ISGAN Project

Annex 3

BENEFIT & COST ANALYSES AND TOOLKITS

A Manual for

Smart Grid BCA Toolkit Revised by EML

AJOU UNIVERSITY

February 2015

International Smart Grid Association Network (ISGAN)

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I. Introduction

The SGCT is an analysis tool that identifies the benefits of a SG project and guides the user through an analysis which quantifies those benefits. It characterizes smart grid (SG) projects by identifying what technology will be installed and what functionality that technology will enable. Based on the characterization of a project it identifies the economic, reliability, environmental and security benefits the SG project will yield. The SGCT uses user entered data to calculate the monetary value of benefits and prepares graphs and tables that compare the costs and benefits to help determine the project's overall value. The SGCT can also perform a sensitivity analysis.

The SGCT adopts an EPRI-based methodology to evaluating the Cost-Benefit Analysis of smart grid projects. The SGCT calculates the incremental costs and benefits of individual existing smart grid technologies. The user inputs the assets that their project will add to the power grid. Next the user chooses the functions that will be added to the grid by the application of the assets. Then the user adds mechanisms that result from the functions. These mechanisms determine the benefits that the project will yield. The final step is to monetize the value of these benefits through the use of provided calculation formulas.

The SGCT has a few issues that limit it from producing a definitive assessment of smart grid value. A key trait that could use more representation in the SGCT is flexibility. It struggles to combat some of the most common challenges of evaluating smart grids. The combined factors of fast-changing information technology, novel and cost-effective resources, multiple and overlapping energy markets, and new business strategies leads to high uncertainty about the future of smart grids, yet the SGCT relies on predefined assets that affect predefined functions that define predefined mechanisms which lead to predefined benefits. All of these predefined inputs are less valuable when considering the uncertainties and the assumptions being made.

Along with uncertainties of the future there is also some uncertainty as to what defines a smart grid. It is nearly impossible to take into account all of the complicating differences between one project and another. There can be any number of differing factors as a result of location alone.

The combined influence of all these uncertainties reduces the value of the single estimate of smart grid value that the SGCT produces. The SGCT methodology defines a standardized set of assets, functions, and benefits in order to evaluate all smart grid projects consistently. Yet it does not help address the numerous uncertainties.

The value of smart grid will be driven by future demand and supply side developments in the electricity sector. The SGCT provides an estimate based on the state of the present and current technologies and is unable to be updated as new information arises.

Another issue with the SGCT is based on its execution. The SGCT is an Excel-based program that was developed using Excel macro. While Excel macro combined with spreadsheet capability is a powerful platform to develop a program such as the SGCT, it has a number of disadvantages.

The excel-based toolkit has less than stellar performance. When running an analysis on an example smart grid project the SGCT has a long execution time which can be frustrating when trying to run detailed analyses with many different scenarios and assumptions.

Excel macro has low scalability and limited capability. The SGCT does not have the analysis capabilities required to accurately study the value of future smart grid power systems. It is limited in its ability to run truly detailed analyses. The SGCT attempts to provide reliable data on the incremental costs and benefits of smart grid technologies but it does not have the scale to do so. The SGCT lacks the potential to accommodate for growth in future smart grid investments.

In a similar vein the excel macro program is also limited in writing sophisticated computational algorithms. The SGCT relies on a simplified modelling approach by evaluating a standardized set of assets, functions, and benefits. The linkage among them, however, is not quite clear and not easy to understand by just examining this excel based SGCT. It also leads to an inability to handle unusual situations and circumstances.

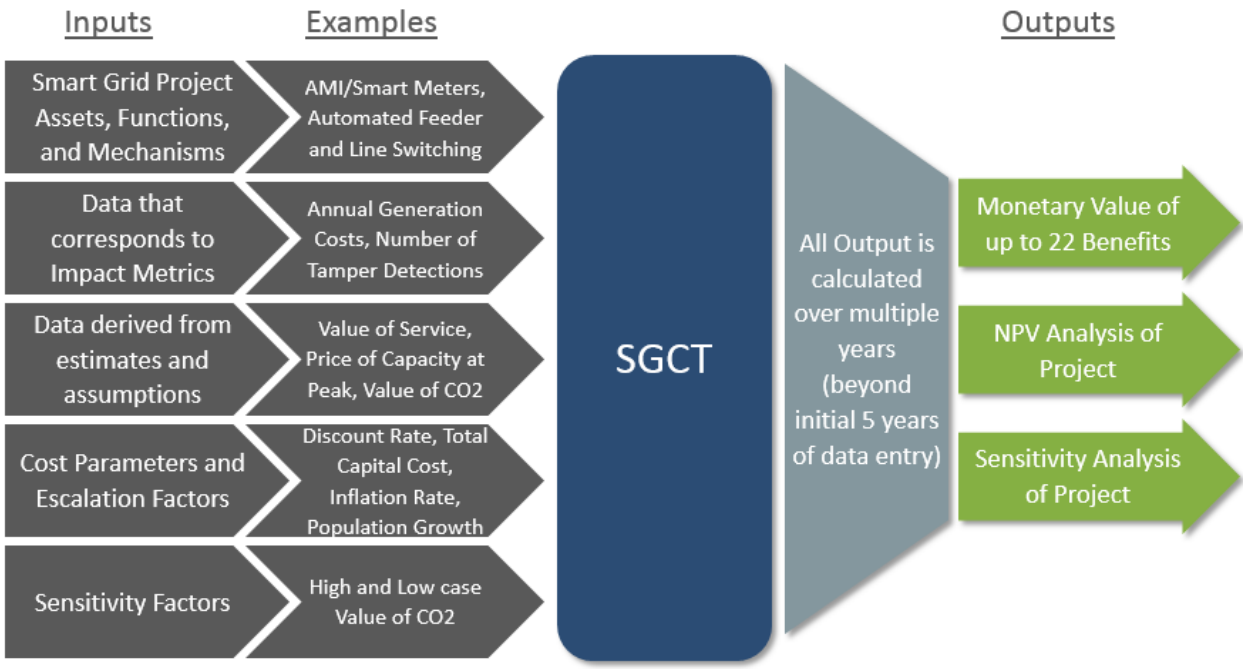


Figure 1 Illustration of the Input and Output of SGCT

Above all, the current SGCT is basically designed for the use of US smart grid projects and is not for any other member countries.

This manual is for the simple replicated version of SGCT of DOE, but it expands the users to all the member countries and all the parameters which are hidden in SGCT can be modified explicitly by the users.

In the following, a brief introduction of SGCT is given first,especially with its focus to the linkage among assets, functions, and benefits. Other details of the workflow including project characterization module (PCM), data inputmodule (DIM) and computational module (CM) will be summarized in the appendix I.

Then, the current replicated and revisedversion of SGCT is presented:

1. Installation process
2. File Structure when installed
3. Brief Explanation of the program – How to use the program?
    A. How a member country can use this program
    B. How to modify the given parameters using default excel files – details of the parameters used in SGCT is provided at Appendix II.
    C. How to choose Assets, Functions and Mechanisms
    D. Continuingfor Final Results
    E. Other issues to run the program
4. Detailed Architecture in the Replication of SGCT
5. Project Characterization Module in SGCT and Its GUI Replication
6. Comparison of Data Input Module in SGCT and Its GUI Replication
7. Computational Module in SGCT and Its GUI Replication

II. A Brief Review of SGCT

In the following diagram, the linkage among assets, functions, and benefits is presented in a very easy way, although the diagram looks a bit complicated. The explanation on such linkage is not quite straight forward when using SGCT of DOE. At appendix I, the details of the linkage between Assets and Functions are given at one table, while the linkage between function and benefits are presented in another table. Combining the two tables into one diagram will simply produce the following diagram.

Once Asset types are selected for smart grid out of 22 assets, those will be linked to 15 types of functions. Those functions will have their linkage to related types of benefits. There are 22 types of benefits presented in SGCT.

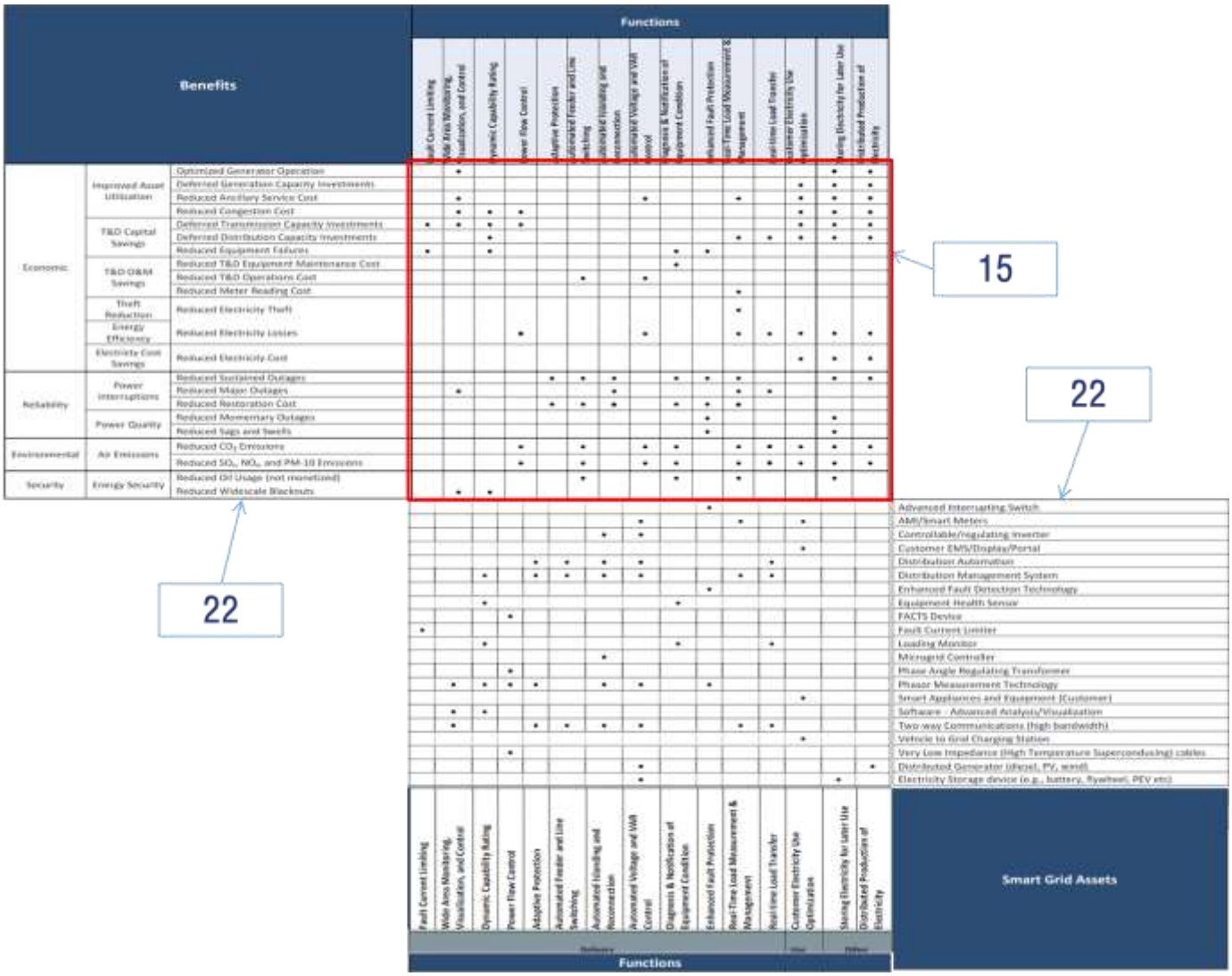


Figure 2 Easy Representation of the Linkage among Assets, Functions, and Benefits

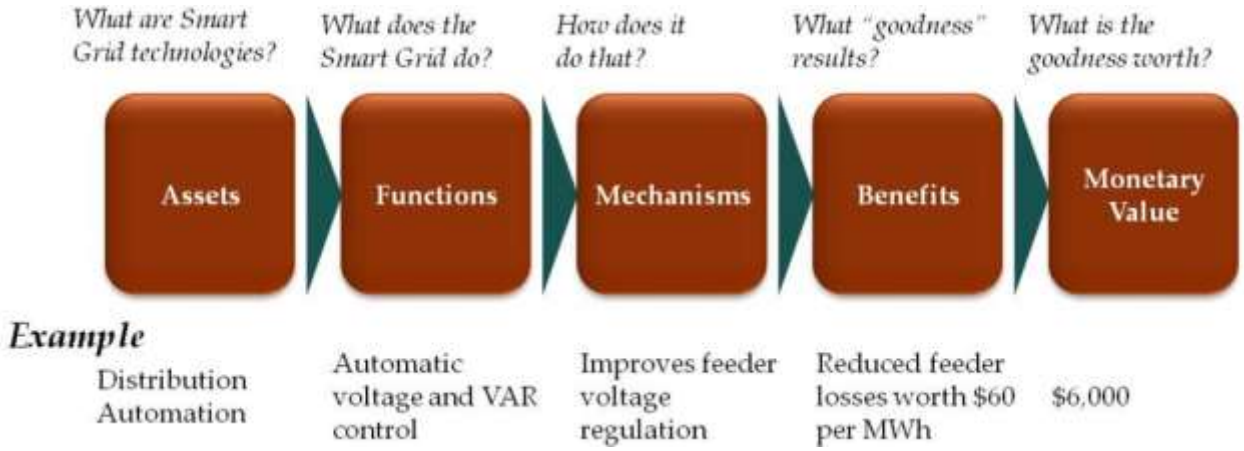


Figure 3 Illustration of the Translation of Smart Grid Assets to Monetary Value

Source: USER GUIDE FOR THE U.S. DEPARTMENT OF ENERGY SMART GRID COMPUTATIONAL TOOL (SGCT) Guide for SGCT Public Version 1.3, Navigant Consulting, March 2011

In the above diagram of SGCT, however, you will see 'Mechanisms' not in the linkage described above. But these are the detailed functional forms to be applied once the linkage between functions and benefits are identified. Appendix I provides a couple of examples of the detailed functional form of 'Mechanisms'.

III. Replicated and Revised Version of SGCT

III.1 Installation Process

First step of installation is really an easy process. Just insert the CD into the computer and the program will automatically install the program. This CD contains installation program 'dotNetFx45_Full_setup.exe'.

Figure 4 Installation CD for Smart Grid BCA Toolkit Revised by EML (Energy Modeling Lab., Ajou Univ.)

All you have to do is to determine where to install at the following dialog box. Choosing the 'change …' button at the following dialog box will give the user a chance to change the default directory to his own choice.

