cap(1,5);

k5= cap(1,6);
```

```
%parameters

gam1 = par(1,1);

gam2 = par(1,2);

gam3 = par(1,3);

b1 = par(1,4);

b2 = par(1,5);

b3 = par(1,6);

Pfz1 = par(1,7);

Pfz2 = par(1,8);

Pfz3 = par(1,9);

PR1 = par(1,10);

PR2 = par(1,11);

PR3 = par(1,12);

Rz1 = par(1,13);

Rz2 = par(1,14);

Rz3 = par(1,15);

alpha = par(1,16);

beta = par(1,17);

gamma = par(1,18);

rho = par(1,19);

theta = par(1,20);

At  = par(1,21);

OMt = par(1,22);

L = par(1,23);

a4 = par(1,24);

a5 = par(1,25);

b4 = par(1,26);

mu1 = par(1,27);

mu2 = par(1,28);
```

```
kap3 = par(1,29);

eta_e = par(1,30);

eta_h = par(1,31);

om = par(1,32);

Ael = par(1,33);

Ah = par(1,34);

tau1 = par(1,35);

tau2 = par(1,36);

tau3 = par(1,37);

nh_weight = 0.25;

fe2_par = par_ff(1,1);

a2_par = par_ff(1,2);

a2p_par = par_ff(1,3);


% Energy economy

z(1) = exp(Y) - OMt*At*K.^alpha*L.^beta*exp(E).^(1-alpha-beta);

z(2) = alpha*L*exp(w) - beta*K*exp(r);

z(3) = alpha*exp(E)*exp(Pe) - (1-alpha-beta)*K*exp(r);

z(4) = exp(Y) + tau1*(exp(Fe1)+exp(Fh1)) + tau2*(fe2_par+exp(Fh2)) + tau3*(exp(Fe3)+exp(Fh3)) - exp(r)*(K) - exp(w)*L -
exp(Pe)*exp(E);


% Production of energy services

z(5) = exp(E) - (gamma*exp(Eh).^theta + (1-gamma)*exp(El).^theta).^(1./theta);

z(6) = gamma*exp(Pel)*exp(El)^(1-theta) - (1-gamma)*exp(Ph)*exp(Eh).^(1-theta);

z(7) = exp(Pe)*exp(E) - exp(Ph)*exp(Eh) - exp(Pel)*exp(El);


% Electricity production

z(8) = exp(El) - Ael*(exp(a1)*exp(Fe1).^eta_e + a2_par*fe2_par.^eta_e + exp(a3)*exp(Fe3).^eta_e + nh_weight*exp(e4).^eta_e
+ nh_weight*exp(e5).^eta_e).^(1./eta_e);

z(9) = exp(Pel) - (exp(TCe1) + exp(TCe2) + exp(TCe3) + exp(r)*k4 + exp(r)*k5)./exp(El);
```

```
z(10) = ((exp(FC1) - (exp(FC1)-tau1)*exp(Fe1)*rho./(PR1-exp(Fe1)-exp(Fh1)))*(exp(short_El)./exp(a1p)) - exp(TCe1)) ...
    - ((exp(FC2) - (exp(FC2)-tau2)*fe2_par*rho./(PR2-fe2_par-exp(Fh2)))*(exp(short_El)./a2p_par) - exp(TCe2));
z(11) = ((exp(FC2) - (exp(FC2)-tau2)*fe2_par*rho./(PR2-fe2_par-exp(Fh2)))*(exp(short_El)./a2p_par) - exp(TCe2)) ...
    - ((exp(FC3) - (exp(FC3)-tau3)*exp(Fe3)*rho./(PR3-exp(Fe3)-exp(Fh3)))*(exp(short_El)./exp(a3p)) - exp(TCe3));

% Heat energy production

z(12) = exp(Eh) - Ah*(b1*exp(Fh1).^eta_h + b2*exp(Fh2).^eta_h + b3*exp(Fh3).^eta_h + b4*exp(Fh4).^eta_h).^(1./eta_h);

z(13) = exp(Ph) - (exp(TCh1) + exp(TCh2) + exp(TCh3) +  exp(TCh4))./exp(Eh);

z(14) = ((exp(FC1) - (exp(FC1)-tau1)*exp(Fh1)*rho./(PR1-exp(Fe1)-exp(Fh1)))*(exp(short_H)./(b1*exp(Fh1).^(eta_h-1))) -
exp(TCh1)) ...
    - ((exp(FC2) - (exp(FC2)-tau2)*exp(Fh2)*rho./(PR2-fe2_par-exp(Fh2)))*(exp(short_H)./(b2*exp(Fh2).^(eta_h-1))) -
exp(TCh2));

z(15) = ((exp(FC2) - (exp(FC2)-tau2)*exp(Fh2)*rho./(PR2-fe2_par-exp(Fh2)))*(exp(short_H)./(b2*exp(Fh2).^(eta_h-1))) -
exp(TCh2)) ...
    - ((exp(FC3) - (exp(FC3)-tau3)*exp(Fh3)*rho./(PR3-exp(Fe3)-exp(Fh3)))*(exp(short_H)./(b3*exp(Fh3).^(eta_h-1))) -
exp(TCh3));

z(16) = ((exp(FC3) - (exp(FC3)-tau3)*exp(Fh3)*rho./(PR3-exp(Fe3)-exp(Fh3)))*(exp(short_H)./(b3*exp(Fh3).^(eta_h-1))) -
exp(TCh3)) ...
    - ((1+mu2)*exp(FC4)*(exp(short_H)./(b4*exp(Fh4).^(eta_h-1))) - exp(TCh4));

% Nuclear and hydro electricity production

z(17) = exp(e4) - a4;

z(18) = exp(e5) - a5;

%Fuel prices

z(19) = exp(FC1) - tau1 - Pfz1*((PR1-exp(Fe1)-exp(Fh1))./Rz1).^rho;

z(20) = exp(FC2) - tau2 - Pfz2*((PR2-fe2_par-exp(Fh2))./Rz2).^rho;

z(21) = exp(FC3) - tau3 - Pfz3*((PR3-exp(Fe3)-exp(Fh3))./Rz3).^rho;

% Total cost functions for electricity

z(22) = exp(TCe1) - exp(r)*k1 - exp(Fe1)*exp(FC1);
```

```
z(23) = exp(TCe2) - exp(r)*k2 - fe2_par*exp(FC2);

z(24) = exp(TCe3) - exp(r)*k3 - exp(Fe3)*exp(FC3);


% Total cost functions for heat energy

z(25) = exp(TCh1) - exp(Fh1)*exp(FC1);

z(26) = exp(TCh2) - exp(Fh2)*exp(FC2);

z(27) = exp(TCh3) - exp(Fh3)*exp(FC3);

z(28) = exp(TCh4) - exp(Fh4)*exp(FC4);


% CES weights for electricity production

z(29) = exp(a1) - (1./om)*(gam1 - (exp(Fe1)./k1).^2);

z(30) = a2_par - exp(a2);

z(31) = exp(a3) - (1./om)*(gam3 - (exp(Fe3)./k3).^2);

z(32) = exp(Fe1).^(1-eta_e)*exp(a1p) - (exp(a1)*eta_e - (2./om)*(exp(Fe1)./k1).^2);

z(33) = a2p_par - exp(a2p);

z(34) = exp(Fe3).^(1-eta_e)*exp(a3p) - (exp(a3)*eta_e - (2./om)*(exp(Fe3)./(k3)).^2);


% Alternative Heat Energy Price Function

z(35) = exp(FC4) - mu1 - exp(Fh4).^mu2;


% Short-Hand Expressions

z(36) = exp(short_El) - (eta_e)*(exp(a1)*exp(Fe1).^eta_e + a2_par*fe2_par.^eta_e + exp(a3)*exp(Fe3).^eta_e +
nh_weight*exp(e4).^eta_e + nh_weight*exp(e5).^eta_e);

z(37) = exp(short_H) - (b1*exp(Fh1).^eta_h + b2*exp(Fh2).^eta_h + b3*exp(Fh3).^eta_h + b4*exp(Fh4).^eta_h);

z(38) = exp(Fe2) - fe2_par;
```

Regional ANEMI Model

List of Variables

Y	Total output
E	Aggregate energy services
Eh	Heat energy services
El	Electric energy services
Fh1	Coal used in heat energy production (GJ)
Fh2	Oil used in heat energy production (GJ)
Fh3	Natural gas used in heat energy production (GJ)
Fe1	Coal used in electricity production (GJ)
Fe2	Oil used in electricity production (GJ)
Fe3	Natural gas used in electricity production (GJ)
r	Gross interest rate
w	Wage rate
Pe	Price of aggregate energy services
Ph	Price of heat energy services
Pel	Price of electricity services
e4	electricity produced from nuclear power
e5	electricity produced from hydro power
FC1	Price of coal
FC2	Price of oil
FC3	Price of natural gas
TCe1	Total cost of electricity produced from coal
TCe2	Total cost of electricity produced from oil

TCe3	Total cost of electricity produced from natural gas
TCh1	Total cost of heat energy produced from coal
TCh2	Total cost of heat energy produced from oil
TCh3	Total cost of heat energy produced from natural gas
a1	CES weight for coal
a2	CES weight for oil
a3	CES weigth for natural gas
a1p	Short hand term for CES weight calculation for coal
a2p	Short hand term for CES weight calculation for oil
a3p	Short hand term for CES weight calculation for natural gas
Fh4	Alternative heat energy (GJ)
FC4	Price of alternatie heat energy
TCh4	Total cost of heat energy produced from alternative energy
short_El	Short hand term for electricity calculations
short_H	Short hand term for heat energy calculations
imports	Net Imports of the generic consumption good

List of Parameters

gam1	Parameter for CES weight function for coal
gam2	Parameter for CES weight function for oil
gam3	Parameter for CES weight function for natural gas
b1	CES weight for coal
b2	CES weight for oil
b3	CES weight for natural gas
b4	CES weight for alternative heat energy
Pfz1	Base year price for coal
Pfz2	Base year price for oil
Pfz3	Base year price for natural gas
PR1	Current reserve value for coal
PR2	Current reserve value for oil
PR3	Current reserve value for natural gas
Rz1	Base year reserve value for coal
Rz2	Base year reserve value for oil
Rz3	Base year reserve value for natural gas
alpha	Capital's share
beta	Labour's share
gamma	Share parameter for energy aggregation
rho	Elasticity parameter for fossil fuel price function
theta	Elasticity parameter for energy aggregation
At	Total Factor Productivity
OMt	Nordhaus damage coefficient
L	Labour force

a4	Prescribed nuclear energy
a5	Prescribed hydro power
mu1	Parameter for alternative heat energy price function
mu2	Parameter for alternative heat energy price function
eta_e	Elasticity parameter for electricity production
eta_h	Elasticity paramater for heat energy production
om	Scale parameter for CES weights in electricity production
Ael	Electricity specific productivity term
Ah	Heat energy specific productivity term
tau1	Carbon tax rate for coal
tau2	Carbon tax rate for oil
tau3	Carbon tax rate for natural gas
nh_weight	CES weight for nuclear and hydro power
fstar1	Total extraction of coal
fstar2	Total extraction of oil
fstar3	Total extraction of natural gas

Solver File

This file is the primary 'solver file' used for the regional model. It takes inputs from Vensim, calls the appropriate function, and produces the solution to the one-period energy-economy model.