Once the file is installed, the following icon can be see at the desktop background such as following:

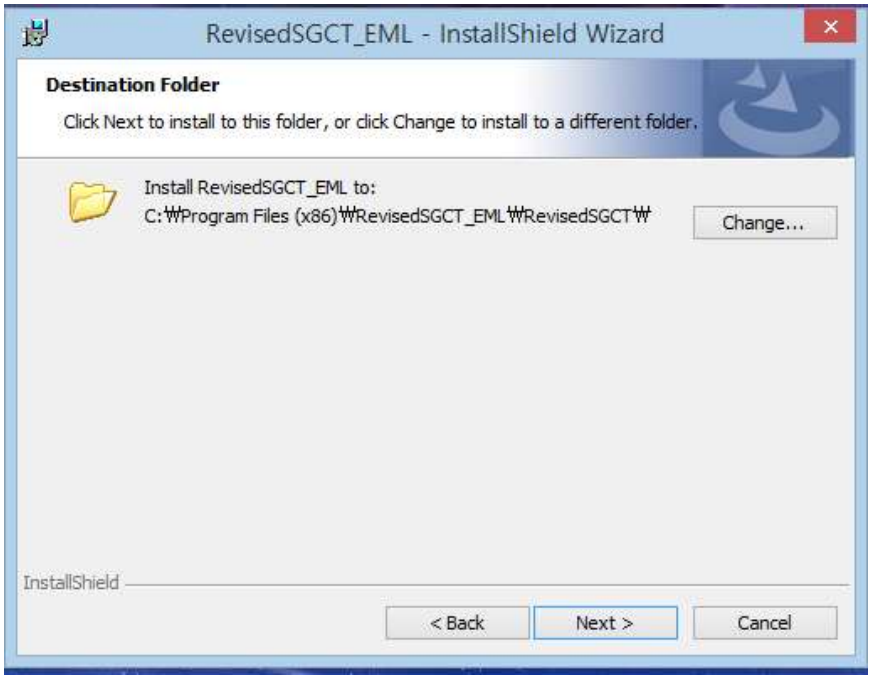


Figure 5 Directory Setting Dialog Box

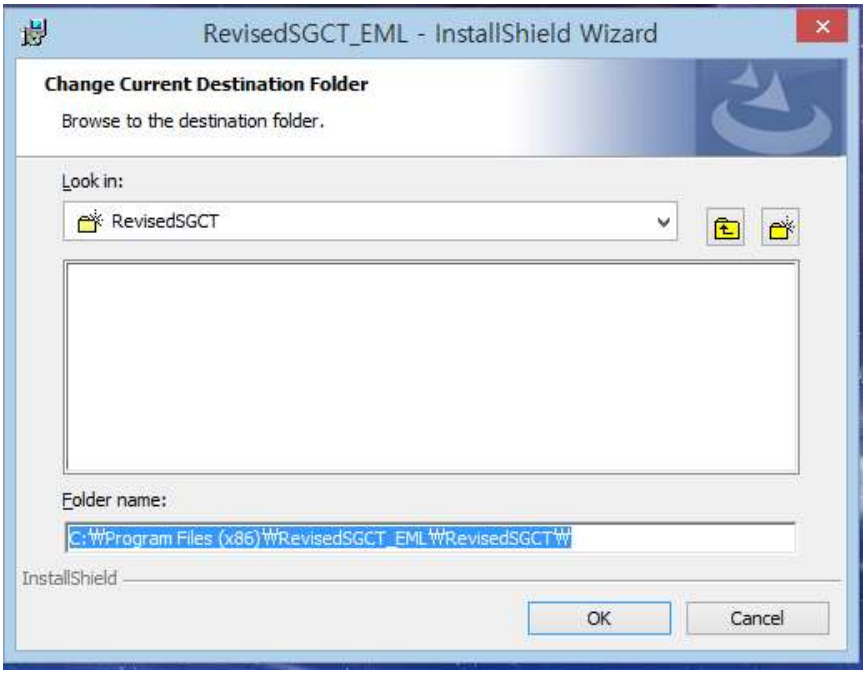


Figure 6 User's Choice of Folder for Installation

III.2 File Structure when installed

Once installed, you will see the directory structure such as following:

At the root directory, you will see the following files:

/data

/xml

ClassLibrary.dll

ControlLibrary.dll

DevExpress.Charts.v14.1.Core.dll

DevExpress.Data.v14.1.dll

DevExpress.Mvvm.v14.1.dll

DevExpress.Xpf.Charts.v14.1.dll

DevExpress.Xpf.Controls.v14.1.dll

DevExpress.Xpf.Core.v14.1.dll

dotNetFx45_Full_setup.exe

ISGAN Project.exe

For the subfolder of /data,

/data/constants.csv

/data/default-values.csv

/data/escalated-factors.csv

For the subfolder of /xml,

/xml/config.xml

/xml/input-def.xml

/xml/project-def.xml

/xml/sys-def.xml

'ISGAN Project.exe' is the execution file for the Smart Grid BCA Toolkit Revised by EML. Following is the initial page of the replicated and revised version of SCGT.

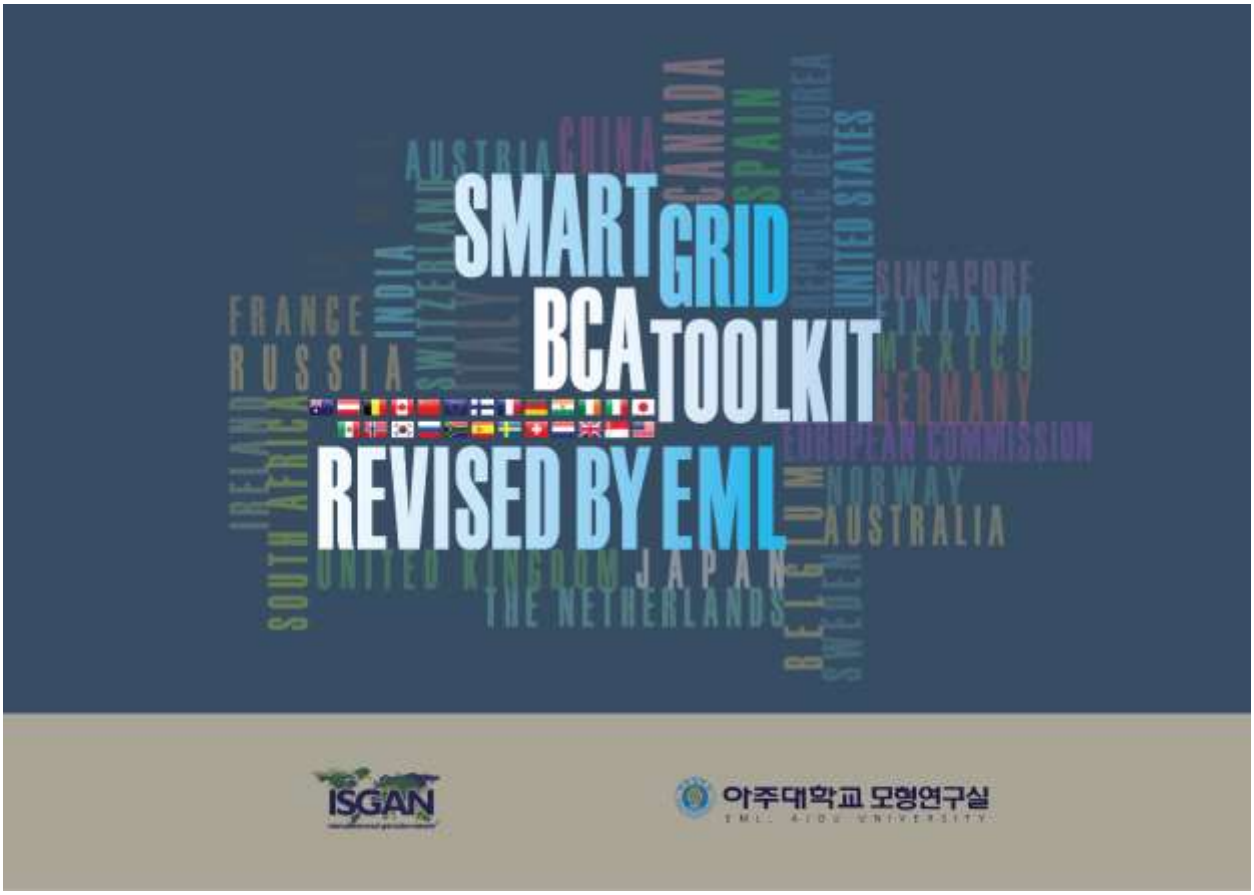


Figure 7 Initial Page of the Replicated Program

III.3 Brief Explanation of the program – How to use the program?

Clicking any place on the initial page will guide to the initial program page of the following:

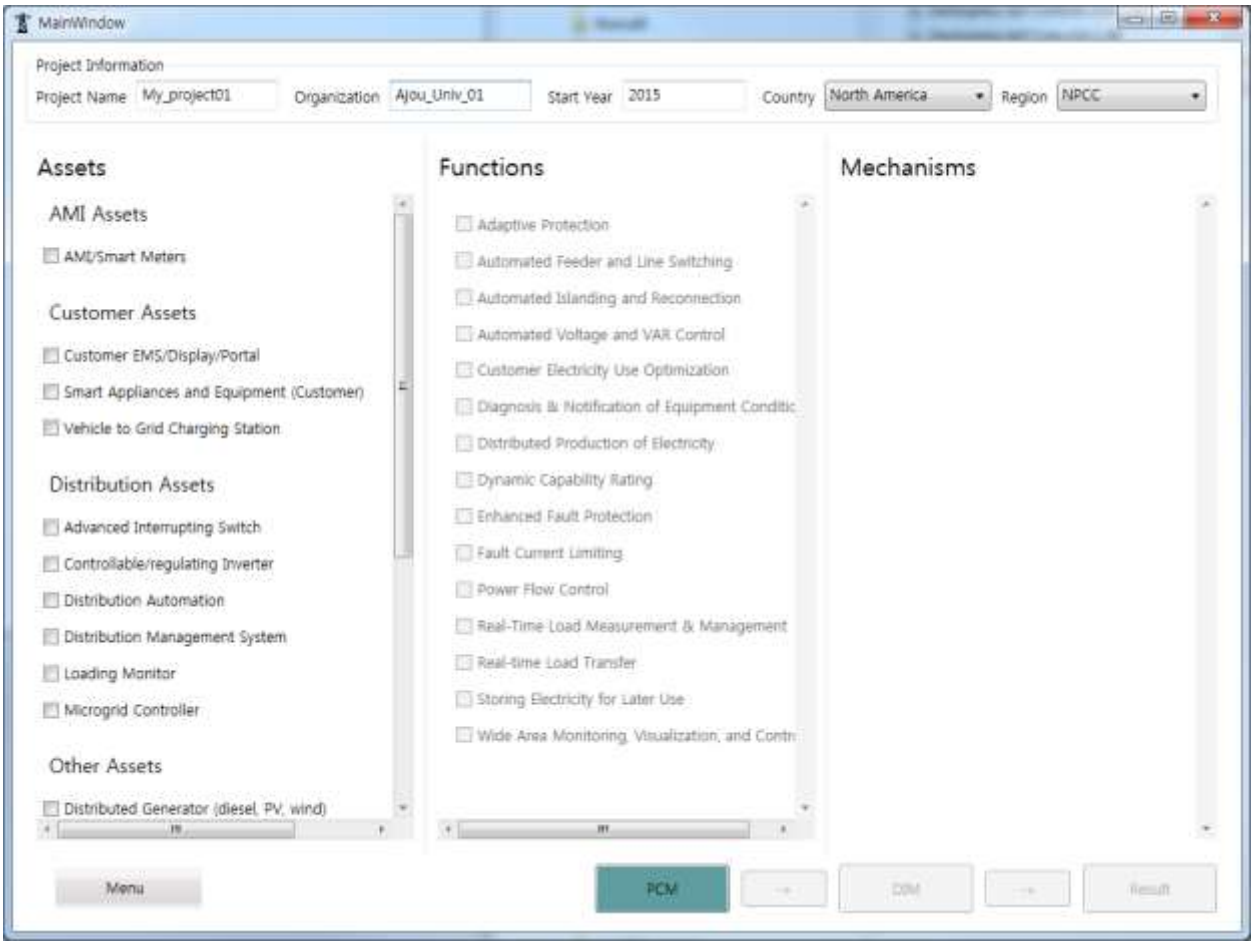


Figure 8 Initial Page of Program

Project information

At the top of the page, you will see the project information related boxes. Default values for

- ✓ Project Name
- ✓ Organization
- ✓ Start Year

will be given for convenience. User will edit or change the project information for his own.

III.3.1 How a member country can use this program

Country

As is explained, the SGCT is originally designed for North America composed of 10 NERC (North American Electric Reliability Corporation) regions and extra one region not in NERC. For this program to be usable for all ISGAN member countries, this designated region should be expanded to all the member countries of ISGAN.

In the following diagram, it can be seen that the choice is expanded for all the member countries.

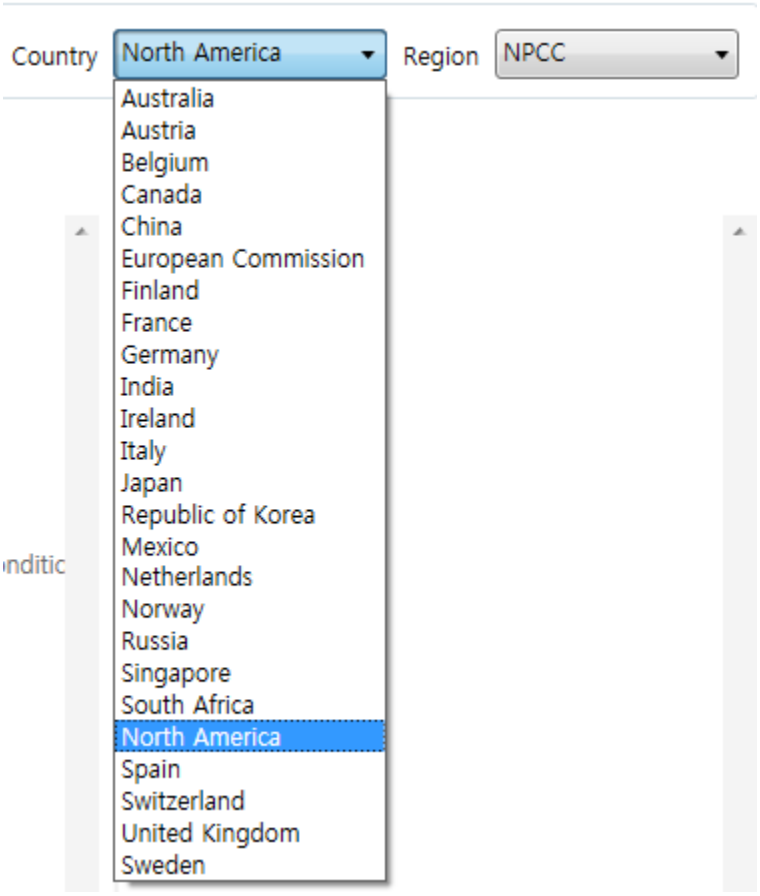


Figure 9 Expansion of Country Choices to all ISGAN Member Countries

However, the parameters used in SGCT are predefined only for those 11 regions including NERC and non-NREC. This part of the SCGT is one of the most important parts of the program. How to choose the choice of your own region and related parameters proper to use will be the critical part of the proper utilization of the program.

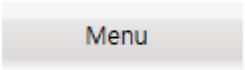
Let's first look at the all the parameters applied in this part, once the region of your choice is selected. Followings are the list of parameters required to use for analysis of your own region:

- ✓ Average Hourly Generation Cost ($/MWh), which is the average hourly cost to generate 1 MWh of energy, which could also be the average hourly cost to purchase 1 MWh of electricity from a supplier, which number is multiplied by the Avoided Annual Generator Dispatch to monetize the value of this benefit
- ✓ Price of Capacity at Annual Peak ($/MW) , which is the price paid for peak capacity,
- ✓ Average Price of Reserves ($/MW), which is the price of electricity reserves, which could be spinning or non-spinning type.
- ✓ Average Price of Frequency Regulation ($/MW), which is the price of frequency regulation service.
- ✓ Average Price of Voltage Control ($/MW), which is the price of voltage control service.
- ✓ Average Price of Congestion ($/MW), which is the price of congestion relief
- ✓ Average Price of Wholesale Energy ($/kWh), which is the average of wholesale price of electricity, which input will be used to monetize electricity losses.
- ✓ Inflation Factor
- ✓ Restoration Cost per Event($/event), which is the average cost of restoration after one outage event
- ✓ Average Fuel Efficiency for Truck Roll (miles/ gallon), which is the average vehicle or fleet fuel efficiency of the vehicles used for service calls and truck rolls.
- ✓ CO2 Emissions per Gallon of Fuel (tons/ gallon), which is the typical amount of CO2 emitted from burning a gallon of fuel in vehicles used for service calls and truck rolls. The default data is based on gasoline.
- ✓ Value of CO2, the anticipated/current market price of CO2 emissions
- ✓ SOx Emissions per Gallon of Gas (tons/gallon), which is the typical amount of SOx emitted from burning a gallon of fuel in vehicles used for service calls and truck rolls. The default data is based on gasoline
- ✓ NOx Emissions per Gallon of Gas (tons/gallon), which is the typical amount of NOx emitted from burning a gallon of fuel in vehicles used for service calls and truck rolls. The default data is based on gasoline
- ✓ Value of SOx, the anticipated/current market price of SOx emissions
- ✓ Value of NOx, the anticipated/current market price of NOx emissions
- ✓ Value of PM-2.5, the anticipated/current market price of PM-10 (or PM-25) emissions
- ✓ Average Fuel Efficiency (miles/gallon), which is the average vehicle or fleet fuel efficiency of the vehicles used for service vehicle.
- ✓ Electricity to Fuel Conversion Factor (gallons/kWh), the equivalent amount of gasoline a PEV would use by consuming one kWh of electricity

Details of the parameter values are found at Appendix II. Some of the parameters could be directly obtained from domestic market conditions, while others may not be. Until the detailed data base for all the possible choices of the regions for each member countries, not all of those parameter information may be available.