```
clear all

tic

options1=optimset('FunValCheck','on', 'TolX',1.0e-9, 'TolFun',1.0e-9, 'MaxFunEvals',1.0e+9, ...

   'MaxIter',0.051e+3, 'Display', 'iter', 'NonlEqnAlgorithm','dogleg');

options2=optimset('FunValCheck','on', 'TolX',1.0e-12, 'TolFun',1.0e-12, 'MaxFunEvals',1.0e+9, ...

   'MaxIter',1.011e+3, 'Display', 'iter', 'NonlEqnAlgorithm','lm');


x0_cal = [4.08882001940707,-0.477802471321497,-
1.38426580086723,2.43003911005965,0.230743656881343,1.06679573151687,0.279711343878389,-1.45433621280950,-
3.38146807797842,-4.12182604247513,-0.347451630119205,1.14350553864074,1.97635532528274,2.32422647439778,-
1.78015055840188,-1.83328793692455,-0.0684980216000813,2.59497758980671,0.0611390618024763,2.22719517990958,-
1.56773148361856,-3.13516025436419,-4.20981366794375,-1.20727187582513,0.533398961718562,-
1.38311945574640,0.698809043866189,2.07385907461717,1.53313088975904,0.635842215996799,3.05030256250949,2.867
66011154329,-3.14436512203694,1.95809178328180,-1.18627333875515,0.521872374469884,-
0.692132900433612,1.07418779215341,3.94053013691443,5.29795162282076,4.76014608768349,-2.68363371516625,-
1.90339098334132,-2.85895371745158];


 par_mat = xlsread('par_values_can_2.xls');

 cap_mat = xlsread('cap_values_can_3.xls');

 eng_mat = xlsread('eng_values_can.xls');


cap = cap_mat(1,:);

eng = eng_mat(1,:);

par = par_mat(1,:);

n=121;

time = linspace(1,n,121);

flag_vect = zeros(1,n);

x0_v = ones(1,3);


par(1,10:12) = par(1,10:12);
```

```
vdg = fsolve('vedge', x0_v, options2, par, eng);
par(1,41:43) = par(1,10:12) - vdg.*par(1,13:15).*(par(1,38:40)./par(1,7:9)).^(1./par(1,19))
[xout_cal, fval, flag] = fsolve('energysect_cal_can', x0_cal, options1, par, cap, eng);
if flag ~= 1
[xout_cal, fval, flag2] = fsolve('energysect_cal_can', xout_cal, options2, par, cap, eng);
end
for j=1:3
   if par(1,40+j) < 0
   par(1,40+j) = 0;
   end
end
y = exp(xout_cal);
y(1,18:20) = log(y(1,18:20));
y(1,38) = log(y(1,38));
x0 = xout_cal(1,1:38);
x0_cal  = xout_cal;
outmat(:,1) = y;
x0_cal_int = x0_cal;
for i=1:n
   filename ='out.txt';
   mmfile = -1;
   while(mmfile == -1)
      pause(5);
      mmfile = fopen(filename,'r');
   end
   par(1,1:34)=fscanf(mmfile,'%e',[1 34]);
   par(1,35:40)=par(1,1:6);
   cap=fscanf(mmfile,'%e',[1 6]);
   fclose(mmfile);
   delete('out.txt');
   if i==1
```

```
eng = eng_mat(1,:);

res_mat(1,:) = par(1,10:12);

vdg = fsolve('vedge', x0_v, options2, par, eng);

par(1,41:43) = res_mat(1,:) - vdg.*par(1,13:15).*(par(1,38:40)./par(1,7:9)).^(1./par(1,19));

elseif i<26

eng = eng_mat(i,:);

par(1,10:12) = res_mat(i,:);

vdg = fsolve('vedge', x0_v, options2, par, eng);

par(1,41:43) = res_mat(i,:) - vdg.*par(1,13:15).*(par(1,38:40)./par(1,7:9)).^(1./par(1,19));

else

vdg(1,1) = vdg_mat(i-1,1).*(1 + 1.00*(vdg_mat(i-1,1)-vdg_mat(i-2,1))./vdg_mat(i-2,1));

vdg(1,2) = vdg_mat(i-1,2).*(1 + 1.00*(vdg_mat(i-1,2)-vdg_mat(i-2,2))./vdg_mat(i-2,2));

vdg(1,3) = vdg_mat(i-1,3).*(1 + 1.05*(vdg_mat(i-1,3)-vdg_mat(i-2,3))./vdg_mat(i-2,3));

if vdg < 0.01

vdg = 0.01;

end

par(1,10:12) = res_mat(i,:);

par(1,41:43) = res_mat(i,:) - vdg.*par(1,13:15).*(par(1,38:40)./par(1,7:9)).^(1./par(1,19));

end

vdg_mat(i,:) = vdg;

par_check(:,i) = par;

for j=1:3

if par(1,40+j) < 0

par(1,40+j) = 0;

end

end

end

if i<121

res_mat(i+1,:) = res_mat(i,:) - par(1,41:43);

end

if i<26

[xout_cal, fval, flag] = fsolve('energysect_cal_can', x0_cal, options1, par, cap, eng);
```

```
if flag ~= 1
[xout_cal, fval, flag2] = fsolve('energysect_cal_can', xout_cal, options2, par, cap, eng);
end
y = exp(xout_cal);
y(1,18:20) = log(y(1,18:20));
y(1,38) = log(y(1,38));
x0_cal=xout_cal;
x0 = x0_cal(1,1:38);
outmat(:,i) = y;
fval_cal_mat(:,i) = fval;
end

if i<26
par(1,1:6) = outmat(39:44,i);
else
par(1,1:6) = outmat(39:44,i-1).*(1 + 0.95*(outmat(39:44,i-1)-outmat(39:44,i-2))./outmat(39:44,i-2));
end
[xout, fval, flag] = fsolve('energysect_can', x0, options1, par, cap);
if flag ~= 1
[xout, fval, flag] = fsolve('energysect_can', xout, options2, par, cap);
end
y=exp(xout);
y(1,18:20) = log(y(1,18:20));
y(1,38) = log(y(1,38));
x0=xout;
outmat(1:38,i) = y;
outmat(39:44,i) = par(1,1:6);
par_check(1:43,i) = par(1,1:43);
fval_mat(:,i) = fval;
fval_vect(1,i) = mean(abs(fval));
flag_vect(1,i) = flag;
```

```
    filename ='in.txt';
  mmfile = fopen(filename,'w');
  if ( mmfile == -1 )
    disp(filename);
    error('File not found');
  end;
  aa =fprintf(mmfile,'%e\n', y);
  fclose(mmfile);
  filename ='b_in.txt';
  mmfile = fopen(filename,'w');
  if ( mmfile == -1 )
    disp(filename);
    error('File not found');
  end;
  aa =fprintf(mmfile,'%e\n', y);
  fclose(mmfile);
end
toc
```

Main Function File

The main function file for MATLAB solves the one-period problem for the regional model. It is a non-linear system of 38 equations and variables.

```
function z = energysect_can(y,par,cap)

%variables
Y = y(1,1);
E = y(1,2);
Eh = y(1,3);
El = y(1,4);
Fh1 = y(1,5);
Fh2 = y(1,6);
Fh3 = y(1,7);
Fe1 = y(1,8);
Fe2 = y(1,9);
Fe3 = y(1,10);
r = y(1,11);
w = y(1,12);
Pe = y(1,13);
Ph = y(1,14);
Pel = y(1,15);
e4 = y(1,16);
e5 = y(1,17);
Exp1 = y(1,18);
Exp2 = y(1,19);
Exp3 = y(1,20);
TCe1 = y(1,21);
```

```
TCe2 = y(1,22);

TCe3 = y(1,23);

TCh1 = y(1,24);

TCh2 = y(1,25);

TCh3 = y(1,26);

a1 = y(1,27);

a2 = y(1,28);

a3 = y(1,29);

a1p = y(1,30);

a2p = y(1,31);

a3p = y(1,32);

Fh4 = y(1,33);

FC4 = y(1,34);

TCh4 = y(1,35);

short_El = y(1,36);

short_H = y(1,37);

imports = y(1,38);


%capital

K = cap(1,1);

k1= cap(1,2);

k2= cap(1,3);

k3= cap(1,4);

k4= cap(1,5);

k5= cap(1,6);


%parameters

gam1 = par(1,1);

gam2 = par(1,2);
```

```
gam3 = par(1,3);

b1 = par(1,4);

b2 = par(1,5);

b3 = par(1,6);

Pfz1 = par(1,7);

Pfz2 = par(1,8);

Pfz3 = par(1,9);

PR1 = par(1,10);

PR2 = par(1,11);

PR3 = par(1,12);

Rz1 = par(1,13);

Rz2 = par(1,14);

Rz3 = par(1,15);

alpha = par(1,16);

beta = par(1,17);

gamma = par(1,18);

rho = par(1,19);

theta = par(1,20);

At  = par(1,21);

OMt = par(1,22);

L = par(1,23);

a4 = par(1,24);

a5 = par(1,25);

b4 = par(1,26);

mu1 = par(1,27);

mu2 = par(1,28);

kap3 = par(1,29);

eta_e = par(1,30);

eta_h = par(1,31);
```

```
om = par(1,32);

Ael = par(1,33);

Ah = par(1,34);

tau1 = par(1,35);

tau2 = par(1,36);

tau3 = par(1,37);

FC1 = par(1,38);

FC2 = par(1,39);

FC3 = par(1,40);

fstar1 = par(1,41);

fstar2 = par(1,42);

fstar3 = par(1,43);

nh_weight = 0.25;


% Energy economy

z(1) = exp(Y) - OMt*At*K.^alpha*L.^beta*exp(E).^(1-alpha-beta);

z(2) = alpha*L*exp(w) - beta*K*exp(r);

z(3) = alpha*exp(E)*exp(Pe) - (1-alpha-beta)*K*exp(r);

z(4) = exp(Y) - imports + tau1*(exp(Fe1) + exp(Fh1)) + tau2*(exp(Fe2) + exp(Fh2)) + tau3*(exp(Fe3) + exp(Fh3)) - exp(r)*(K) -
exp(w)*L - exp(Pe)*exp(E);