Configuration and Other Choices in Menu

Here is how we revised, once again, for the use of the program:



1. Choose Menu at the lower left corner of the initial program page.
2. Clicking Menu will give the following pull-down menus.

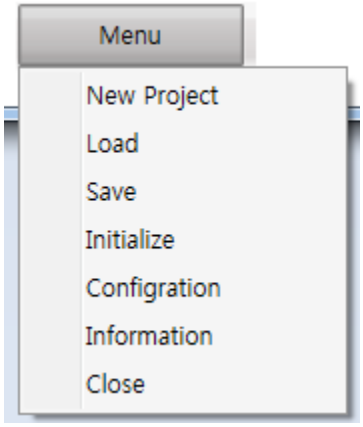


Figure 10 Pull-down Menu of Menu

3. Select Configuration, then you will see the following diagram. There are many options you can choose.
   A. Digit will allow you to control the digits below decimal point.
   B. Parameter setting will allow you to take the default values from North America and modify them at your own disposal. That is, you can choose any specific region out of NERC or take the average of NERC with 'similarity weight' of your own choice in between 0 to 100%. Details are as following:
      - In the following dialog box after choosing 'Configuration' in Menu, user can add country name (when a new member country is added or any other country might want to try the program!) by clicking 'Add' button just below the Country list.

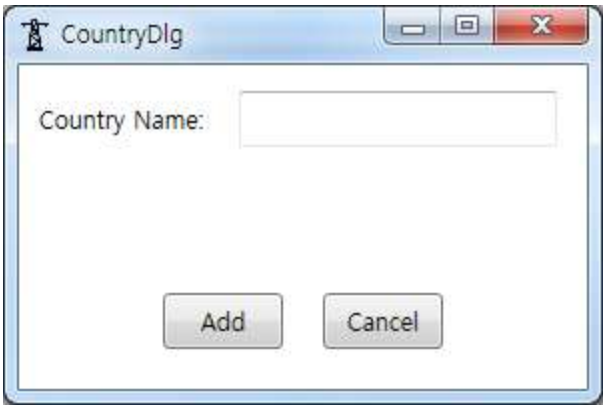


Figure 11 Addition of a New Country

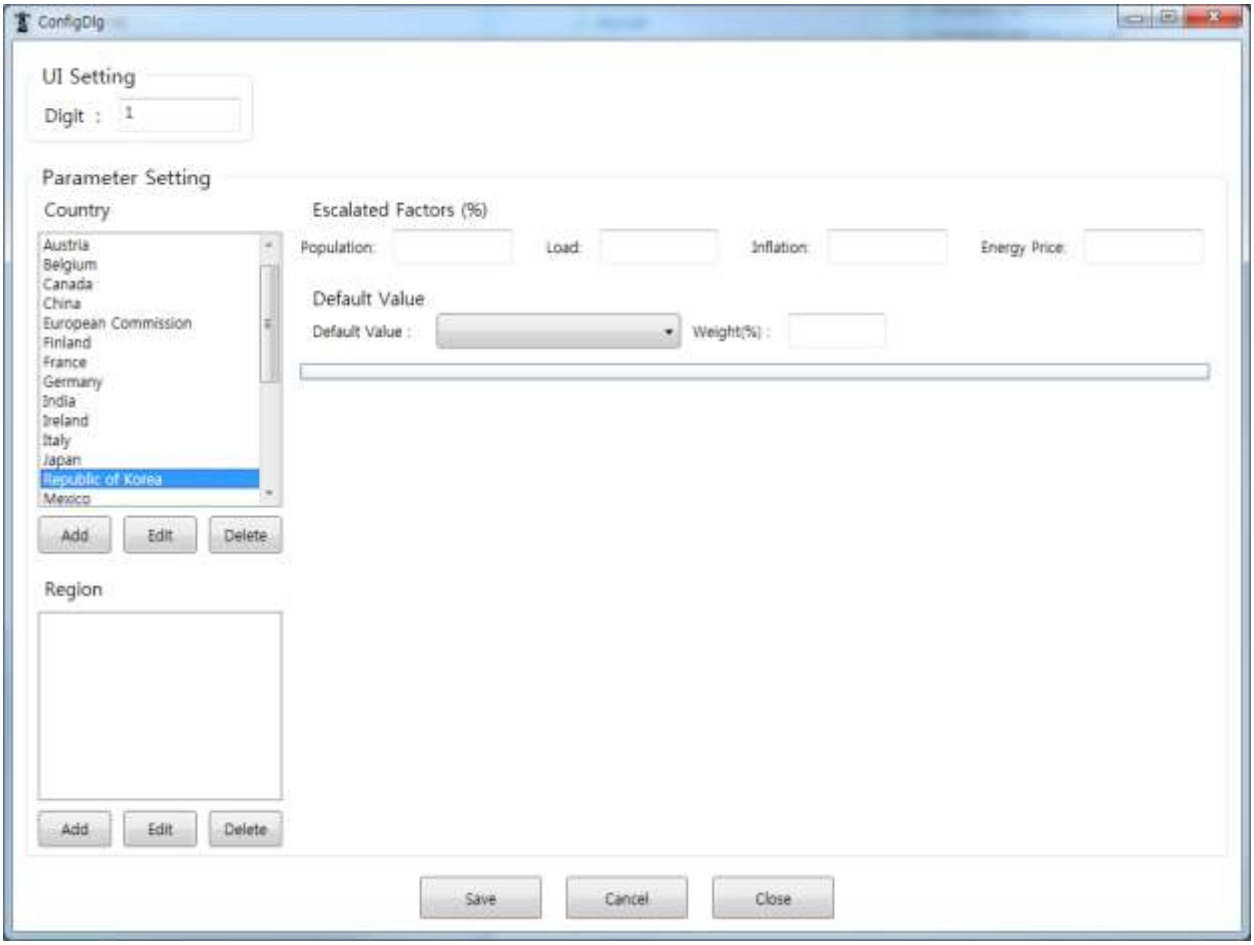


Figure 12 Dialog box for 'Configuration' in Menu

- When a country is selected and a user's choice of region is to be added, choose the button 'Add' down below the Region.
- This will give the user a choice of parameter values to be used. He can give his own region name and choose to copy the default parameter values from North America's

NERC regions. Even if he chooses not to, this process of copying the parameter values will create and save the values for his own region so that he can modify it later at his disposal.

- 'Similarity weight (%)' is what you can use for discounting the default parameter values at 0 to 100% range. Once the values are saved, user can utilize the saved data file for further modification. (Details are explained in the following subchapter.)
- User may also want to modify the values one by one once the region of his choice is added. With the cursor on the newly added region (here, it is named as 'My Region' as below), choosing the pull-down menu next to 'Default Value' will give all the detailed choices possible.

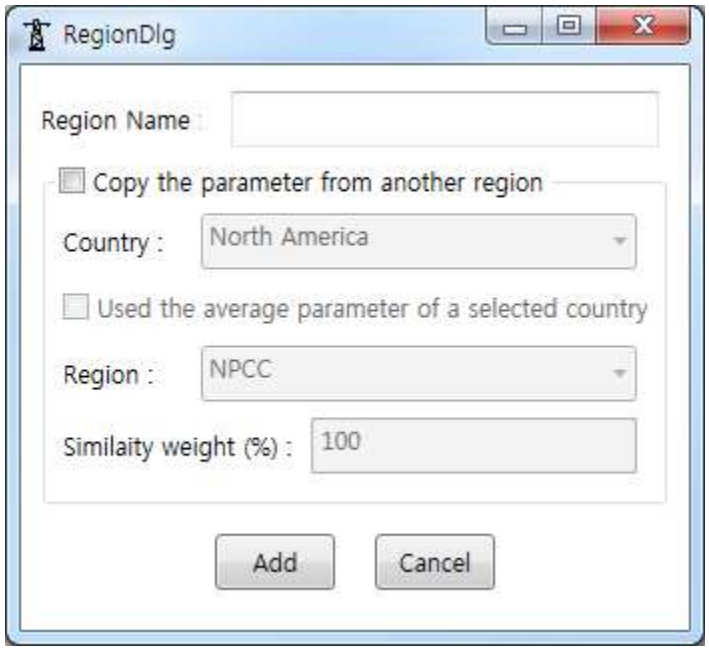


Figure 13 Addition of New Region and the Use of Parameter Values

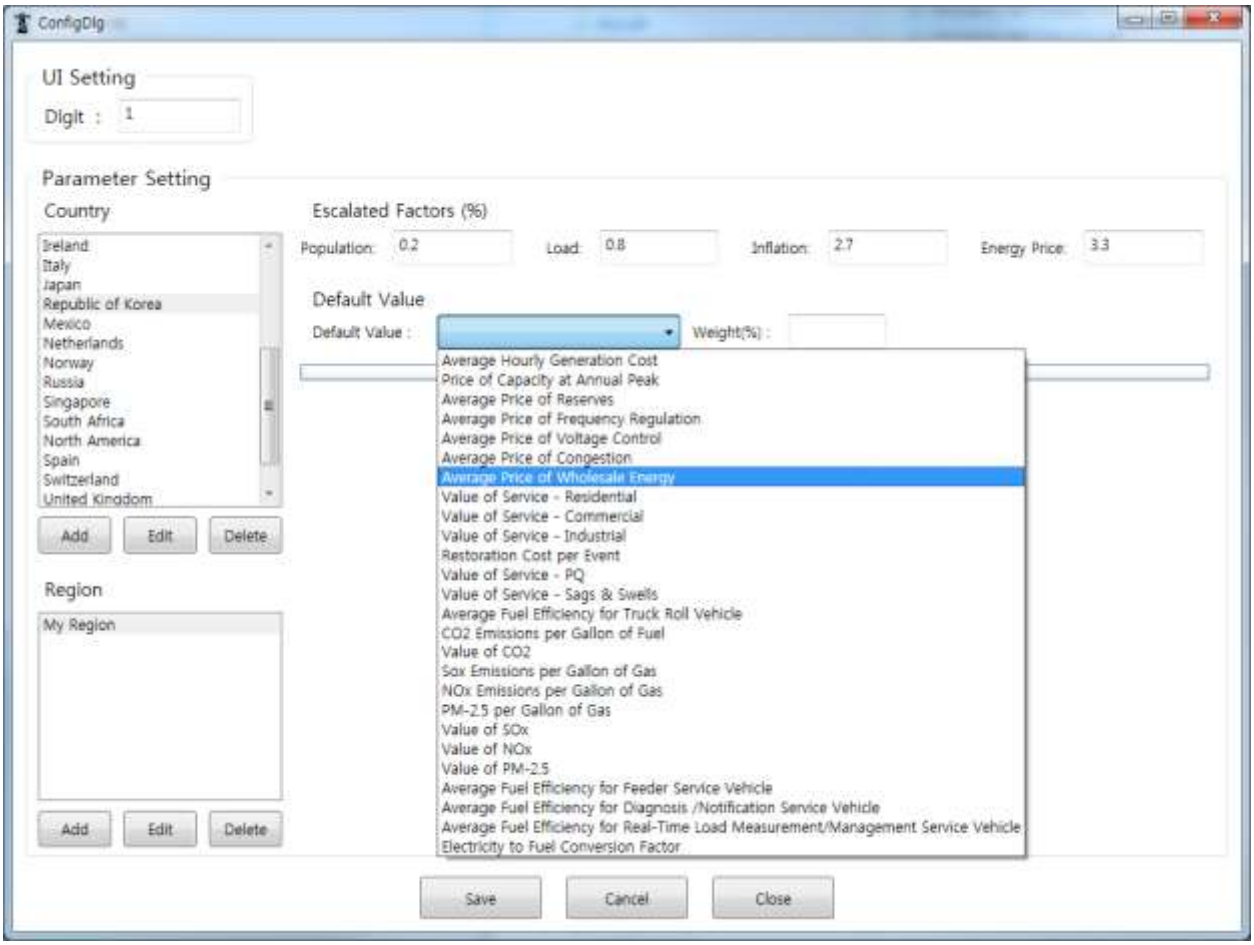


Figure 14 Detailed Items for the Change of Default Parameter Values

- Suppose the user chose 'Average Price of Wholesale Energy', there will be the default values of the user's choice shown as below and the user can edit them right at the dialog box.

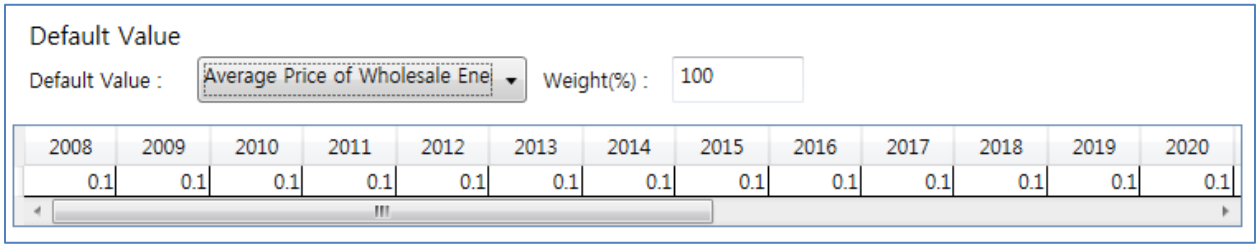


Figure 15 Values Shown at the Dialog Box

C. (For advanced users) You can also change the excel files which contains the parameter values of your own choice once your project is 'Save'd at the above Menu. Detailed explanation will be given in the next subchapter.

4. Once the parameter values are properly input, you can 'Save' and 'Close' the dialog box to continue.

5. Other items in the above Menu are simple:
   A. The choice of 'New Project' will ask you whether you want to save the current project to initiate a new one as following:

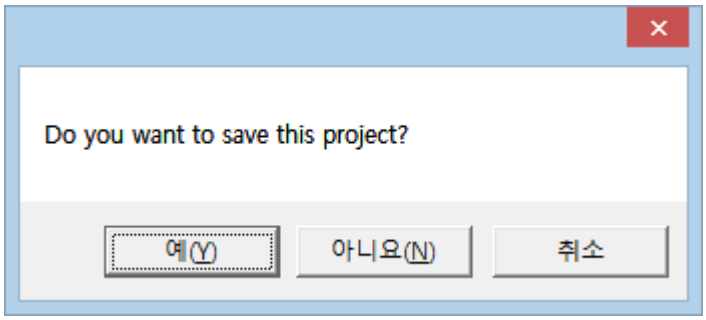


Figure 16 Dialog box for 'New Project' in Menu

   B. The choice of 'Save' or 'Load' will ask you whether you want to save the current project or load any existing project.
   C. The choice of 'Information' will provide information on those who worked for this project.

III.3.2 How to modify the given parameters using default excel files

(For advanced users) As discussed, user can also change the excel files which contains the parameter values of your own choice once your project is 'Save'd at the above Menu. This will be useful when there are so many parameters to modify. You don't have to go through the GUi of the revised SGCT one by one. Rather, you can go directly to the portion of excel file which contains the values for your region after you saved your project, and modify the values with your prior knowledge of domestic market with all the functionalities provided by excel.

III.3.3 How to choose Assets, Functions and Mechanisms

This replicated and revised SGCT by EML has very much simplified the process of linkage among assets, functions and mechanisms shown in the following diagram.

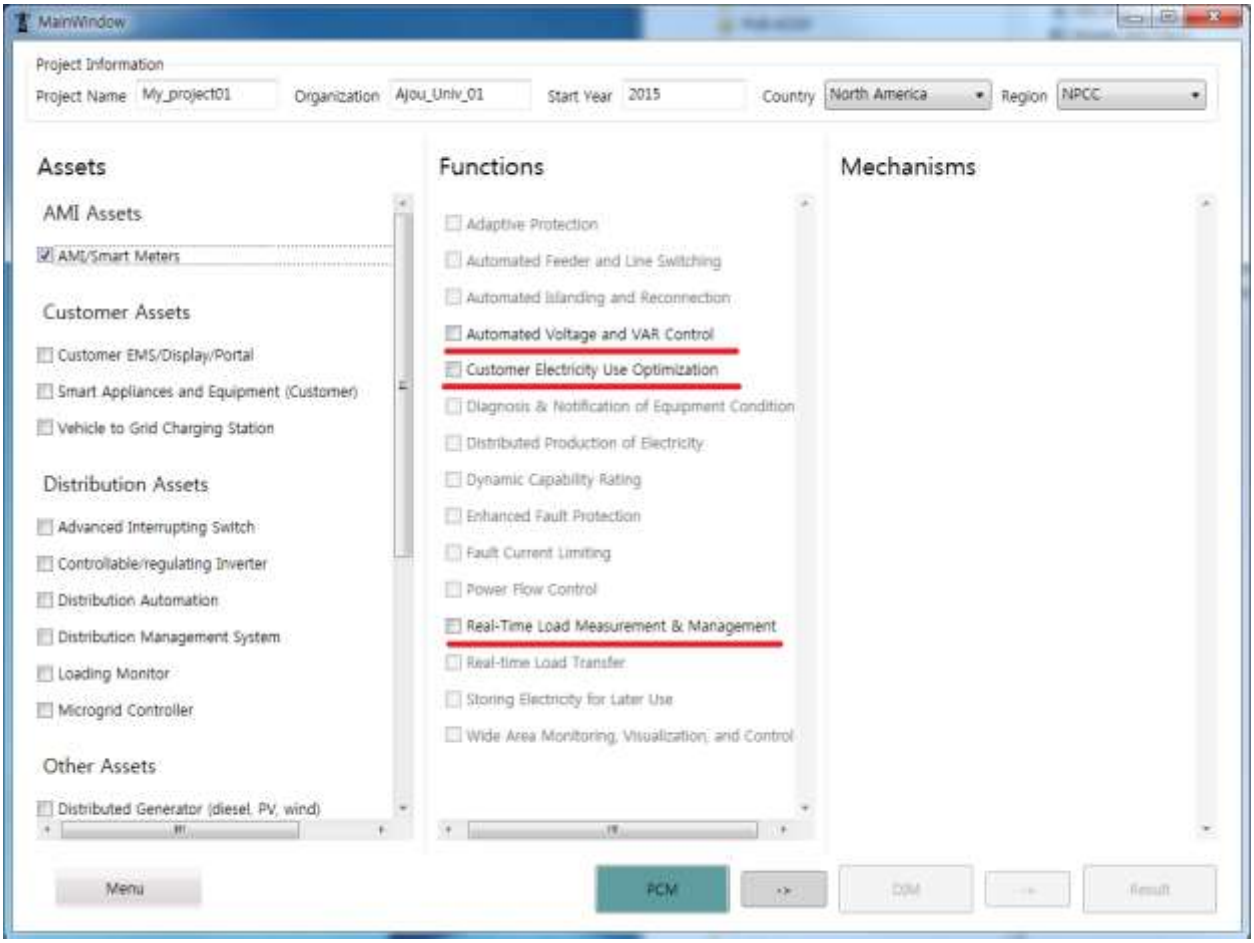


Figure 17 Choosing among Assets, Functions and Mechanisms

For the test, suppose the user choose AMI/Smart Meters among all types of Assets. It will give available choices in functions as shown above. The boxes on the left of the list of functions which are related to the selection of asset is given in different colors.

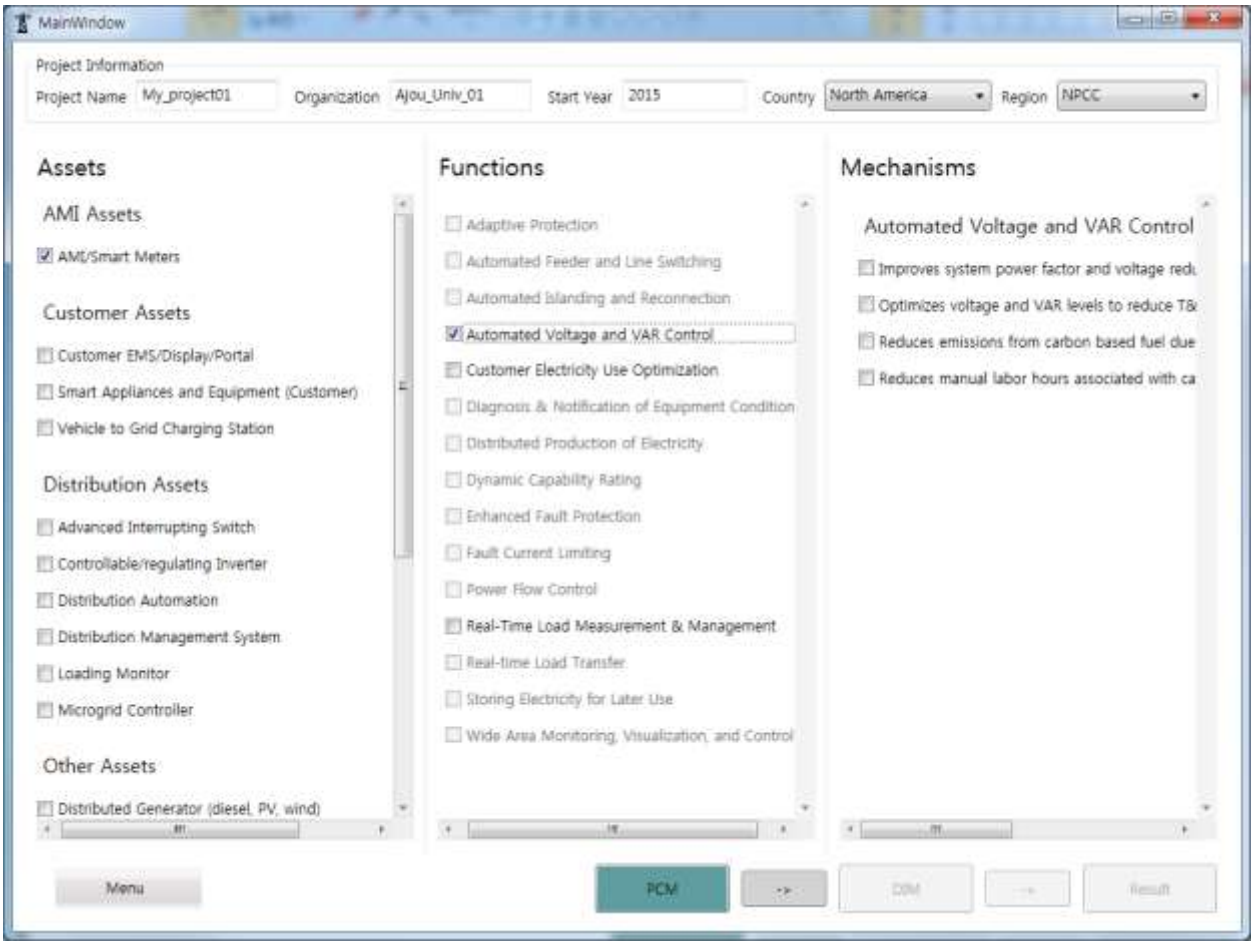
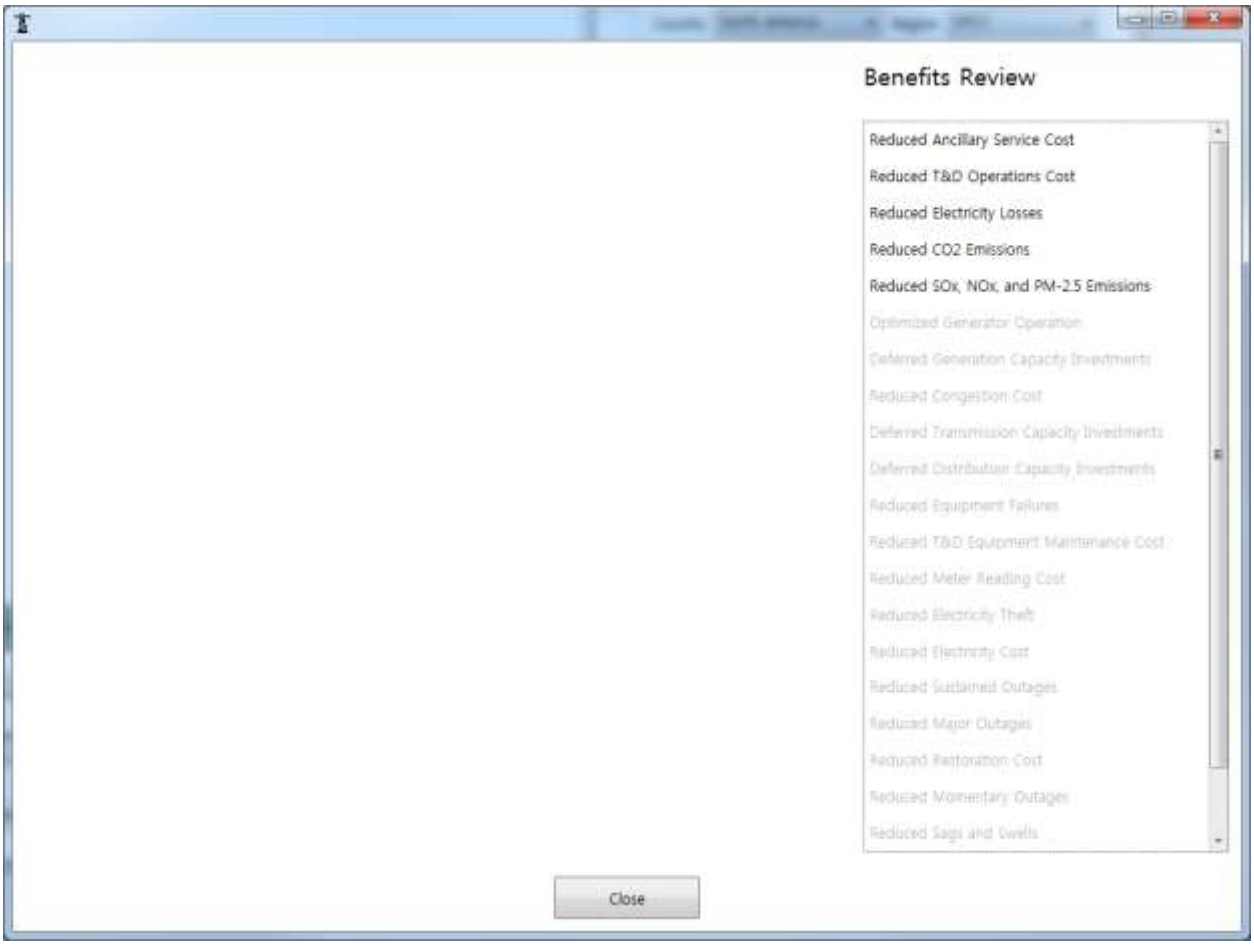


Figure 18 Choice of Function Gives Following Choice of Mechanisms

Choosing one of the candidate choice of functions will give the list of available Mechanisms as shown above. Once the choice of assets, functions and mechanisms are made, the user can move to the next stage by clicking the right arrow box 

.

Suppose the user chose all the choices given in Mechanisms, the next page will be given as following:



This page shows what kind of benefits are being considered for monetary value calculation. On the left hand side, there is a diagram which shows the selected choices of assets, functions and mechanisms and their relationship for the user's information.

III.3.4 Continuing for Final Results

When the user close the above dialog box, the following page will be shown. This part is basically the replicated DIM (Data Input Module) of SGCT. This stage will require a bunch of detailed information on power market of user's choice:

- ✓ For each customer class (Residential, Commercial, and Industrial), information on average energy rate, average demand charges, and customer served for sub-classes are required to be entered.
- ✓ Escalation factors and cost data are also required to enterred for the user's choice of assets.

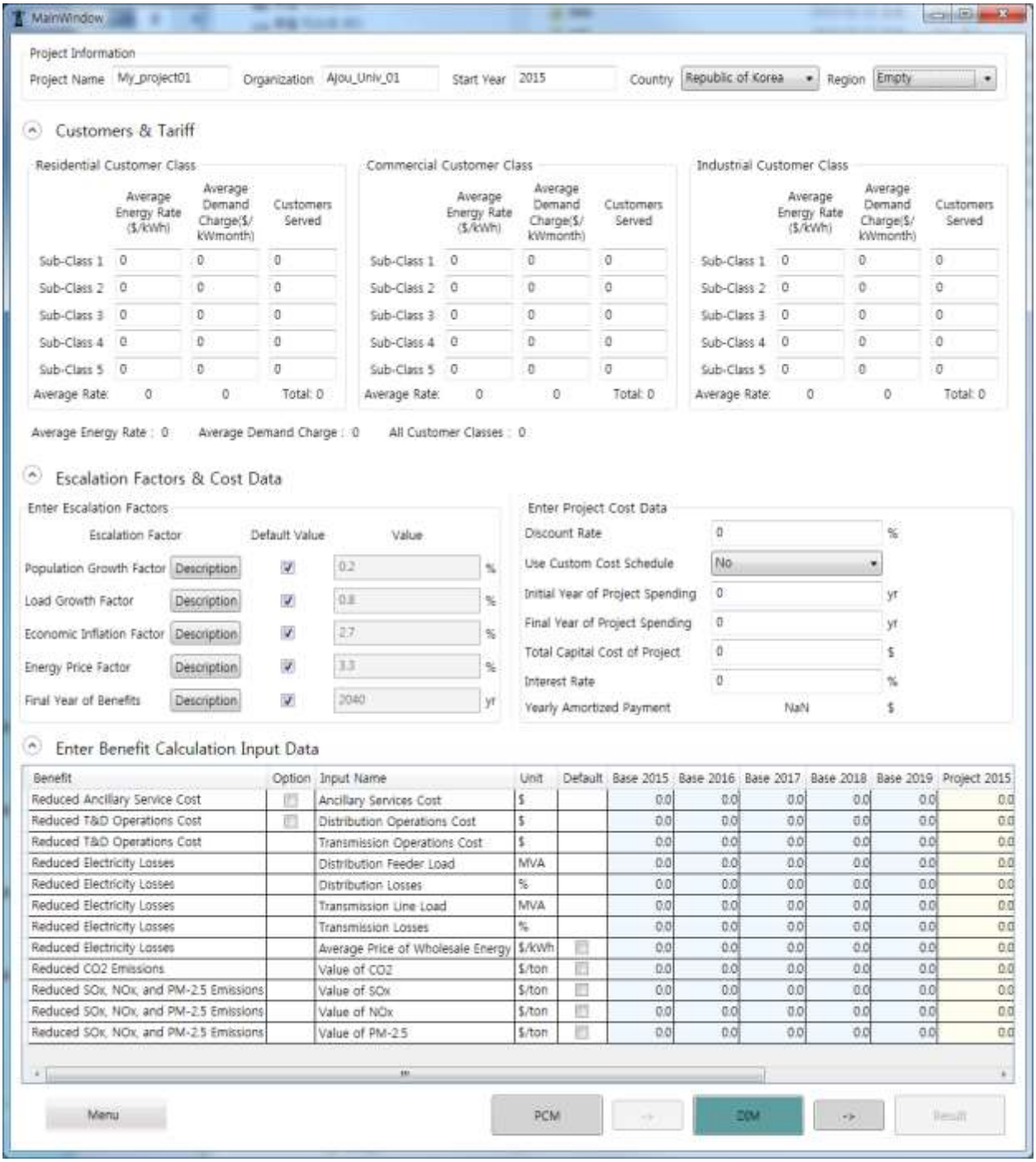


Figure 19 Data Input Module Dialog Box Replicated

After all appropriate data are inputted into the program, then the user can go to the Result tab. Followings are all types of result related dialog boxes available:

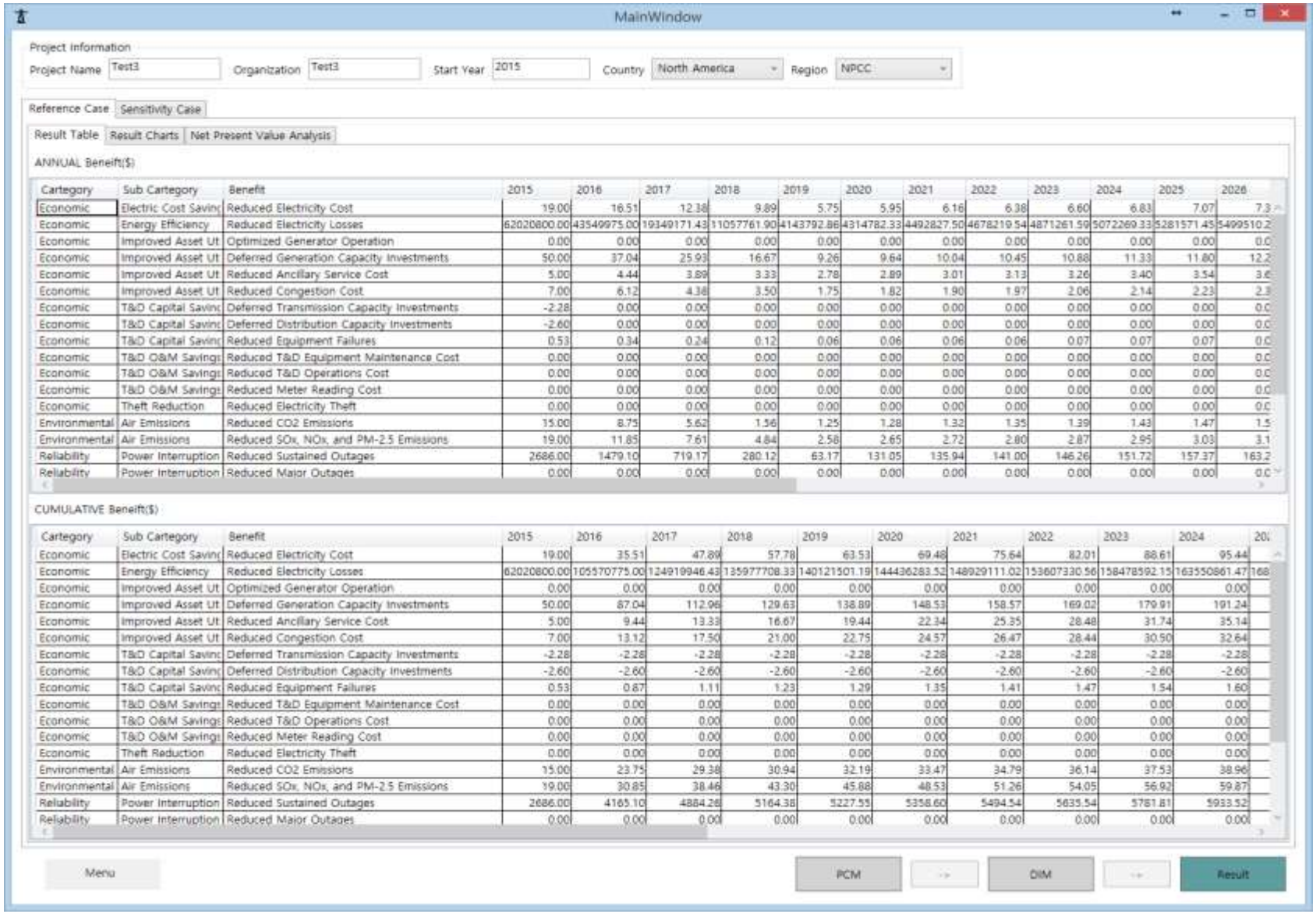


Figure 20 Replication Reference case: Result Table

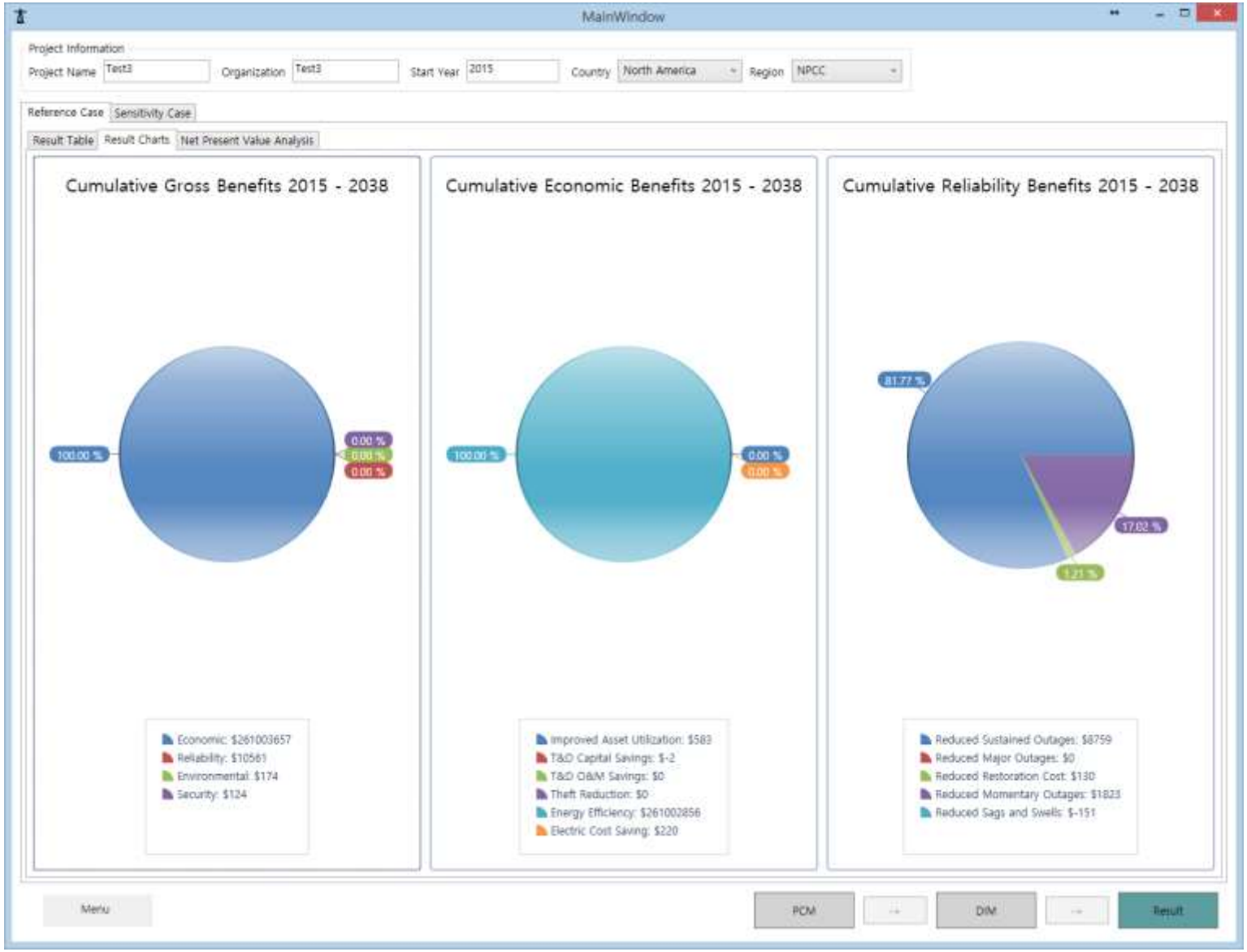
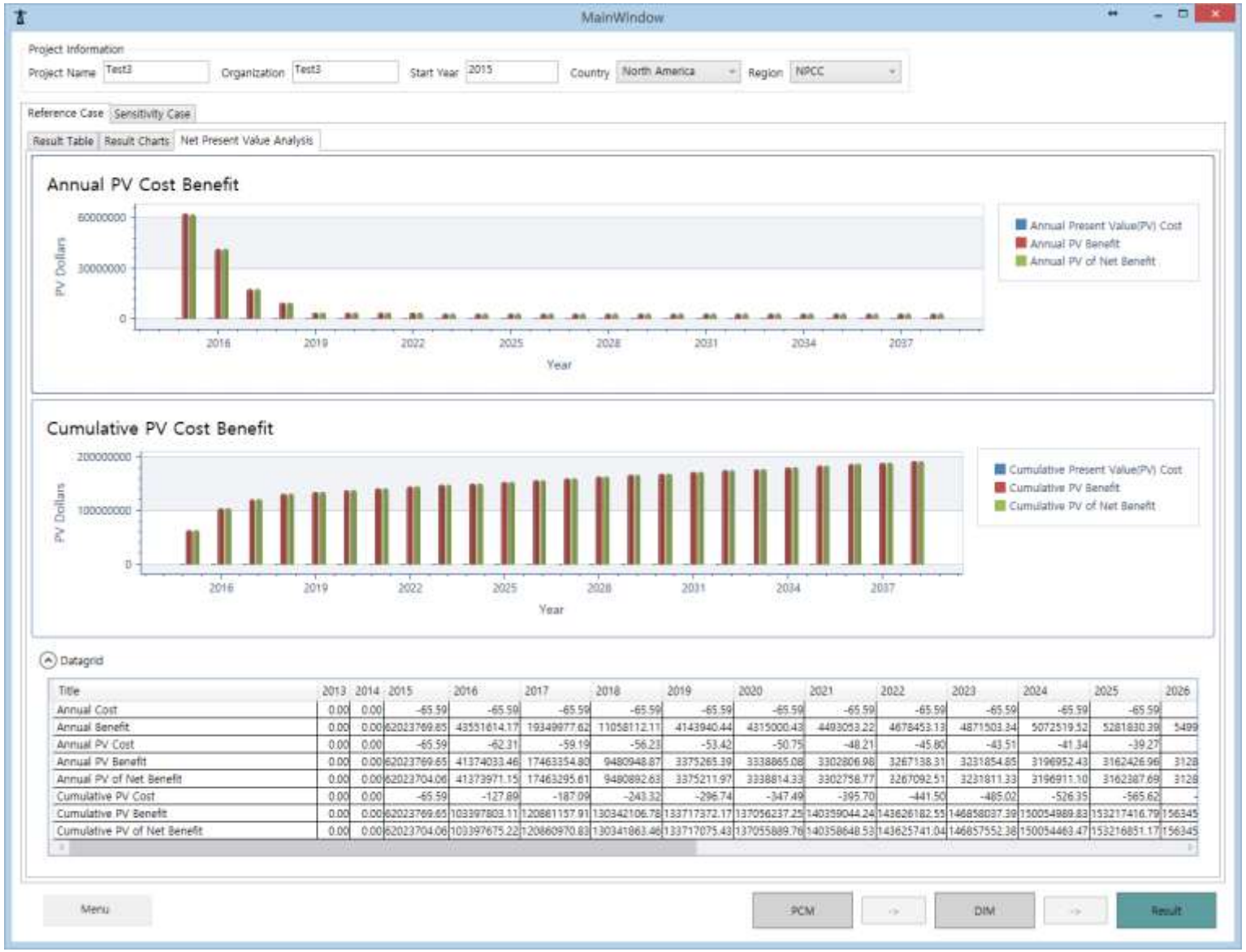


Figure 21 Replication Reference case: Result Chart



Title	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026
Annual Cost	0.00	0.00	-65.59	-65.59	-65.59	-65.59	-65.59	-65.59	-65.59	-65.59	-65.59	-65.59	-65.59	
Annual Benefit	0.00	0.00	62023769.65	43531614.17	19349977.62	11058112.11	4143940.44	4315000.43	4493053.22	4678453.13	4871503.34	5072519.52	5281830.39	5499
Annual PV Cost	0.00	0.00	-65.59	-62.31	-59.19	-56.23	-53.42	-50.75	-48.21	-45.80	-43.51	-41.34	-39.27	
Annual PV Benefit	0.00	0.00	62023769.65	41374033.46	17463354.80	9480948.87	3375265.39	3338865.08	3302806.98	3267138.31	3231854.85	3196952.43	3162426.96	3128
Annual PV of Net Benefit	0.00	0.00	62023704.06	41373971.15	17463295.61	9480892.63	3375211.97	3338814.33	3302758.77	3267092.51	3231811.33	3196911.10	3162387.69	3128
Cumulative PV Cost	0.00	0.00	-65.59	-127.89	-187.09	-243.32	-296.74	-347.49	-395.70	-441.50	-485.02	-526.35	-565.62	-
Cumulative PV Benefit	0.00	0.00	62023769.65	103397803.11	120881157.91	130342106.78	133717372.17	137056237.25	140359044.24	143626182.55	146858037.39	150054989.83	153217416.79	156345
Cumulative PV of Net Benefit	0.00	0.00	62023704.06	103397675.22	120860970.83	130341863.46	133717075.43	137055889.76	140358648.53	143625741.04	146857552.38	150054463.47	153216851.17	156345