% Production of energy services

z(5) = exp(E) - (gamma*exp(Eh).^theta + (1-gamma)*exp(El).^theta).^(1./theta);

z(6) = gamma*exp(Pel)*exp(El)^(1-theta) - (1-gamma)*exp(Ph)*exp(Eh).^(1-theta);

z(7) = exp(Pe)*exp(E) - exp(Ph)*exp(Eh) - exp(Pel)*exp(El);


% Electricity production

z(8) = exp(El) - Ael*(exp(a1)*exp(Fe1).^eta_e + exp(a2)*exp(Fe2).^eta_e + exp(a3)*exp(Fe3).^eta_e +
nh_weight*exp(e4).^eta_e + nh_weight*exp(e5).^eta_e).^(1./eta_e);

 z(9) = exp(Pel) - (exp(TCe1) + exp(TCe2) + exp(TCe3) + exp(r)*k4 + exp(r)*k5)./exp(El);
```

```
z(10) = ((FC1+tau1)*exp(short_El)./exp(a1p) - exp(TCe1)) - ((FC2+tau2)*exp(short_El)./exp(a2p) - exp(TCe2));

z(11) = ((FC2+tau2)*exp(short_El)./exp(a2p) - exp(TCe2)) - ((FC3+tau3)*exp(short_El)./exp(a3p) - exp(TCe3));


% Heat energy production

z(12) = exp(Eh) - Ah*(b1*exp(Fh1).^eta_h + b2*exp(Fh2).^eta_h + b3*exp(Fh3).^eta_h + b4*exp(Fh4).^eta_h).^(1./eta_h);

z(13) = exp(Ph) - (exp(TCh1) + exp(TCh2) + exp(TCh3) +  exp(TCh4))./exp(Eh);

 z(14) = ((FC1+tau1)*exp(short_H)./(b1*exp(Fh1).^(eta_h-1)) - exp(TCh1)) - ((FC2+tau2)*exp(short_H)./(b2*exp(Fh2).^(eta_h-1))
- exp(TCh2));

z(15) = ((FC2+tau2)*exp(short_H)./(b2*exp(Fh2).^(eta_h-1)) - exp(TCh2)) - ((FC3+tau3)*exp(short_H)./(b3*exp(Fh3).^(eta_h-1))
- exp(TCh3));

 z(16) = ((FC3+tau3)*exp(short_H)./(b3*exp(Fh3).^(eta_h-1)) - exp(TCh3)) -
((1+mu2)*exp(FC4)*exp(short_H)./(b4*exp(Fh4).^(eta_h-1)) - exp(TCh4));


% Nuclear and hydro electricity production

z(17) = exp(e4) - a4;

z(18) = exp(e5) - a5;


%Fuel prices

z(19) = fstar1 - (exp(Fe1) + exp(Fh1) + Exp1);

z(20) = fstar2 - (exp(Fe2) + exp(Fh2) + Exp2);

z(21) = fstar3 - (exp(Fe3) + exp(Fh3) + Exp3);


% Total cost functions for electricity

z(22) = exp(TCe1) - exp(r)*k1 - exp(Fe1)*(FC1+tau1);

z(23) = exp(TCe2) - exp(r)*k2 - exp(Fe2)*(FC2+tau2);

z(24) = exp(TCe3) - exp(r)*k3 - exp(Fe3)*(FC3+tau3);


% Total cost functions for heat energy

z(25) = exp(TCh1) - exp(Fh1)*(FC1+tau1);
```

```
z(26) = exp(TCh2) - exp(Fh2)*(FC2+tau2);

z(27) = exp(TCh3) - exp(Fh3)*(FC3+tau3);

z(28) = exp(TCh4) - exp(Fh4)*exp(FC4);


% CES Function weights

z(29) = exp(a1) - (1./om)*(gam1 - (exp(Fe1)./k1).^2);

z(30) = exp(a2) - (1./om)*(gam2 - (exp(Fe2)./k2).^2);

z(31) = exp(a3) - (1./om)*(gam3 - (exp(Fe3)./k3).^2);

 z(32) = exp(Fe1).^(1-eta_e)*exp(a1p) - (exp(a1)*eta_e - (2./om)*(exp(Fe1)./k1).^2);

z(33) = exp(Fe2).^(1-eta_e)*exp(a2p) - (exp(a2)*eta_e - (2./om)*(exp(Fe2)./k2).^2);

z(34) = exp(Fe3).^(1-eta_e)*exp(a3p) - (exp(a3)*eta_e - (2./om)*(exp(Fe3)./k3).^2);


% Price Function for alternative Heat Energy

z(35) = exp(FC4) - (mu1*exp(Fh4).^mu2);


% Short-hand expressions

z(36) = exp(short_El) - (eta_e)*(exp(a1)*exp(Fe1).^eta_e + exp(a2)*exp(Fe2).^eta_e + exp(a3)*exp(Fe3).^eta_e +
nh_weight*exp(e4).^eta_e + nh_weight*exp(e5).^eta_e);

z(37) = exp(short_H) - (b1*exp(Fh1).^eta_h + b2*exp(Fh2).^eta_h + b3*exp(Fh3).^eta_h + b4*exp(Fh4).^eta_h);


% Balanced Trade Condition

z(38) = imports - (FC1+tau1)*Exp1 - (FC2+tau2)*Exp2 - (FC3+tau3)*Exp3;
```

Calibration Function File

The calibration function file for MATLAB solves the one-period problem for the regional model, and matches the historical trend for fossil fuel consumption in heat energy and electricity production.

```
function z = energysect_cal_can(y,par,cap,eng)

%variables
Y = y(1,1);
E = y(1,2);
Eh = y(1,3);
El = y(1,4);
Fh1 = y(1,5);
Fh2 = y(1,6);
Fh3 = y(1,7);
Fe1 = y(1,8);
Fe2 = y(1,9);
Fe3 = y(1,10);
r = y(1,11);
w = y(1,12);
Pe = y(1,13);
Ph = y(1,14);
Pel = y(1,15);
e4 = y(1,16);
e5 = y(1,17);
Exp1 = y(1,18);
Exp2 = y(1,19);
Exp3 = y(1,20);
```

```
TCe1 = y(1,21);

TCe2 = y(1,22);

TCe3 = y(1,23);

TCh1 = y(1,24);

TCh2 = y(1,25);

TCh3 = y(1,26);

a1 = y(1,27);

a2 = y(1,28);

a3 = y(1,29);

a1p = y(1,30);

a2p = y(1,31);

a3p = y(1,32);

Fh4 = y(1,33);

FC4 = y(1,34);

TCh4 = y(1,35);

short_El = y(1,36);

short_H = y(1,37);

imports = y(1,38);

 gam1 = y(1,39);

gam2 = y(1,40);

gam3 = y(1,41);

b1 = y(1,42);

b2 = y(1,43);

b3 = y(1,44);


%capital

K = cap(1,1);

k1= cap(1,2);

k2= cap(1,3);
```

```
k3= cap(1,4);

k4= cap(1,5);

k5= cap(1,6);


%parameters

Pfz1 = par(1,7);

Pfz2 = par(1,8);

Pfz3 = par(1,9);

PR1 = par(1,10);

PR2 = par(1,11);

PR3 = par(1,12);

Rz1 = par(1,13);

Rz2 = par(1,14);

Rz3 = par(1,15);

alpha = par(1,16);

beta = par(1,17);

gamma = par(1,18);

rho = par(1,19);

theta = par(1,20);

At  = par(1,21);

OMt = par(1,22);

L = par(1,23);

a4 = par(1,24);

a5 = par(1,25);

b4 = par(1,26);

mu1 = par(1,27);

mu2 = par(1,28);

kap3 = par(1,29);

eta_e = par(1,30);
```

```
eta_h = par(1,31);

om = par(1,32);

Ael = par(1,33);

Ah = par(1,34);

tau1 = par(1,35);

tau2 = par(1,36);

tau3 = par(1,37);

FC1 = par(1,38);

FC2 = par(1,39);

FC3 = par(1,40);

fstar1 = par(1,41);

fstar2 = par(1,42);

fstar3 = par(1,43);

e1 = eng(1,1);

e2 = eng(1,2);

e3 = eng(1,3);

h1 = eng(1,4);

h2 = eng(1,5);

h3 = eng(1,6);

nx1 = eng(1,7);

nx2 = eng(1,8);

nx3 = eng(1,9);

nh_weight = 0.25;


% Energy economy

z(1) = exp(Y) - OMt*At*K.^alpha*L.^beta*exp(E).^(1-alpha-beta);

z(2) = alpha*L*exp(w) - beta*K*exp(r);

z(3) = alpha*exp(E)*exp(Pe) - (1-alpha-beta)*K*exp(r);

z(4) = exp(Y) - exp(r)*(K) - exp(w)*L - exp(Pe)*exp(E);
```

```
% Production of energy services

z(5) = exp(E) - (gamma*exp(Eh).^theta + (1-gamma)*exp(El).^theta).^(1./theta);

z(6) = gamma*exp(Pel)*exp(El)^(1-theta) - (1-gamma)*exp(Ph)*exp(Eh).^(1-theta);

z(7) = exp(Pe)*exp(E) - exp(Ph)*exp(Eh) - exp(Pel)*exp(El);


% Electricity production

z(8) = exp(El) - Ael*(exp(a1)*exp(Fe1).^eta_e + exp(a2)*exp(Fe2).^eta_e + exp(a3)*exp(Fe3).^eta_e +
nh_weight*exp(e4).^eta_e + nh_weight*exp(e5).^eta_e).^(1./eta_e);

z(9) = exp(Pel) - (exp(TCe1) + exp(TCe2) + exp(TCe3) + exp(r)*k4 + exp(r)*k5)./exp(El);

z(10) = (FC1*exp(short_El)./exp(a1p) - exp(TCe1)) - (FC2*exp(short_El)./exp(a2p) - exp(TCe2));

z(11) = (FC2*exp(short_El)./exp(a2p) - exp(TCe2)) - (FC3*exp(short_El)./exp(a3p) - exp(TCe3));


% Heat energy production

z(12) = exp(Eh) - Ah*(exp(b1)*exp(Fh1).^eta_h + exp(b2)*exp(Fh2).^eta_h + exp(b3)*exp(Fh3).^eta_h +
b4*exp(Fh4).^eta_h).^(1./eta_h);

z(13) = exp(Ph) - (exp(TCh1) + exp(TCh2) + exp(TCh3) +  exp(TCh4))./exp(Eh);

z(14) = (FC1*exp(short_H)./(exp(b1)*exp(Fh1).^(eta_h-1)) - exp(TCh1)) - (FC2*exp(short_H)./(exp(b2)*exp(Fh2).^(eta_h-1)) -
exp(TCh2));

z(15) = (FC2*exp(short_H)./(exp(b2)*exp(Fh2).^(eta_h-1)) - exp(TCh2)) - (FC3*exp(short_H)./(exp(b3)*exp(Fh3).^(eta_h-1)) -
exp(TCh3));

z(16) = (FC3*exp(short_H)./(exp(b3)*exp(Fh3).^(eta_h-1)) - exp(TCh3)) -
((1+mu2)*exp(FC4)*exp(short_H)./(b4*exp(Fh4).^(eta_h-1)) - exp(TCh4));