Figure 22 Replication Reference case: Net present value Analysis

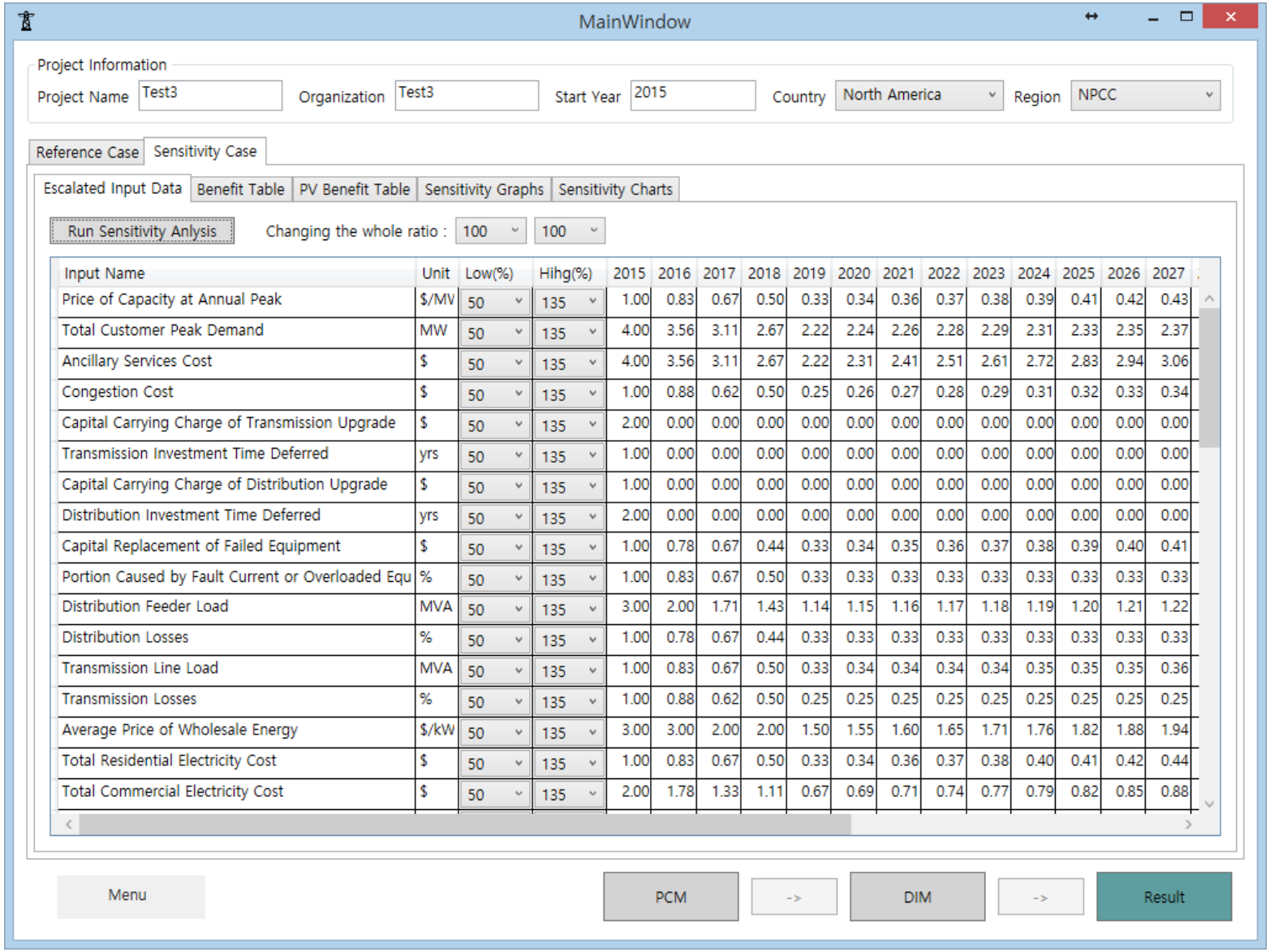


Figure 23 Replication Sensitivity case: Escalated Input Data

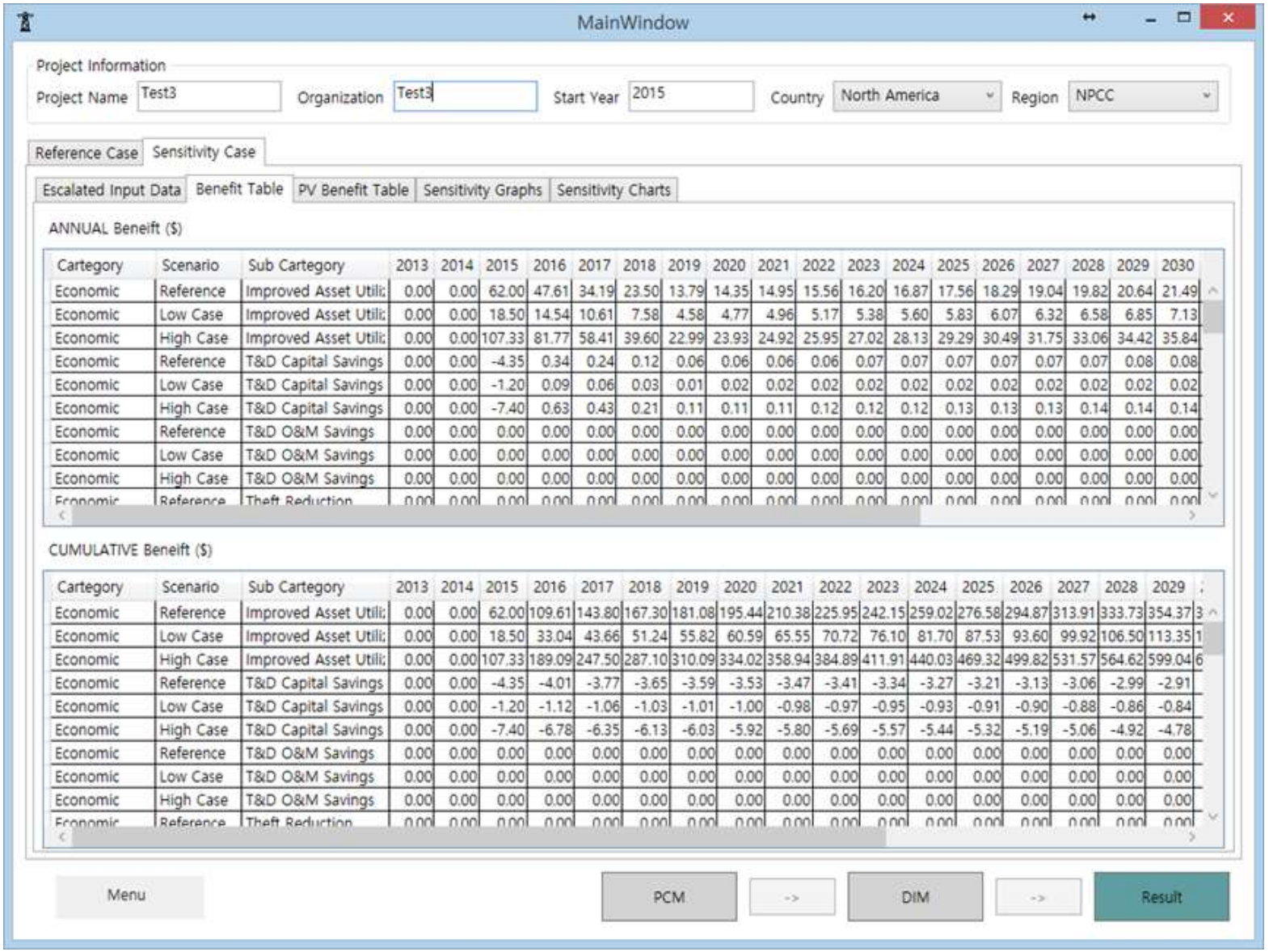


Figure 24 Replication Sensitivity case: Benefit Table

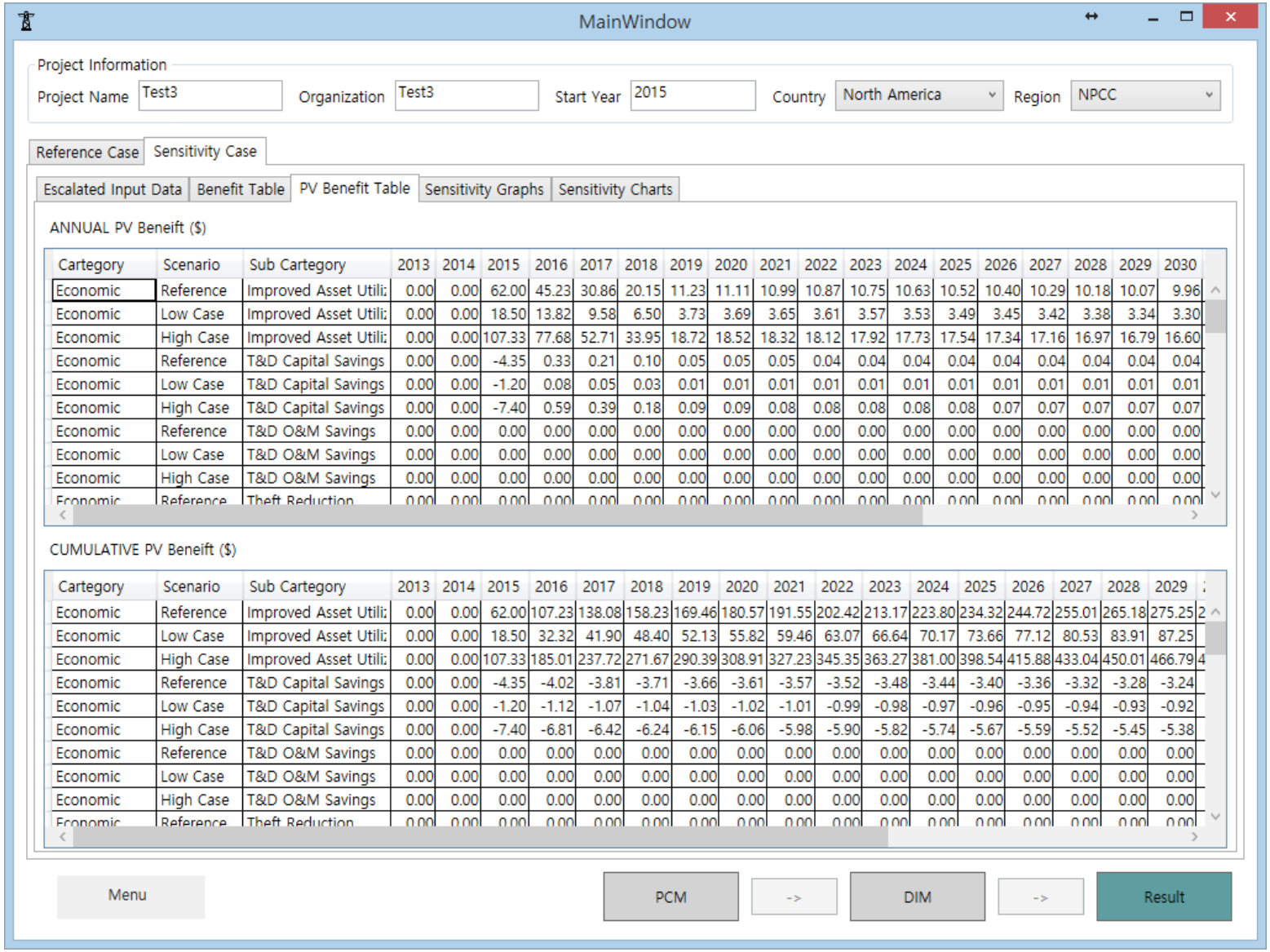


Figure 25 Replication Sensitivity case: PV Benefit Table

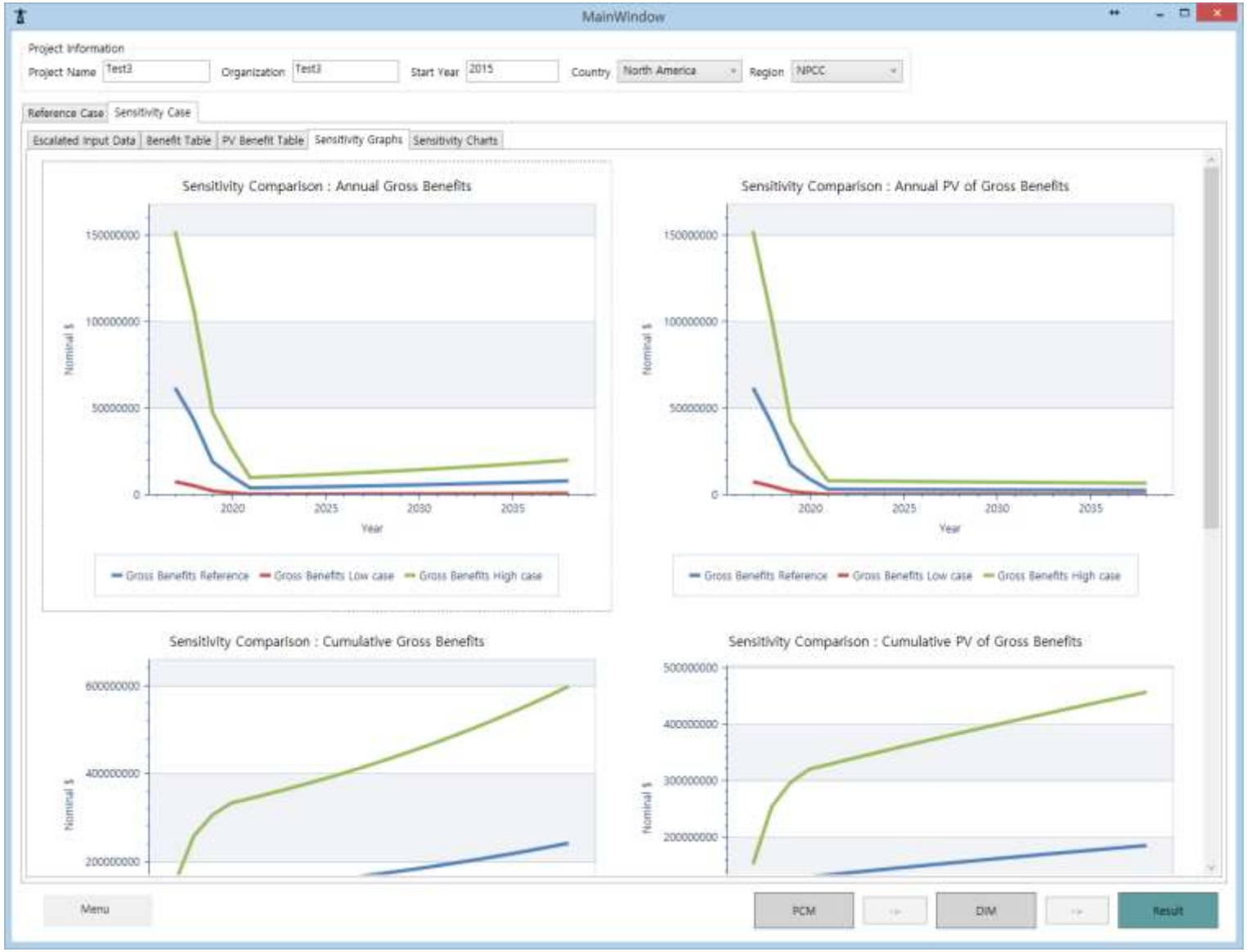


Figure 26 Replication Sensitivity case: Sensitivity Graphs

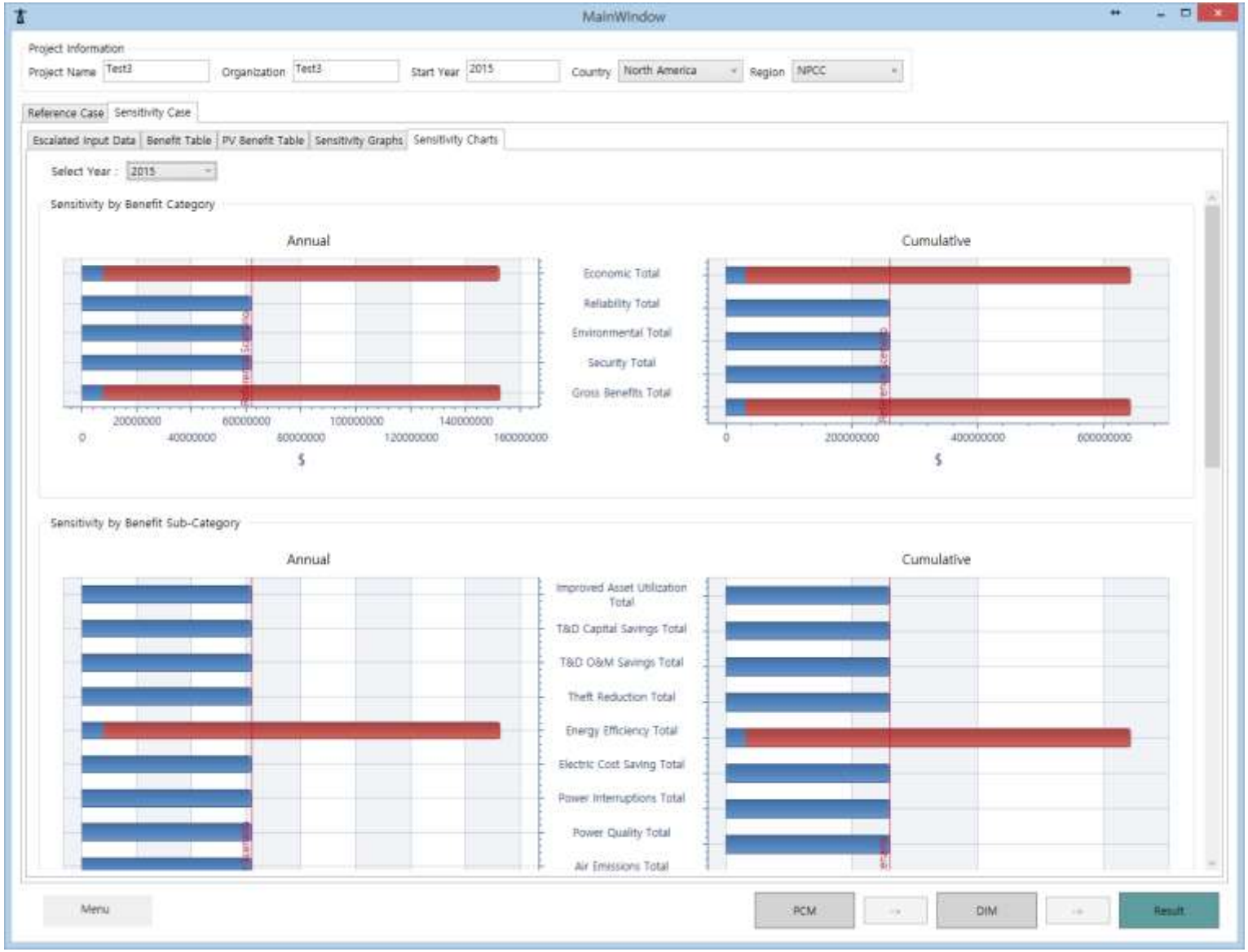


Figure 27 Replication Sensitivity case: Sensitivity Chart

III.4 Detailed Architecture in the Revised SGCT

After the separation of UI and data, it is possible for us to design flexible and extensible UI at our disposal. For example, if data changes to new data or edits some data, UI does not have to be designed. Since the controls in SGCT is fixed already by predefined data set, but controls in our program are created from data when program begins.