% Nuclear and hydro electricity production

z(17) = exp(e4) - a4;

z(18) = exp(e5) - a5;


%Fuel prices

z(19) = fstar1 - (exp(Fe1) + exp(Fh1) + Exp1);

z(20) = fstar2 - (exp(Fe2) + exp(Fh2) + Exp2);

z(21) = fstar3 - (exp(Fe3) + exp(Fh3) + Exp3);
```

```
% Total cost functions for electricity

z(22) = exp(TCe1) - exp(r)*k1 - exp(Fe1)*FC1;

z(23) = exp(TCe2) - exp(r)*k2 - exp(Fe2)*FC2;

z(24) = exp(TCe3) - exp(r)*k3 - exp(Fe3)*FC3;


% Total cost functions for heat energy

z(25) = exp(TCh1) - exp(Fh1)*FC1;

z(26) = exp(TCh2) - exp(Fh2)*FC2;

z(27) = exp(TCh3) - exp(Fh3)*FC3;

z(28) = exp(TCh4) - exp(Fh4)*exp(FC4);


% CES Function weights

z(29) = exp(a1) - (1./om)*(exp(gam1) - (exp(Fe1)./k1).^2);

z(30) = exp(a2) - (1./om)*(exp(gam2) - (exp(Fe2)./k2).^2);

z(31) = exp(a3) - (1./om)*(exp(gam3) - (exp(Fe3)./k3).^2);

z(32) = exp(Fe1).^(1-eta_e)*exp(a1p) - (exp(a1)*eta_e - (2./om)*(exp(Fe1)./k1).^2);

z(33) = exp(Fe2).^(1-eta_e)*exp(a2p) - (exp(a2)*eta_e - (2./om)*(exp(Fe2)./k2).^2);

z(34) = exp(Fe3).^(1-eta_e)*exp(a3p) - (exp(a3)*eta_e - (2./om)*(exp(Fe3)./k3).^2);


% Alternative Heat Energy Fuel Price

z(35) = exp(FC4) - (mu1*exp(Fh4).^mu2);


% Short-Hand Expressions

z(36) = exp(short_El) - (eta_e)*(exp(a1)*exp(Fe1).^eta_e + exp(a2)*exp(Fe2).^eta_e + exp(a3)*exp(Fe3).^eta_e +
nh_weight*exp(e4).^eta_e + nh_weight*exp(e5).^eta_e);

z(37) = exp(short_H) - (exp(b1)*exp(Fh1).^eta_h + exp(b2)*exp(Fh2).^eta_h + exp(b3)*exp(Fh3).^eta_h + b4*exp(Fh4).^eta_h);
```

```
% Matching Trend in Fossil Fuels

z(38) = exp(Fe1) - e1;

z(39) = exp(Fe2) - e2;

z(40) = exp(Fe3) - e3;

z(41) = exp(Fh1) - h1;

z(42) = exp(Fh2) - h2;

z(43) = exp(Fh3) - h3;


% Balanced Trade Condition

z(44) = imports - FC1*Exp1 - FC2*Exp2 - FC3*Exp3;
```

Vedge Function File

The 'vedge function' is a simple MATLAB function that is used to calibrate the extraction of fossil fuels in the regional model. Because the fossil fuel prices are taken as given in the regional model, we need an adjustment factor to match the level of fossil fuels to be extracted. The function solves for the appropriate 'vedge' for each fossil fuel type over the period from 1980-2005 (the calibration period). From 2006 and onwards the parameters are extrapolated following a naïve updating rule.

```
function z = vedge(v,par,eng)
 vedge1 = v(1,1);
vedge2 = v(1,2);
vedge3 = v(1,3);

te1 = eng(1,1)+eng(1,4)+eng(1,7);
te2 = eng(1,2)+eng(1,5)+eng(1,8);
te3 = eng(1,3)+eng(1,6)+eng(1,9);

Pfz1 = par(1,7);
Pfz2 = par(1,8);
Pfz3 = par(1,9);
PR1 = par(1,10);
PR2 = par(1,11);
PR3 = par(1,12);
Rz1 = par(1,13);
Rz2 = par(1,14);
Rz3 = par(1,15);
rho = par(1,19);
FC1 = par(1,38);
FC2 = par(1,39);
```

```
FC3 = par(1,40);


z(1) = te1 - (PR1 - vedge1*Rz1*(FC1./Pfz1).^(1./rho));

z(2) = te2 - (PR2 - vedge2*Rz2*(FC2./Pfz2).^(1./rho));

z(3) = te3 - (PR3 - vedge3*Rz3*(FC3./Pfz3).^(1./rho));
```

APPENDIX B: EXTERNAL FUNCTIONS

```
//#include <imsl.h>
#include <stdio.h>
#include <math.h>
#include <time.h>
#include <windows.h>


#define WANT_WINDOWS_INCLUDES /* the sample implementation of this requires windows includes/libraries */
#define VENEXT_GLOBALS
#include "vensim.h"
#include <malloc.h>
GLOB_VARS *VENGV ; /* the value for this is set by set_gv below */



/*****************************************
 1 - function ids - used to swich between choices
 *****************************************/

#define COS_FUNC 0
#define INRANGE_FUNC 1
#define PSUM_FUNC 2
#define INVERT_FUNC 3
#define INPLACE_INVERT_FUNC 4
#define INTERNAL_ROR_FUNC 5
#define MYMESSAGE_FUNC 6
#define MYFINDZERO_FUNC 7
#define MYLOOKUP_FUNC 8
#define MYALLTYPES_FUNC 9
#define MYCONSTDEF_FUNC 10
#define MYDATADEF_FUNC 11
#define MY_FUNC 12
#define ARRAY_READ 13
#define N 32 //before it was 26

/*****************************************
 2 - function prototypes
 *****************************************
  each external function is prototyped here
  arguments can reasonably be doubles - for normal number manipulation,
  COMPREAL * for vector manipulation or int for indexing.  Recasting of
  values takes place in
  Note that if you use more than 1 file for the external function definitions
  you should probably put these prototypes into a #include file.  Also, for
  working with compiled simulation a # include file is helpfule, and should
  be nested into vensim.h

  Note that all the external functions are all upper case.  This is required
  if you want to use compile simulations - since the calls in mdl.c will
  be upper case.  Our apologies to those this offends.
*****************************************/
//double writing(double a1, double a2, double a3,double a4, double a5, double a6,double a7, double a8, double a9,double a10,
double a11, double a12,double a13, double a14, double a15,double a16, double a17, double a18,double a19, double a20,
```

```
double a21,double a22, double a23, double a24,double a25, double a26, double a27,double a28, double a29, double
a30,double a31, double a32, double a33,double a34, double a35, double a36, double a37);
double writing(double a1, double a2, double a3,double a4, double a5, double a6,double a7, double a8, double a9,double a10,
double a11, double a12,double a13, double a14, double a15,double a16, double a17, double a18,double a19, double a20,
double a21,double a22, double a23, double a24,double a25, double a26, double a27,double a28, double a29, double
a30,double a31, double a32, double a33,double a34, double a35, double a36, double a37, double a38,double a39,double
a40,double a41);
double COSINE(double x) ;
double read(double x) ;
double readmat(double x);
double INRANGE(double norm,double minval,double maxval) ;
double PSUM(VECTOR_ARG *vec,double num_arg,int maxarg) ;
double MATRIX_INVERT(VECTOR_ARG *invmat,VECTOR_ARG *mat1) ;
double MATRIX_INPLACE_INVERT(VECTOR_ARG *mat1) ;
double INTERNAL_ROR(double inval,double time,double minval,double maxval,
        int streamid,double do_compute) ;
double MYMESSAGE(const char *message,double time) ;
double MYFINDZERO(VECTOR_ARG *x,VECTOR_ARG *y,int narg) ;
double MYLOOKUP(TAB_TYPE *tab,double x) ;
double MYALLTYPES(VECTOR_ARG *lhs,const char *literal,TAB_TYPE *tab,VECTOR_ARG *vecarg,double x) ;
double MYCONSTDEF(CONSTANT_MATRIX *cmat,const char *literal) ;
double MYDATADEF(DATA_MATRIX *dmat,const char *literal) ;
void fcn(int, float[], float[]);
float Solve_Sys_of_Nonlinear_Equations( int index,float par1, float par2, float par3,float par4, float par5, float par6,float par7,
float par8, float par9,float par10, float par11, float par12,float par13, float par14, float par15,float  par16, float par17, float
par18, float par19, float par20, float  par21,float par22, float par23, float par24,float par25, float par26, float par27,float par28,
float par29, float par30,float par31, float par32, float par33,float par34,float par35,float par36,float par37,float par38,float
par39,float par40);
float
OMt,At,K,alpha,L,beta,gamma,theta,gam1,gam2,gam3,a4,a5,mu4,mu5,k1,k2,k3,k4,k5,b1,b2,b3,PR1,PR2,PR3,Pfz1,Pfz2,Pfz3,rho
,Rz1,Rz2,Rz3,om;
//double con1,con2,con3;
/*****************************************************
 3 - Grouping of functions in a structure - see venext.h
 ******************************************************/

static FUNC_DESC Flist[] = {
                    //{"COSINE"," {x} ",1,0,COS_FUNC,0,0,0,0},
            {"READ"," {x} ",1,0,COS_FUNC,0,0,0,0},
            {"INRANGE"," {x} , {minval} , {maxval} ",3,0,INRANGE_FUNC,0,0,0,0},
            {"PSUM"," {vector} , {nelm} , {nelmlimit} ",3,1,PSUM_FUNC,0,0,0,0},
            {"MATRIX_INVERT"," {matrix} ",1,1,INVERT_FUNC,2,0,0,0},
            {"MATRIX_INPLACE_INVERT"," {matrix} ",1,1,INPLACE_INVERT_FUNC,0,1,0,0},
            {"INTERNAL_ROR"," {x} , {time} , {minror} , {maxror} , {streamid} , {compute} ",6,0,INTERNAL_ROR_FUNC,0,0,0,0},
            {"MYMESSAGE"," {'message'} , {time} ",2,0,MYMESSAGE_FUNC,0,0,1,0},
            {"MYFINDZERO"," {vector_to_zero} , {nelement} ",2,1,MYFINDZERO_FUNC,1,2,0,0},
            {"MYLOOKUP"," {lookup} , {x} ",2,0,MYLOOKUP_FUNC,0,0,0,1},
            {"MYALLTYPES"," {'literal'} , {lookup} , {vector} , {x} ",4,1,MYALLTYPES_FUNC,1,0,1,1},
            {"MYCONSTDEF"," {'literal'} ",1,0,MYCONSTDEF_FUNC,CONSTDEF_MARKER,0,1,0},
            {"MYDATADEF"," {'literal'} ",1,0,MYDATADEF_FUNC,DATADEF_MARKER,0,1,0},
                                        //{"SOLVE_NONLINEAR_SYSTEM"," 34 parameters ",34,0,MY_FUNC,0,0,0,0},
                                        {"WRITE"," 40 parameters",41,0,MY_FUNC,0,0,0,0},
                                        {"READMAT","ReadTheMatrix",1,0, ARRAY_READ,0,0,0,0},
            {'\0',0,0,0}} ;

/*****************************************************
4 - DLL required functions LibMain and WEP
 Obsolete - 16 bit windows only
```

```
/*****************************************************************
 5 External function definitions
 *****************************************************************/

 /*************************
  This function is a version check - it is required to be sure
  the external functions are compatible with the current Vensim
  version. Note that for 5.8c this number has changed but you can
  simply update this version number, the set_gv function and the
  funcversion_info function (these 2 return different value types)
  make no other changes to your external functions and they will
  work. To simplify use with different configurations (ie the
  Model Reader and DLLs) we recommend that you not link with
  vensim.lib or vensimdp.lib and replace

  vensim_error_message with (*VENGV->error_message)
  vensim_alloc_simmem with (*VENGV->alloc_simmem)
  vensim_execute_curloop with (*VENGV->execute_curloop)

  /* ***************************
   This function is _exported and called multiple times at Vensim
   startup with an index  - it returns 1 on success and 0 to
   indicate the end of the function list.  For convenience the structure
   defined in section 3 is used, but all the functions could also be declared
   with a switch statement on i
 *****************************************************************/
double dataStore[37];
int flag=1;

double  readmat(double x)
{
                                return read(x);

}

double  read(double x)
{
        double i, a = 0.0;
        FILE * PTR;
        clock_t endwait;
        //
        if(flag == 1){
        //
        do{

                PTR = fopen("in.txt", "r+");

                endwait = clock () + 1 * CLOCKS_PER_SEC;
                while(clock() < endwait) {}


        }while(PTR == NULL);
        for(i = 1.0; i <=37.0 ; i+=1.0)
        {
                fscanf(PTR, "%lf",&dataStore[(int)(i-1.0)] );
        }
        fclose(PTR);
```

```
		//
		}
		//
		flag = 0;
		return dataStore[(int)(x-1)];
}

double counter =1.0;
double writing(double a1, double a2, double a3,double a4, double a5, double a6,double a7, double a8, double a9,double a10,
double a11, double a12,double a13, double a14, double a15,double a16, double a17, double a18,double a19, double a20,
double a21,double a22, double a23, double a24,double a25, double a26, double a27,double a28, double a29, double
a30,double a31, double a32, double a33,double a34, double a35,double a36,double a37,double a38,double a39,double
a40,double a41)
{
		FILE * PTR;
		clock_t endwait;
		if(a41==counter){
			counter=1.0;
		PTR = fopen("out.txt", "w+");


		fprintf(PTR, "%E\n",a1 );
		fprintf(PTR, "%E\n",a2 );
		fprintf(PTR, "%E\n",a3 );
		fprintf(PTR, "%E\n",a4 );
		fprintf(PTR, "%E\n",a5 );
		fprintf(PTR, "%E\n",a6 );
		fprintf(PTR, "%E\n",a7 );
		fprintf(PTR, "%E\n",a8 );
		fprintf(PTR, "%E\n",a9 );
		fprintf(PTR, "%E\n",a10 );
		fprintf(PTR, "%E\n",a11);
		fprintf(PTR, "%E\n",a12 );
		fprintf(PTR, "%E\n",a13 );
		fprintf(PTR, "%E\n",a14 );
		fprintf(PTR, "%E\n",a15 );
		fprintf(PTR, "%E\n",a16 );
		fprintf(PTR, "%E\n",a17 );
		fprintf(PTR, "%E\n",a18 );
		fprintf(PTR, "%E\n",a19 );
		fprintf(PTR, "%E\n",a20 );
		fprintf(PTR, "%E\n",a21 );
		fprintf(PTR, "%E\n",a22 );
		fprintf(PTR, "%E\n",a23 );
		fprintf(PTR, "%E\n",a24 );
		fprintf(PTR, "%E\n",a25 );
		fprintf(PTR, "%E\n",a26 );
		fprintf(PTR, "%E\n",a27 );
		fprintf(PTR, "%E\n",a28 );
		fprintf(PTR, "%E\n",a29 );
		fprintf(PTR, "%E\n",a30 );
		fprintf(PTR, "%E\n",a31 );
		fprintf(PTR, "%E\n",a32 );
		fprintf(PTR, "%E\n",a33 );
		fprintf(PTR, "%E\n",a34 );
		fprintf(PTR, "%E\n",a35 );
		fprintf(PTR, "%E\n",a36 );
		fprintf(PTR, "%E\n",a37 );
```

```
            fprintf(PTR, "%E\n",a38 );
            fprintf(PTR, "%E\n",a39 );
            fprintf(PTR, "%E\n",a40 );


            fclose(PTR);



   endwait = clock () + 1 * CLOCKS_PER_SEC;
   while (clock() < endwait) {}


            remove("in.txt");
            flag = 1;
}
else{                   counter =counter+1.0;}
            return (a1);
}

int VEFCC version_info()
 {
  return(EXTERNAL_VERSION) ;
  }

/* When you make changes to functions update this. If Vensim opens a .vmf file
   that references aexternal functions and there is a mismatch a message will
   be given indicating that the model should be reformed and cleaned
   - if you return 0 no checking will occur

  If you have multiple external function libraries you can also use this to
  signal when a model is not matched to the library (though it won't indicate
  which library should be used) */
unsigned short VEFCC funcversion_info()
{
   return(1) ;
   }

int VEFCC set_gv(GLOB_VARS *vgv)
 {
  VENGV = vgv ;
  if(!VENGV ||
     VENGV->vgv_magic_start != VGV_MAGIC_START ||
     VENGV->vgv_magic_end != VGV_MAGIC_END)
     return 0 ;
  return 1 ;
  }

  /* ****************************
   This function is _exported and called multiple times at Vensim
   startup with an index  - it returns 1 on success and 0 to
   indicate the end of the function list.  For convenience the structure
   defined in section 3 is used, but all the functions could also be declared
   with a switch statement on i
 ******************************************************************/

int VEFCC user_definition(
   int i, /* an index for requesting information - this is mapped to Flist
```

```
        but could be used another way - vensim repeatedly calls
        user_definition with i bigger by 1 until user_definition returns
        0 */
 char **sym,/* the name of the function to be used in the Vensim model */
 char **argument_desc, /* description of arguments to be used by the function */
 int *num_arg, /* the number of arguments (in Vensim) the function takes
            note that for user loop functions this will be one less
            than the number of arguments the function actually takes on */
 int *num_vector, /* the number of arguments that are passed as real number vectors */
 int *func_index, /* a number between 0 and 254 that identifies the function
              vensim_external is called with this number */
 int *dim_act,  /* reserved - for doing dimensional analysis but not implemented */
 int *modify,  /* a flag to indicate that the function will modify value that
            are passed to it -
            0 is a normal function that does not modify its argument
            1 is a function that does modify arguments
            2 is a function that modifies arguments and serves as a solver
             of a simultaneous set of conditions as FIND_ZERO */
int *num_loop, /* the number of loops that are managed by the function -
            this is nonzero (normally 1 or 2) for a function that
            needs to return a vector or matrix of values - if this is
            nonzero Vensim will put a pointer to the vector or array to
            be filled in and pass it as the first argument to the function
            NOTE use -1 for a constdef function and -2 for a datadef function */

 int *num_literal, /* the number of literals that are passed to the function -
              arguments are always passed in the order literals,
              lookups, vectors, numbers - if num_loop is set the
              first argument is a vector even if num_literal is positive */
 int *num_lookup  /* the number of lookup functions passed - this structure is
            not currently accessible but will be made so in the future */
 )
{

 if(Flist[i].sym) {
   *sym = Flist[i].sym ;
   *argument_desc = Flist[i].argument_desc ;
   *num_arg = Flist[i].num_args ;
   *num_vector = Flist[i].num_vector ;
   *func_index = Flist[i].func_index ;
   *dim_act = 0 ;
   *modify = Flist[i].modify ;
   *num_loop = Flist[i].num_loop ;
   *num_literal = Flist[i].num_literal ;
   *num_lookup = Flist[i].num_lookup ;
   return(1) ;
   }
 return(0) ; /* indicating the end of the list */
 }
/***************************
 5a some memory management utility routines used by the examples that
   may be of value for other functions
 ************************************/
typedef struct _rorstr RORSTR ;
struct _rorstr {
 COMPREAL *times ;
 HANDLE times_hndl ;
 COMPREAL *vals ;
```

```
 HANDLE vals_hndl ;
 RORSTR *next ;
 int streamid ;
 int ntimes ;
 int maxtimes ;
 } ;

/* any flags that individual function need set to perform properly on the next
   invocation must be reset by vext_clearmem */
static int Matrix_invert_maxn ;
static RORSTR *Internal_ror_fror ;
static HANDLE *Mem_used = '\0' ;
static int Num_mem_used = 0 ;
static int Max_mem_used = 0 ;


static void *vext_allocate(unsigned nbytes,HANDLE *hndl)
 {
  HANDLE lhndl ;
  if(Num_mem_used >= Max_mem_used) {
     Max_mem_used += 100 ;
     if(Mem_used) {
        Mem_used = (HANDLE *)realloc(Mem_used,Max_mem_used*sizeof(HANDLE)) ;
        memset(Mem_used+Max_mem_used-100,'\0',100*sizeof(HANDLE)) ;
        }
     else
        Mem_used = (HANDLE *)calloc(Max_mem_used,sizeof(HANDLE)) ;
     }
  if(!Mem_used)
     return('\0') ;
  lhndl = (HANDLE)malloc(nbytes) ;
  if(!lhndl)
     return('\0') ;
  if(hndl)
     *hndl = lhndl ;
  Mem_used[Num_mem_used++] = lhndl ;
  return(lhndl) ;
  }
static void *vext_reallocate(unsigned nbytes,HANDLE *hndl)
 {
   int i ;
   if(!*hndl)
      return(vext_allocate(nbytes,hndl)) ;
  if(Mem_used) {
     /* find old - otherwise live with the memory leak */
     for(i=0;i<Num_mem_used;i++)
        if(Mem_used[i] == *hndl)
           break ;
     }
  *hndl = realloc(*hndl,nbytes) ;
  if(Mem_used) {
     if(i < Num_mem_used)
        Mem_used[i] = *hndl ;
     }
  return(*hndl) ;
  }
static void vext_clearmem()
{
```