DB structure can be summarized as is shown below. Contents in the colored boxes in the following diagram presents some of data information included in several files.

- ✓ Data in blue box are PC (Project Characterization) data which consist of definition of assets, functions and benefits. PC data is defined in 'sys-def.xml'.
- ✓ Data in green box are defined data to calculate benefit and it defined in 'input-def.xml'.
- ✓ Data in brown boxes are rearranged default values and it is defined in 'defulat-values.xlsx.
- ✓ Lastly, data in black box is saved information data of project and it is defined in 'project-def.xml'.

Original default values are hidden in SGCT. User can save and load those data information which is being utilized by the software program.

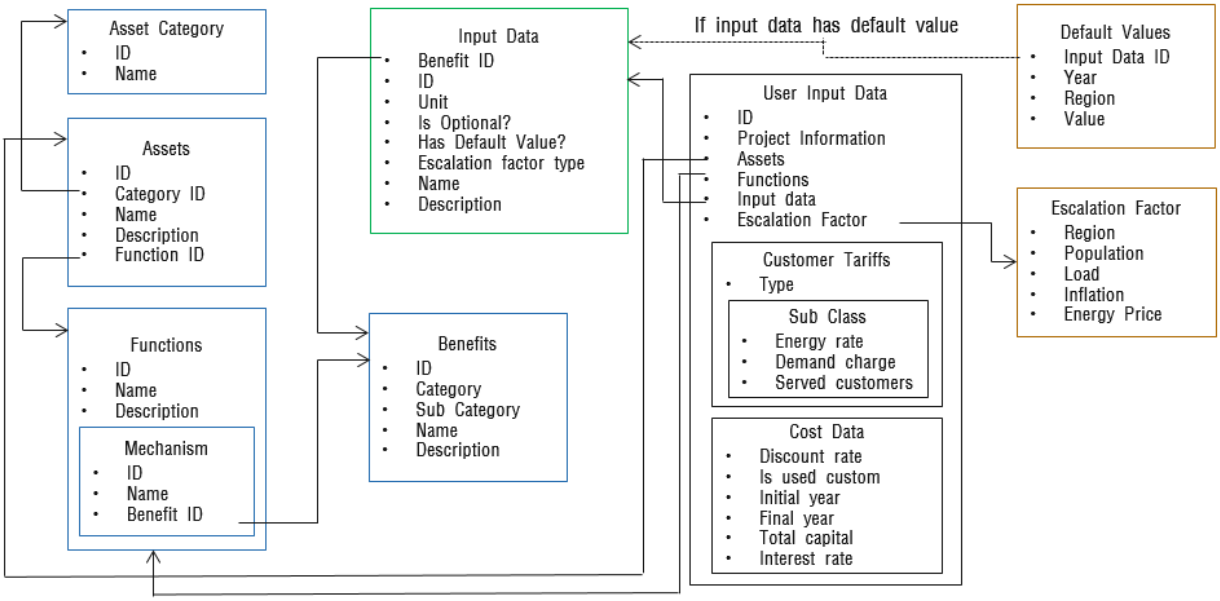


Figure 28 Detailed Architecture of DIM in Replicated Tool Kit

In the following, each of the component boxes in the above diagram are show in detail for the information it contains.

Asset Category
- ID
- Name

	Tag name/Text	Text	id
1	category	AMI Assets	1
2	category	Customer Assets	2
3	category	Distribution Assets	3
4	category	Other Assets	4
5	category	Transmission Assets	5

Figure 29 Asset Category DB

Assets
- ID
- Category ID
- Name
- Description
- Function ID

2 Attributes:

	name	value
1	id	1
2	category	3

3 Subtags:

	Tag name/Text	Text
1	name	Advanced Interrupting Switch
2	description	Switches or technology that can...
3	function	10

Figure 30 Asset DB details

Functions
- ID
- Name
- Description

Mechanism
- ID
- Name
- Benefit ID

1 Attributes:

	name	value
1	id	6

3 Subtags:

	Tag name/Text	Text
1	name	Automated Feeder and Line Switching
2	description	Automated feeder and line switching is realized throug...
3	mechanisms	

2 Subtags:

	Tag name/Text	id	name
1	mechanism	1	Prevents fault currents from exceeding the levels of the e
2	mechanism	2	Reduce stress on equipment

Figure 31 Function Details

Benefits
- ID
- Category
- Sub Category
- Name
- Description

3 Attributes:

	name	value
1	id	1
2	category	Economic
3	sub-category	ImprovedAssetUtilization

2 Subtags:

	Tag name/Text	Text
1	name	Optimized Generator Operation
2	description	Better forecasting and monitoring of load and grid performance w

Figure 32 Benefit Details

Input Data

- Benefit ID
- ID
- Unit
- Is Optional?
- Has Default Value?
- Escalation factor type
- Name
- Description

1 Attributes:

	name	value
1	benefit	1

3 Subtags:

	Tag name/Text	id	unit	is-...	has-...	esc-type	t..	nan
1	input	45	$	false	false	EnergyLoad	0	Annual
2	input	2	MWh	True	false	Load	0	Avoided
3	input	1	$/MWh	True	true	EnergyPrice	0	Average

Figure 33 Input Data Details

User Input Data

- ID
- Project Information
- Assets
- Functions
- Input data
- Escalation Factor

Customer Tariffs

- Type

Sub Class

- Energy rate
- Demand charge
- Served customers

Cost Data

- Discount rate
- Is used custom
- Initial year
- Final year
- Total capital
- Interest rate

5 Attributes:

	name	value
1	id	141127154448
2	name	test
3	organization	test
4	start-yr	2013
5	nerc	MRO

6 Subtags:

	Tag name/Text	discount-rate	is-used-custom	Unique
1	assets			asset (5
2	founctions			function
3	customer-tariffs			custome
4	input-data			data (36
5	esc-factor			5 Unique
6	cost-data	3	False	def-sche

Figure 34 User Input Data Details

III.5 Project Characterization Module in SGCT and Its GUI Replication

First, four dialog boxes from PCM are compiled in a single dialog box in the following page.

Figure 35 PCM Project Information Screen

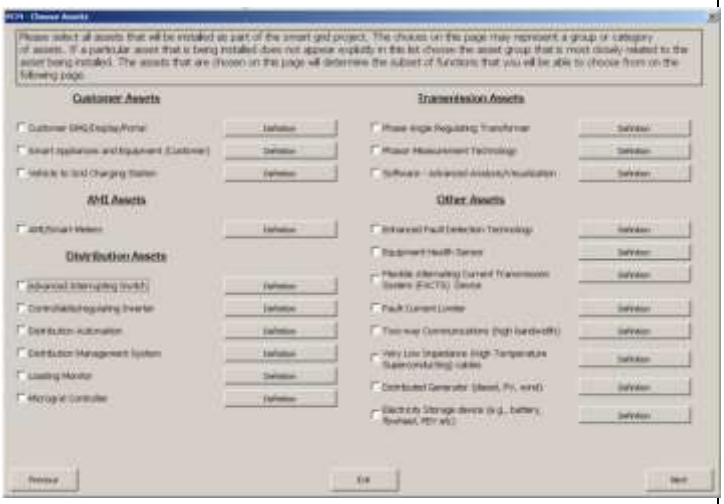


Figure 36 PCM Asset Selection Screen

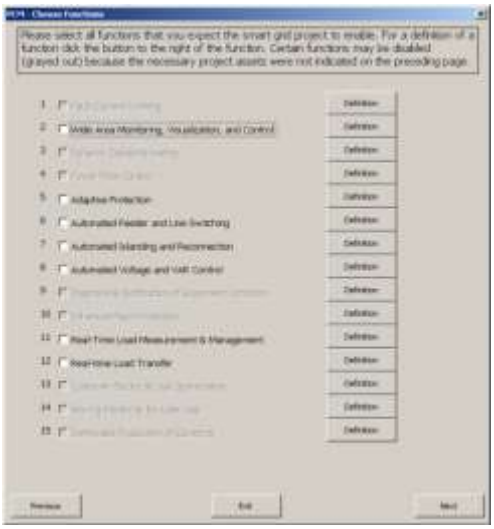


Figure 37 PCM Function Selection Screen

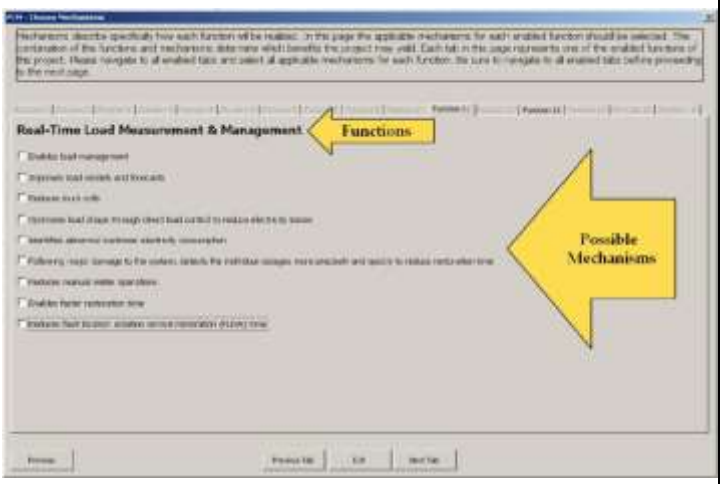


Figure 38 PCM Mechanism Selection Screen

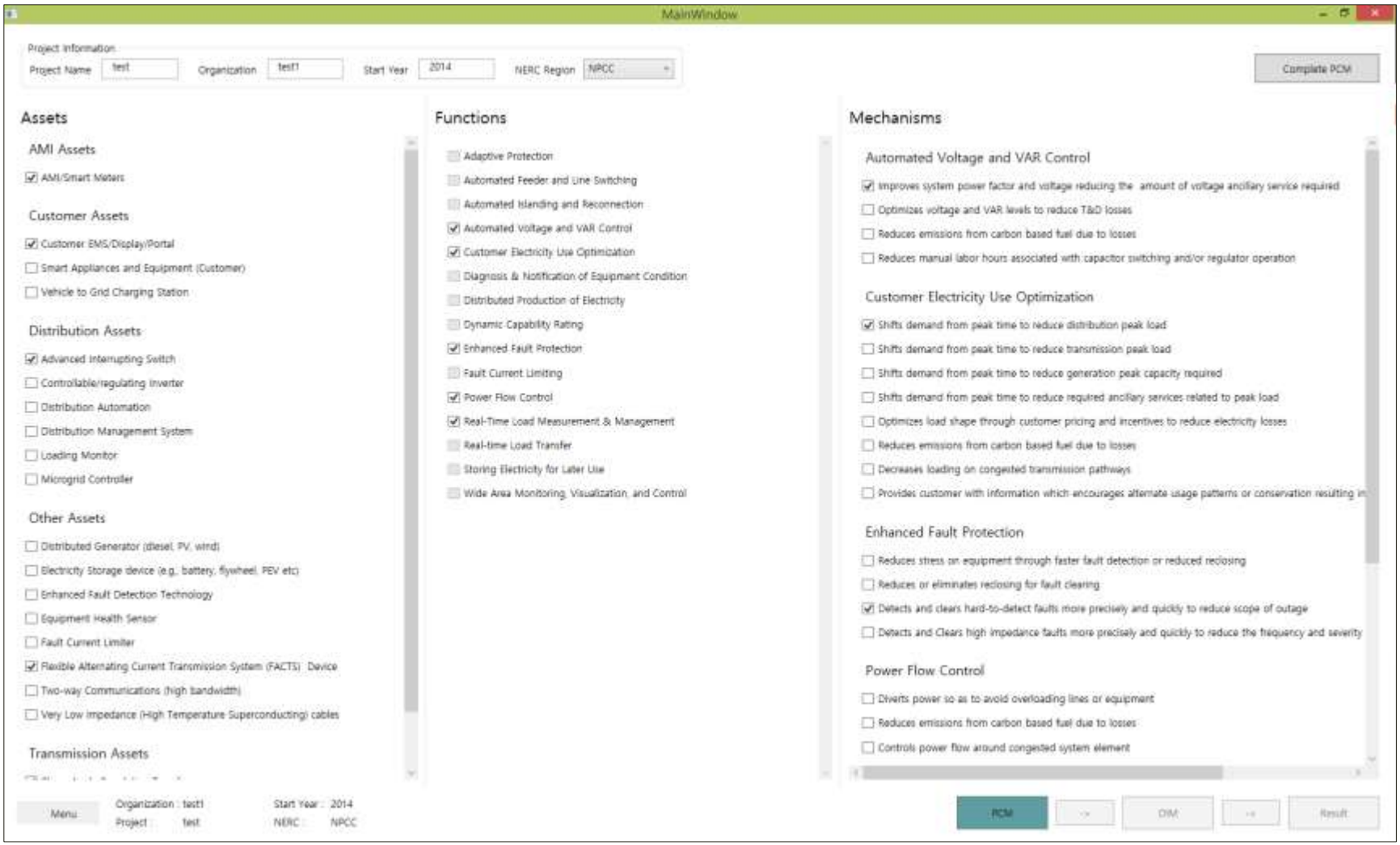


Figure 39 Project Information and Asset/Function/Mechanism Selection Screen (Replicated Tool Kit)

The SCGT selects the benefits that the smart grid project shouldyield, given the assets, functions, and mechanisms user have selected.The PCM Benefits Screen displays related benefits.

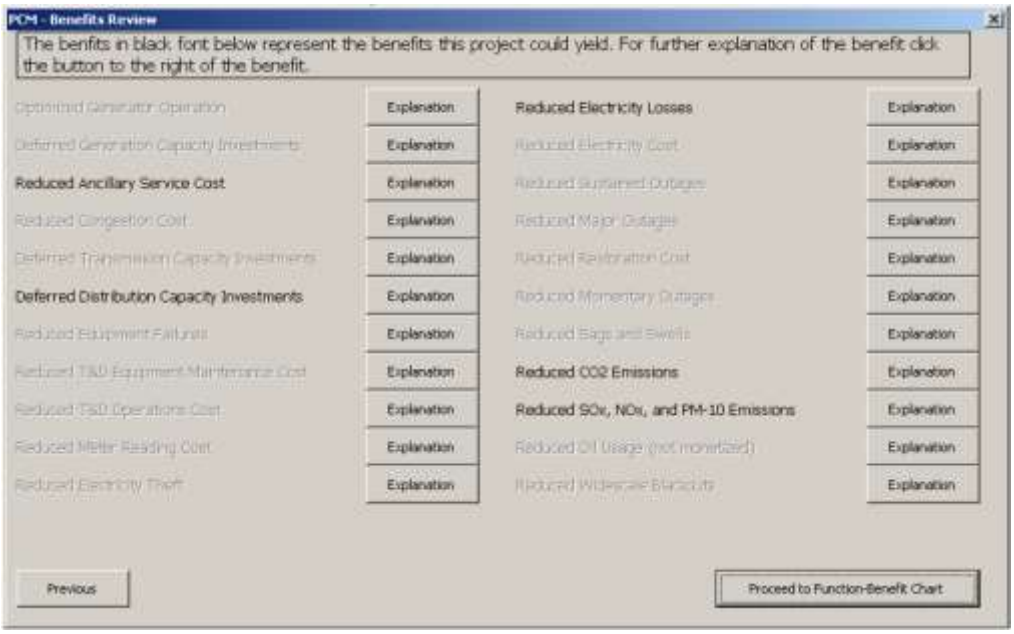


Figure 40 PCM Benefits Screen (DOE SGCT)

Following dialog box is from Replicated Tool Kit – left hand side of the box is still to be incorporated with further information on the detailed asset, function, mechanism and benefits. Current diagram is simple example of what it would be after the details are implemented in the code.