```
  int i ;

  if(Mem_used) {
    for(i=0;i<Num_mem_used;i++) {
      if(Mem_used[i]) {
        free(Mem_used[i]) ;
        }
      }
    free(Mem_used) ;
    }
  Mem_used = '\0' ;
  Num_mem_used = Max_mem_used = 0 ;

  Matrix_invert_maxn = 0 ;
  Internal_ror_fror = '\0' ;
  }


/*************************************************************************
 6 - startup and shutdown routines
 *************************************************************************
   these two functions (if they exist and are exported)
   are called before the simulation starts and
   after it ends - in a normal simulation the order is
     simulation_setup(1) ;
     simulation_setup(0) ;
     simulation_shutdown(0) ;
     simulation_shutdown(1) ;
   for an optimization it the middle two calls are repeated for
   every simulation - the setup routine should return 0 on failure
   the return value is only used when iniflag == 1.  If the function
   returns 0 simulation will not proceed.
 ************************************************************************/

CFUNCTION int VEFCC simulation_setup(int iniflag)
 {
  return(1) ;
  }
CFUNCTION int VEFCC simulation_shutdown(int finalflag)
 {
  vext_clearmem() ;
  return(1) ;
  }

/* this is a safety function to validate vector ranges when passing
   vectors to Vensim - you don't need to use it but it will help to
   prevent nasty memory errors */
static void validate_vector_arg(VECTOR_ARG *v,int firstind,int lastind)
{
  int itemp ;
  if(firstind > lastind) {
    itemp = firstind ;
    firstind = lastind ;
    lastind = itemp ;
    }
  if(v->vals + firstind < v->firstval ||
    v->vals+lastind > v->firstval + v->dim_info->tot_vol) {
    vensim_error_message(VERROR,"Vector argument out of bounds") ;
```

```
    v->vals[0] = (COMPREAL)0.0 ;
    v->vals[0] = (COMPREAL)(1.0/v->vals[0]) ; /* generate a floating point exception */
    }
  }

/*****************************************************************
 6 - vensim_external - the actual external function call
 *****************************************************************
  note that all the functions doing floating point are passed and
  return doubles to prevent any compiler specific problems from
  arising
 *****************************************************************/

CFUNCTION int VEFCC vensim_external(VV *val,int nval,int funcid)
 {
  double rval ;
  int n,n2 ;

  switch(funcid) {
    case COS_FUNC : /* simple function - call with double return double */
                        rval = read(val[0].val) ;
     break ;
             case MY_FUNC:

            rval=writing(val[0].val,val[1].val,val[2].val,val[3].val,val[4].val,val[5].val,val[6].val,val[7].val,val[8].val,val[9].val,val[10].
val,val[11].val,val[12].val,val[13].val,val[14].val,val[15].val,val[16].val,val[17].val,val[18].val,val[19].val,val[20].val,val[21].val,val[
22].val,val[23].val,val[24].val,val[25].val,val[26].val,val[27].val,val[28].val,val[29].val,val[30].val,val[31].val,val[32].val,val[33].val,
val[34].val,val[35].val,val[36].val,val[37].val,val[38].val,val[39].val,val[40].val);
              break;
   case INRANGE_FUNC : /* simple function */
     rval = INRANGE(val[0].val,val[1].val,val[2].val) ;
     break ;
    case PSUM_FUNC :
     n = (int)(val[1].val+.5) ; /* n and n2 are rounded to integers */
     n2 = (int)(val[2].val+.5) ;
     /* first argument is a vector - note the importance of telling Vensim
       how many arguments should be passed by address - if you attempt to
       use a floating point number as an address the function will not
       work */
     rval = PSUM(val[0].vec,n,n2) ;
     break ;
    case INVERT_FUNC :
     /* note that this function is self looping and therefore
       Vensim has added in another argument to this function.
       and this argument is passed by address.  Vensim passes all arrays
       as vectors - the last subscripts varies the fastest - in some cases
       you may also need to pass the size of the containing array if you
       are not operating on all elements. */

     rval = MATRIX_INVERT(val[0].vec,val[1].vec) ;
     break ;

    case INPLACE_INVERT_FUNC :
     /* the outgoing and returning matrix are the same, but the same
       underlying C function is called. */
     n = (int)(val[1].val+.5) ;
     rval = MATRIX_INPLACE_INVERT(val[0].vec) ;
     break ;
```

```
   case INTERNAL_ROR_FUNC :
     n = (int)(val[4].val) ;
     rval = INTERNAL_ROR(val[0].val,val[1].val,val[2].val,val[3].val,
            n,val[5].val) ;
     break ;
   case MYMESSAGE_FUNC :
     rval = MYMESSAGE(val[0].literal,val[1].val) ;
     break ;
   case MYFINDZERO_FUNC :
     n = (int)(val[2].val + .5) ;
     rval = MYFINDZERO(val[0].vec,val[1].vec,n) ;
     break ;
   case MYLOOKUP_FUNC :
      rval = MYLOOKUP(val[0].tab,val[1].val) ;
      break ;
   case MYALLTYPES_FUNC :
      rval = MYALLTYPES(val[0].vec,val[1].literal,val[2].tab,val[3].vec,val[4].val) ;
      break ;
   case MYCONSTDEF_FUNC :
      rval = MYCONSTDEF(val[0].constmat,val[1].literal) ;
      break ;
   case MYDATADEF_FUNC :
      rval = MYDATADEF(val[0].datamat,val[1].literal) ;
      break ;

   default :
    return(0) ; /* indicate an error condition to Vensim */
   }
 /* set val[0], this value will be used in the equation output */
 val[0].val = (COMPREAL)rval ;
 return(1) ; /* a 1 return value signals vensim of successful completetion */
 }


/************************************************************************
 7 - actual function bodies - these could be a separate file
 ************************************************************************
 actual function bodies are all set up to use and return doubles
 (except when acting on vectors) this aids portability across different
 platforms and compilers as the C standard for floating point argument
 passing uses doubles.
 ************************************************************************/

float Solve_Sys_of_Nonlinear_Equations( int index,float par1, float par2, float par3,float par4, float par5, float par6,float par7,
float par8, float par9,float par10, float par11, float par12,float par13, float par14, float par15,float  par16, float par17, float
par18, float par19, float par20, float  par21,float par22, float par23, float par24,float par25, float par26, float par27,float par28,
float par29, float par30,float par31, float par32, float par33,float par34, float par35, float par36, float par37)
{
        int maxitn = 10000;
        float *x, err_rel = 0.00000000001, fnorm;

        float xguess[N] = {0.2, 0.2, 0.5, 0.5, 0.5,0.5, 0.5, 0.5, 0.5, 0.5, 0.5,0.5, 0.5, 0.5, 0.5, 0.5, 0.5,0.5, 0.5, 0.5, 0.5, 0.5,
0.5,0.5,0.5,0.5,0.5};
        OMt=par1;At=par2;K=par3;alpha=par4;L=par5;beta=par6;gamma=par7;theta=par8;gam1=par9;gam2=par10;gam3=p
ar11;
        a4=par12;a5=par13;mu4=par14;mu5=par15;k1=par16;k2=par17;k3=par18;k4=par19;k5=par20;b1=par21;b2=par22;
        b3=par23;PR1=par24;PR2=par25;PR3=par26;Pfz1=par27;Pfz2=par28;Pfz3=par29;rho=par30;Rz1=par31;Rz2=par32;Rz3
=par33;
```

```
//		x = imsl_f_zeros_sys_eqn(fcn, N,IMSL_ERR_REL, err_rel,IMSL_MAX_ITN, maxitn,IMSL_XGUESS, xguess,IMSL_FNORM,
&fnorm,0);
		return x[index];
}
void fcn(int n, float x[], float f[])
{
		f[0] = exp(x[0]) - OMt*At*pow(K,alpha)*pow(L,beta)*(pow(exp(x[1]),(1-alpha-beta)));
		f[1] = alpha*L*exp(x[2]) - beta*K*exp(x[3]);
		f[2] = alpha*exp(x[1])*exp(x[4]) - (1-alpha-beta)*K*exp(x[3]);
		f[3] = exp(x[0]) - exp(x[3])*K - exp(x[2])*L - exp(x[4])*exp(x[1]);
		// Production of energy services
		f[4] = pow(exp(x[1]), theta) -(gamma*pow(exp(x[5]),theta) + (1-gamma)*pow(exp(x[6]),theta));

		f[5] = gamma*exp(x[7])*pow(exp(x[6]),(1-theta)) - (1-gamma)*exp(x[8])*pow(exp(x[5]),(1-theta));
		f[6] = exp(x[4])*exp(x[1]) - exp(x[8])*exp(x[5])- exp(x[7])*exp(x[6]);
		// Electricity production

		// Heat energy production
		f[11] = exp(x[5]) - b1*exp(x[20]) - b2*exp(x[21]) - b3*exp(x[22]);
		f[12] = exp(x[5])*exp(x[8]) - (b1*exp(x[20])/exp(x[5]))*exp(x[23]) - (b2*exp(x[21])/exp(x[5]))*exp(x[24]) -
(b3*exp(x[22])/exp(x[5]))*exp(x[25]);
		f[13] = exp(x[20])*exp(x[17])*(2*(1-b1*exp(x[20])/exp(x[6])) - (rho*exp(x[20])/(PR1-exp(x[9])-exp(x[20])))) -
exp(x[21])*exp(x[18])*(2*(1-b2*exp(x[21])/exp(x[6])) - (rho*exp(x[21])/(PR2-exp(x[10])-exp(x[21]))));
		f[14] = exp(x[21])*exp(x[18])*(2*(1-b2*exp(x[21])/exp(x[6])) - (rho*exp(x[21])/(PR2-exp(x[10])-exp(x[21])))) -
exp(x[22])*exp(x[19])*(2*(1-b3*exp(x[22])/exp(x[6])) - (rho*exp(x[22])/(PR3-exp(x[11])-exp(x[22]))));
		// Nuclear and hydro electricity production
		f[15] = exp(x[12]) - a4*pow(k4,mu4);
		f[16] = exp(x[13]) - a5*pow(k5,mu5);
		// Fuel-price functions

		f[17] = Rz1*pow((exp(x[17])/Pfz1),(1/rho))-PR1+ exp(x[9])+ exp(x[20]);
		f[18] = Rz2*pow((exp(x[18])/Pfz2),(1/rho))-PR2+ exp(x[10])+ exp(x[21]);
		f[19] = Rz3*pow((exp(x[19])/Pfz3),(1/rho))-PR3+ exp(x[11])+ exp(x[22]);

		// Total cost functions for electricity
		f[20] = exp(x[14]) - exp(x[3])*k1 - exp(x[9])*exp(x[17]);
		f[21] = exp(x[15]) - exp(x[3])*k2 - exp(x[10])*exp(x[18]);
		f[22] = exp(x[16]) - exp(x[3])*k3 - exp(x[11])*exp(x[19]);
		// Total cost functions for heat energy
		f[23] = exp(x[23]) - exp(x[20])*exp(x[17]);
		f[24] = exp(x[24]) - exp(x[21])*exp(x[18]);
		f[25] = exp(x[25]) - exp(x[22])*exp(x[19]);
}



double COSINE(double x)
 {

		 return x;
  }
double INRANGE(double norm,double minval,double maxval)
 {
  if(norm > maxval)
    return(maxval) ;
  if(norm < minval)
    return(minval) ;
```

```
 return(norm) ;
 }
double PSUM(VECTOR_ARG *vec,double num_arg,int maxarg)
 {
 double rval ;
 int i,n ;
 if(num_arg > maxarg)
   num_arg = maxarg ;
 n = (int)(num_arg+.5) ;
 validate_vector_arg(vec,0,n) ;
 for(i=0,rval=0.0;i<n;i++)
   rval += vec->vals[i] ;
 return(rval) ;
 }


/*****************************************************************
 *****************************************************************
 7.2 MATRIX INVERSION

 This is done using an LU (Lower triangular, Upper triangular)
 decomposition.  Information on the algorithm is available in
   Numerical Recipes in C as referenced in the Reference Manual

 Note that the C functions take COMPREAL * and a dimension while
 the function call passes just the matrix - the dispatch routine
 checks squareness and adds in dimension
 *****************************************************************
 *****************************************************************/
#define TINY_VAL ((COMPREAL)1.0E-20)
void lu_decomposition(COMPREAL *a,int n,int *indx,COMPREAL *d,COMPREAL *vv) ;
void lu_back_substitution(COMPREAL *a,int n,int *indx,COMPREAL *b) ;

double MATRIX_INPLACE_INVERT(VECTOR_ARG *mat)
 {
 return(MATRIX_INVERT(mat,mat)) ;
 }
double MATRIX_INVERT(VECTOR_ARG *v_invmat,VECTOR_ARG *v_mat1)
 {
 int i,j,k ;
 COMPREAL d ;
 double rval ;
 COMPREAL *scratch ;
 static HANDLE scr_hndl ;
 static COMPREAL *tempmat ;
 int *indx ;
 COMPREAL *col ;
 int n ;
 COMPREAL *invmat,*mat1 ;

 /* validate the last two dimensions are same on both and also the same
   if not issue an error message and cause a floating point exception to
   give more info about the error */
 i = 0 ;
 if(v_invmat->dim_info->tot_dim < 2 || v_mat1->dim_info->tot_dim < 2)
   i = 1 ;
 else {
   n = v_invmat->dim_info->dim[v_invmat->dim_info->tot_dim-1] ;
```

```
  if(n != (int)v_invmat->dim_info->dim[v_invmat->dim_info->tot_dim-2]  ||
    n != (int)v_mat1->dim_info->dim[v_mat1->dim_info->tot_dim-1] ||
    n != (int)v_mat1->dim_info->dim[v_mat1->dim_info->tot_dim-2])
    i = 1 ;
  }
 invmat = v_invmat->vals ;
 mat1 = v_mat1->vals ;
 if(i) {
  vensim_error_message(VERROR,"Matrix inversion can only be preformed on square arrays (in last two dimensions)") ;
  v_invmat->vals[0] = (COMPREAL)0.0 ;
  return(1.0/invmat[0]) ;/* cause a floating point exception */
  }
 if(n > Matrix_invert_maxn) {
  if(!Matrix_invert_maxn)
   tempmat = (COMPREAL *)vext_allocate(n*n*sizeof(COMPREAL) +
          n*(2*sizeof(COMPREAL)+sizeof(int)),&scr_hndl) ;
  else
   tempmat = (COMPREAL *)vext_reallocate(n*n*sizeof(COMPREAL) +
          n*(2*sizeof(COMPREAL)+sizeof(int)),&scr_hndl) ;
  Matrix_invert_maxn = n ;
  }
 scratch = tempmat + n*n ;
 col = (scratch+n) ;
 indx = (int *)(col+n) ;

 /* first copy the matrix to its inverse, then work on inverse */
 for(i=0,k=0;i<n;i++)
  for(j=0;j<n;j++,k++)
   tempmat[k] = mat1[k] ;
 lu_decomposition(tempmat,n,indx,&d,scratch) ;
 if(d != 0.0) {
  for(j=0;j<n;j++) {
   for(i=0;i<n;i++)
    col[i] = (COMPREAL)0.0 ;
   col[j] = (COMPREAL)1.0 ;
   lu_back_substitution(tempmat,n,indx,col) ;
   for(i=0;i<n;i++)
    invmat[i*n+j] = col[i] ;
   }
  }
 if(d == 0.0) { /* return a 0 matrix */
  for(i=0,k=0;i<n;i++)
   for(j=0;j<n;j++,k++)
    invmat[k] = (COMPREAL)0.0 ;
  }
 rval = invmat[0] ; /* return first element */
 return(rval) ;
 }

void lu_decomposition(COMPREAL *a,int n,int *indx,COMPREAL *d,COMPREAL *vv)
{
 int i,j,k,imax ;
 COMPREAL big,dum,sum ;

 *d = (COMPREAL)1.0 ;
 for(i=0,k=0;i<n;i++) {
  big = (COMPREAL)0.0 ;
  for(j=0;j<n;j++,k++) {
```

```
      if(a[k] > big)
        big = a[k] ;
      else if(a[k] < 0 && -a[k] > big)
        big = -a[k] ;
      }
    if(big == 0.0) {
      *d = (COMPREAL)0.0 ;
      return ;
      }
    vv[i] = (COMPREAL)(1.0/big) ;
    }
  for(j=0;j<n;j++) {
    for(i=0;i<j;i++) {
      sum = a[i*n+j] ;
      for(k=0;k<i;k++)
        sum -= a[i*n+k]*a[k*n+j] ;
      a[i*n+j] = sum ;
      }
    big = (COMPREAL)0.0 ;
    for(i=j;i<n;i++) {
      sum = a[i*n+j] ;
      for(k=0;k<j;k++)
        sum -= a[i*n+k]*a[k*n+j] ;
      a[i*n+j] = sum ;
      dum = vv[i]*sum ;
      if(dum < 0.0)
        dum = -dum ;
      if(dum > big) {
        big = dum ;
        imax = i ;
        }
      }
    if(j != imax) {
      for(k=0;k<n;k++) {
        dum = a[imax*n+k] ;
        a[imax*n+k] = a[j*n+k] ;
        a[j*n+k] = dum ;
        }
      *d = -(*d) ;
      vv[imax] = vv[j] ;
      }
    indx[j] = imax ;
    if(a[j*n+j] == 0.0)
      a[j*n+j] = TINY_VAL ;
    if(j != n-1) {
      dum = (COMPREAL)1.0/a[j*n+j] ;
      for(i=j+1;i<n;i++)
        a[i*n+j] *= dum ;
      }
    }
  } /* lu_decomposition */

void lu_back_substitution(COMPREAL *a,int n,int *indx,COMPREAL *b)
 {
  int i,ii,ip,j ;
  COMPREAL sum ;
  ii= -1 ;
  for(i=0;i<n;i++) {
```

```
   ip = indx[i] ;
   sum = b[ip] ;
   b[ip] = b[i] ;
   if(ii != -1)
     for(j=ii;j<i;j++)
       sum -= a[i*n+j]*b[j] ;
   else if(sum)
     ii = i ;
   b[i] = sum ;
   }
 for(i=n;i-- > 0;) {
   sum = b[i] ;
   for(j=i+1;j<n;j++)
     sum -= a[i*n+j]*b[j] ;
   b[i] = sum/a[i*n+i] ;
   }
 } /* lu_back_substitution */


double INTERNAL_ROR(double inval,double time,double minval,double maxval,
         int streamid,double compute_flag)
{
 RORSTR *ror ;
 double result,npv,range ;
 int granular ;
 int i ;

 for(ror = Internal_ror_fror ;ror;ror=ror->next)
   if(ror->streamid == streamid)
     break ;
 if(!ror) {
   ror = (RORSTR *)vext_allocate(sizeof(RORSTR),'\0') ;
   ror->streamid = streamid ;
   ror->maxtimes = 101 ;
   ror->times = (COMPREAL *)vext_allocate(ror->maxtimes*sizeof(COMPREAL),&ror->times_hndl) ;
   ror->vals = (COMPREAL *)vext_allocate(ror->maxtimes*sizeof(COMPREAL),&ror->vals_hndl) ;
   ror->next = Internal_ror_fror ;
   ror->ntimes = 0 ;
   Internal_ror_fror = ror ;
   }
 if(compute_flag < 0.0) {
   ror->ntimes = 0 ;
   }
 if(compute_flag == 0.0)
   return(0.0) ;
 while(ror->ntimes > 0 && ror->times[ror->ntimes-1] > time)
   ror->ntimes-- ; /* back up if necessary */
 if(ror->ntimes >= ror->maxtimes) { /* reallocate */
   ror->maxtimes += 100 ;
   ror->times = (COMPREAL *)vext_reallocate(ror->maxtimes*sizeof(COMPREAL),&ror->times_hndl) ;
   ror->vals = (COMPREAL *)vext_reallocate(ror->maxtimes*sizeof(COMPREAL),&ror->vals_hndl) ;
   }
 ror->times[ror->ntimes] = (COMPREAL)time ;
 ror->vals[ror->ntimes] = (COMPREAL)inval ;
 ror->ntimes++ ;

 if(compute_flag > 1.0) {
   for(range = (maxval-minval)/4.0,result = (minval + maxval)/2.0,
```

```
        granular = 1;granular < 20;granular++,range /= 2.0) {
      npv = 0 ;
      for(i=0;i<ror->ntimes;i++)
        npv += ror->vals[i] * exp(result * (ror->times[0] - ror->times[i])) ;
      if(npv < 0.0)
        result -= range ;
      else if(npv > 0.0)
        result += range ;
      else
         break ;
      }
    return(result) ;
    }
  return(0.0) ;
  }


/*************************/
double MYMESSAGE(const char *message,double time)
 {
  char timestr[40] ;
  sprintf(timestr,"At time %g",time) ;
  MessageBox(NULL,message,timestr,
            MB_ICONSTOP | MB_OK) ;
  //return(1.0) ;
  /* note that we could also use the following call */
  vensim_error_message(INFORM,timestr) ;
  return(1.0) ;
  }

/*********************************
 Note the following will often fail it is included
 here as an example only */
double MYFINDZERO(VECTOR_ARG *vx,VECTOR_ARG *vy,int narg)
 {
  int i,j ;
  int rval ;
  double maxerr ;
  COMPREAL *x,*y ;
  char buf[128] ;
  validate_vector_arg(vx,0,narg) ;
  validate_vector_arg(vy,0,narg) ;
  x = vx->vals ;
  y = vy->vals ;
  if(x[0] == NA) { /* initialize */
    for(i=0;i<narg;i++)
      x[i] = (COMPREAL)1.0 ;
    }
  for(j=0;j<50;j++) {
    rval = (*VENGV->execute_curloop)() ;
    if(!rval) /* execution failuer - give up - should not happen */
       break ;
    if(rval == -1) { /* floating point error */
      (*VENGV->error_message)(VERROR,"Floating point error in solving MYFINDZERO") ;
      /* now generate a floating point error so that Vensim can report back on the problem
        vensim still knows where it trapped the problem - can't use raise(SIGFPE) because
        this causes everyting to close (via an untrapped exit call) */
      maxerr = (1.0+y[0])/(x[0] - x[0]) ; /* compiling this will likely generate a warning message */
```

```
      /* now we use maxerr otherwise the the above line will never be executed
        when the code is optimized */
      if(maxerr < 0)
        return -1 ;
      return NA ; /* give up for this example */
      }
    else {
      for(i=0,maxerr=0.0;i<narg;i++) {
        if(fabs(y[i]) > maxerr)
          maxerr = fabs(y[i]) ;
        x[i] += y[i]/10 ;
        }
      if(maxerr < 1.0E-4)
        break ;
      }
    }
  if(maxerr > 1.0E-4) {
    sprintf(buf,"MYFINDZERO convergance failure at time %g",VENGV->time) ;
    (*VENGV->error_message)(VERROR,buf) ;
    }
  return(x[0]) ;
  }

double MYLOOKUP(TAB_TYPE *tab,double x)
{
  REAL *xvals,*yvals ;
  int i ;
  if(!VENGV)
    return(NA) ;
  xvals = (REAL *)(VENGV->tabbase+tab->x) ;
  yvals = (REAL *)(VENGV->tabbase+tab->y) ;
  if(x <= xvals[0])
    return(yvals[0]) ;
  for(i=0;i<tab->lstind-1;i++) {
    if(x <= xvals[i+1])
      break ;
    }
  if(i == tab->lstind-1)
    return(yvals[tab->lstind-1]) ;
  return(yvals[i] + (yvals[i+1]-yvals[i])*(x-xvals[i])/(xvals[i+1]-xvals[i])) ;
  }

/* this is just to illustrate how different arguments are passed and in what order
  this is a self looping function taking one each of the different argument types
  note that the first argument is the left hand side variable passed as a vector */
double MYALLTYPES(VECTOR_ARG *lhs,const char *literal,TAB_TYPE *tab,VECTOR_ARG *vecarg,double x)
{
  int i,n ;
  i = 0 ;
  if(lhs->dim_info->tot_dim == 0|| vecarg->dim_info->tot_dim == 0)
    i = 1 ;
  else {
    n = lhs->dim_info->dim[lhs->dim_info->tot_dim-1] ;
    if(n != (int)vecarg->dim_info->dim[vecarg->dim_info->tot_dim-1])
      i = 1 ;
    }
  if(i) {
    (*VENGV->error_message)(VERROR,"The third argument must have same dimension as left hand side") ;
```

```
    lhs->vals[0] = (COMPREAL)0.0 ;
    return(1.0/lhs->vals[0]) ;/* cause a floating point exception */
    }
  for(i=0;i<n;i++)
    lhs->vals[i] = (COMPREAL)(vecarg->vals[i] * x) ;
  return(lhs->vals[0]) ;
  }
double MYCONSTDEF(CONSTANT_MATRIX *cmat,const char *literal)
{
  int i,j ;
  if(cmat->keyval != CONSTANT_MATRIX_KEY) {
    (*VENGV->error_message)(STOP,"Bad call to MYCONSTDEF") ;
    return 0 ;
    }
  /* just fill in the matrix with some simple numbers */
  (*VENGV->alloc_simmem)('\0',cmat,0) ;
  for(i=0;i<cmat->nrow;i++) {
    for(j=0;j<cmat->ncol;j++) {
      cmat->vals[i][j] = (REAL)(i * 100.0 + j) ;
      }
    }
  return(cmat->vals[0][0]) ;
  }
double MYDATADEF(DATA_MATRIX *dmat,const char *literal)
{
  int i,j ;
  REAL time,time_step,initial_time ;
  /* get the data over the simulation range - this may not work if
    any of TIME_STEP, INITIAL TIME or FINAL TIME are not constants */
  if(dmat->keyval != DATA_MATRIX_KEY) {
    (*VENGV->error_message)(STOP,"Bad call to MYDATADEF") ;
    return 0 ;
    }
  if(VENGV->time_step > 0)
    time_step = VENGV->time_step ;
  else
    time_step = 1 ;
  if(VENGV->initial_time != NA)
    initial_time = VENGV->initial_time ;
  else
    initial_time = 0.0 ;
  if(VENGV->final_time > initial_time)
    dmat->ntime = (long)((VENGV->final_time - initial_time)/time_step + 1.5) ;
  else
    dmat->ntime = 100 ;
  (*VENGV->alloc_simmem)(dmat,'\0',0) ;
  for(time=initial_time,j=0;j<dmat->ntime;j++,time+=time_step)
    dmat->timevals[j] = time ;
  for(i=0;i<dmat->nvar;i++) {
    for(j=0;j<dmat->ntime;j++) {
      dmat->vals[i][j] = (REAL)(i * 100.0 + j) ;
      }
    }
  return(dmat->vals[0][0]) ;
  }
```

APPENDIX C: DISAGGREGATION MODEL CODE (R)

APPENDIX D: PREVIOUS REPORTS IN THE SERIES

ISSN: (print) 1913-3200; (online) 1913-3219

(1) Slobodan P. Simonovic (2001). Assessment of the Impact of Climate Variability and Change on the Reliability, Resiliency and Vulnerability of Complex Flood Protection Systems. Water Resources Research Report no. 038, Facility for Intelligent Decision Support, Department of Civil and Environmental Engineering, London, Ontario, Canada, 91 pages. ISBN: (print) 978-0-7714-2606-3; (online) 978-0-7714-2607-0.

(2) Predrag Prodanovic (2001). Fuzzy Set Ranking Methods and Multiple Expert Decision Making. Water Resources Research Report no. 039, Facility for Intelligent Decision Support, Department of Civil and Environmental Engineering, London, Ontario, Canada, 68 pages. ISBN: (print) 978-0-7714-2608-7; (online) 978-0-7714-2609-4.

(3) Nirupama and Slobodan P. Simonovic (2002). Role of Remote Sensing in Disaster Management. Water Resources Research Report no. 040, Facility for Intelligent Decision Support, Department of Civil and Environmental Engineering, London, Ontario, Canada, 107 pages. ISBN: (print) 978-0-7714-2610-0; (online) 978-0-7714- 2611-7.

(4) Taslima Akter and Slobodan P. Simonovic (2002). A General Overview of Multiobjective Multiple-Participant Decision Making for Flood Management. Water Resources Research Report no. 041, Facility for Intelligent Decision Support, Department of Civil and Environmental Engineering, London, Ontario, Canada, 65 pages. ISBN: (print) 978-0-7714-2612-4; (online) 978-0-7714-2613-1.

(5) Nirupama and Slobodan P. Simonovic (2002). A Spatial Fuzzy Compromise Approach for Flood Disaster Management. Water Resources Research Report no. 042, Facility for Intelligent Decision Support, Department of Civil and Environmental Engineering, London, Ontario, Canada, 138 pages. ISBN: (print) 978-0-7714-2614-8; (online) 978-0-7714-2615-5.

(6) K. D. W. Nandalal and Slobodan P. Simonovic (2002). State-of-the-Art Report on Systems Analysis Methods for Resolution of Conflicts in Water Resources Management. Water Resources Research Report no. 043, Facility for Intelligent Decision Support, Department of Civil and Environmental Engineering, London, Ontario, Canada, 216 pages. ISBN: (print) 978-0-7714-2616-2; (online) 978-0-7714-2617-9.

(7) K. D. W. Nandalal and Slobodan P. Simonovic (2003). Conflict Resolution Support System – A Software for the Resolution of Conflicts in Water Resource Management. Water Resources Research Report no. 044, Facility for Intelligent Decision Support, Department of Civil and Environmental Engineering, London, Ontario, Canada, 144 pages. ISBN: (print) 978-0-7714-2618-6; (online) 978-0-7714-2619-3.

(8) Ibrahim El-Baroudy and Slobodan P. Simonovic (2003). New Fuzzy Performance Indices for Reliability Analysis of Water Supply Systems. Water Resources Research Report no. 045, Facility for Intelligent Decision Support, Department of Civil and Environmental Engineering, London, Ontario, Canada, 90 pages. ISBN: (print) 978-0-7714-2620-9; (online) 978-0-7714- 2621-6.

(9) Juraj Cunderlik (2003). Hydrologic Model Selection for the CFCAS Project: Assessment of Water Resources Risk and Vulnerability to Changing Climatic Conditions. Water Resources Research Report no. 046, Facility for Intelligent Decision Support, Department of Civil and Environmental Engineering, London, Ontario, Canada, 40 pages. ISBN: (print) 978-0-7714- 2622-3; (online) 978-0-7714- 2623-0.

(10) Juraj Cunderlik and Slobodan P. Simonovic (2004). Selection of Calibration and Verification Data for the HEC-HMS Hydrologic Model. Water Resources Research Report no. 047, Facility for Intelligent Decision Support, Department of Civil and Environmental Engineering, London, Ontario, Canada, 29 pages. ISBN: (print) 978-0-7714-2624-7; (online) 978-0-7714-2625-4.

(11) Juraj Cunderlik and Slobodan P. Simonovic (2004). Calibration, Verification and Sensitivity Analysis of the HEC-HMS Hydrologic Model. Water Resources Research Report no. 048, Facility for Intelligent Decision Support, Department of Civil and Environmental Engineering, London, Ontario, Canada, 113 pages. ISBN: (print) 978- 0-7714-2626-1; (online) 978-0-7714- 2627-8.

(12) Predrag Prodanovic and Slobodan P. Simonovic (2004). Generation of Synthetic Design Storms for the Upper Thames River basin. Water Resources Research Report no. 049, Facility for Intelligent Decision Support, Department of Civil and Environmental Engineering, London, Ontario, Canada, 20 pages. ISBN: (print) 978- 0-7714-2628-5; (online) 978-0-7714-2629-2.

(13) Ibrahim El-Baroudy and Slobodan P. Simonovic (2005). Application of the Fuzzy Performance Indices to the City of London Water Supply System. Water Resources Research Report no. 050, Facility for Intelligent Decision Support, Department of Civil and Environmental Engineering, London, Ontario, Canada, 137 pages. ISBN: (print) 978-0-7714-2630-8; (online) 978-0-7714-2631-5.

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