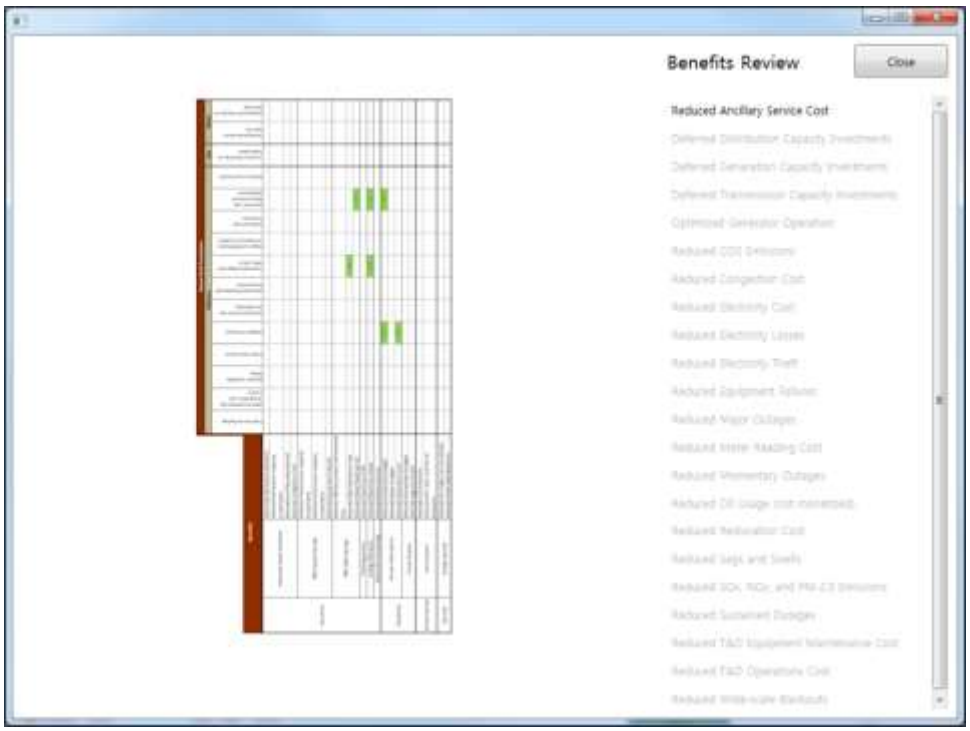


Figure 41 Benefits Screen (Replicated Tool Kit)

III.6 Comparison of Data Input Module in SGCT and Its GUI Replication

In DIM Step I, the user is required to enter information on electricity tariff and customer population. This data entry is required regardless of which benefits were enabled by the PCM because it used in many of the benefit calculations. The two tables are the Electricity Rates by Customer Class and the Number of Customers by Class tables, or Table 1 and 2 respectivelyin upper left figure in the following table.

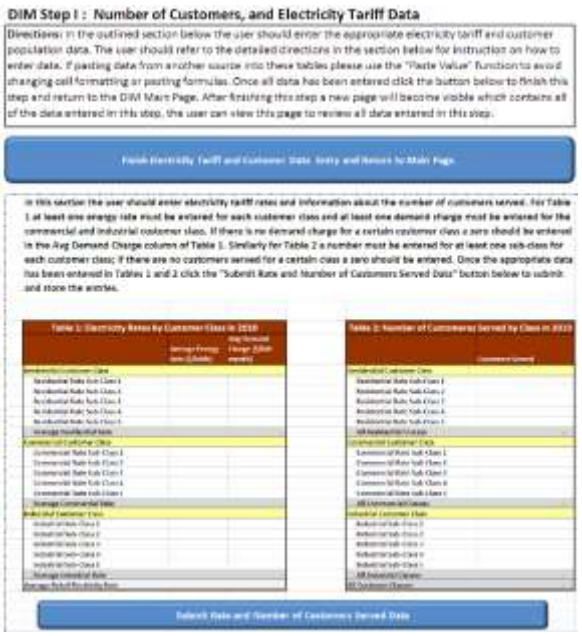


Figure 42 Electricity tariff data and customers served data entry tables

Figure 43 Cost calculation inputs

Figure 44 Escalation factor table

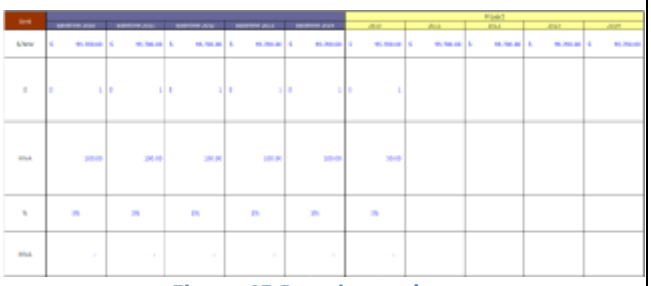


Figure 45 Data input sheet

The above four dialog boxes are now compiled in a single box presented in the following in Replicated Tool Kit.

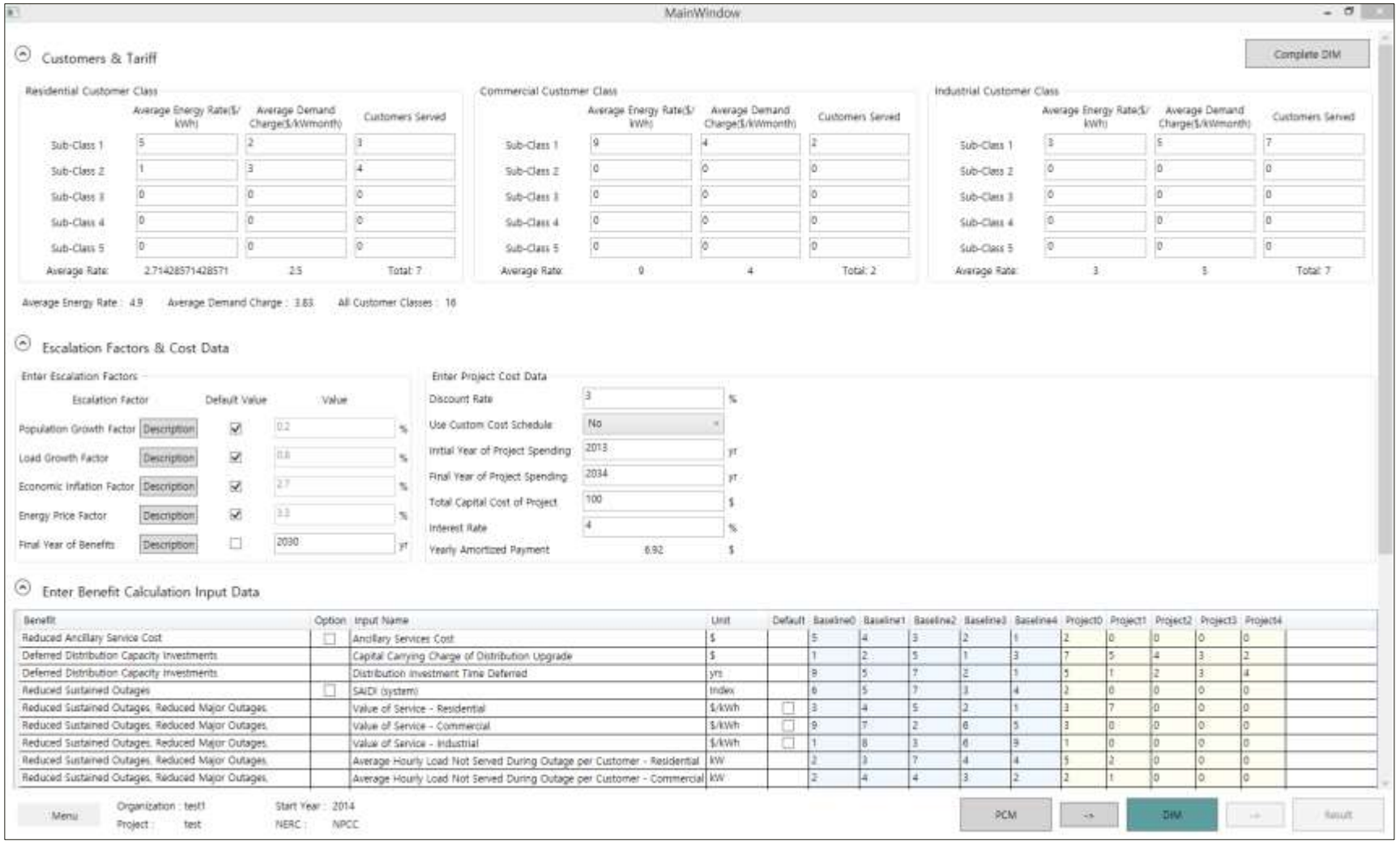


Figure 46 Data Input Module (DIM) Screen (Replicated Tool Kit)

III.7 Computational Module in SGCT and Its GUI Replication

CM Main page allows you to run the cost-benefit analysis with the inputs entered in the DIM, collectively referred to as the Reference Case, or it allows for an analysis to be run with high and low sensitivity case inputs, collectively referred to as the Sensitivity Case.

Figure 47 CM Main Page (DOE SGCT)

The above dialog box is now compiled as the following in Replicated Tool Kit.

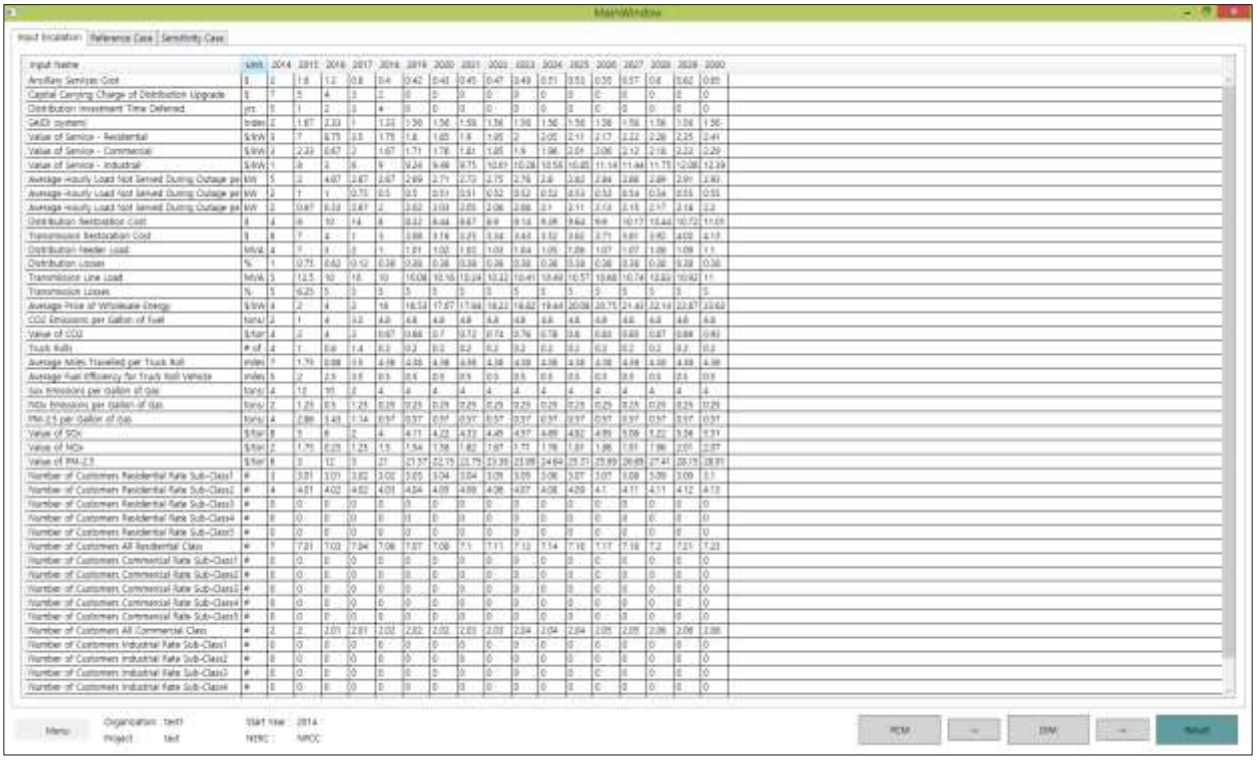


Figure 48 CM Main Page (Replicated Tool Kit)

For the results, the below three graphs would show how it was done in the original SGCT program. As for the case of the Replicated Toolkit, please refer to the previous subchapter

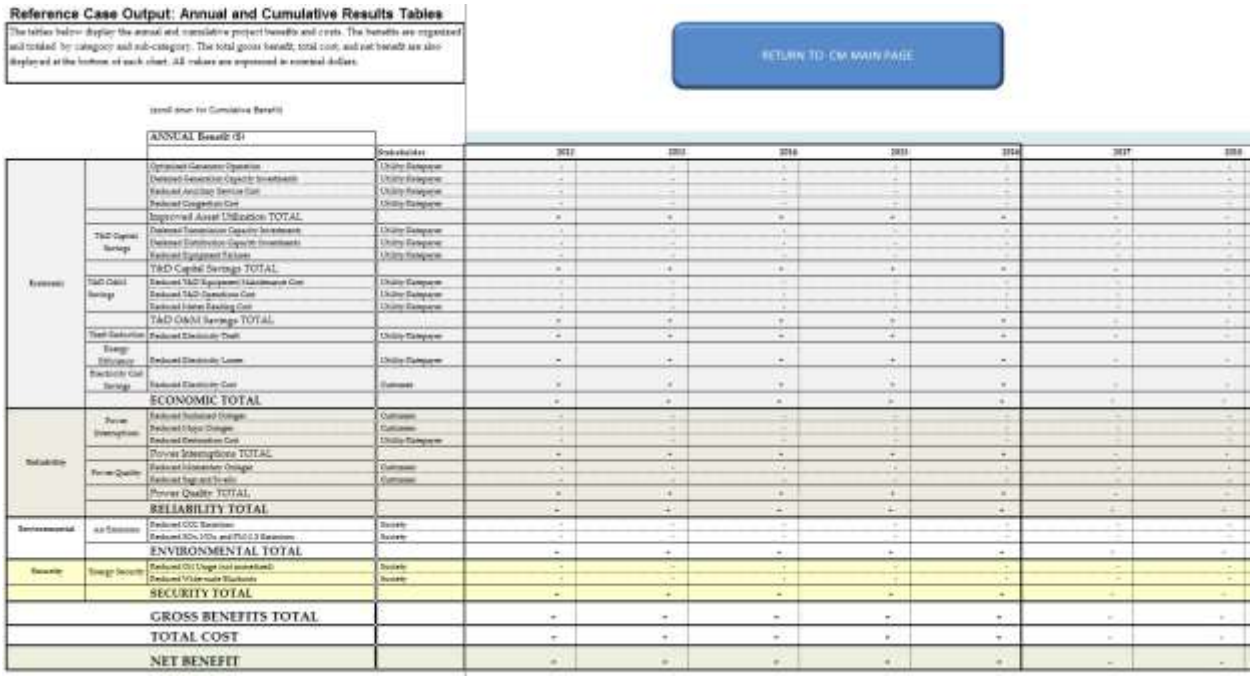


Figure 49 Results table (DOE SGCT)

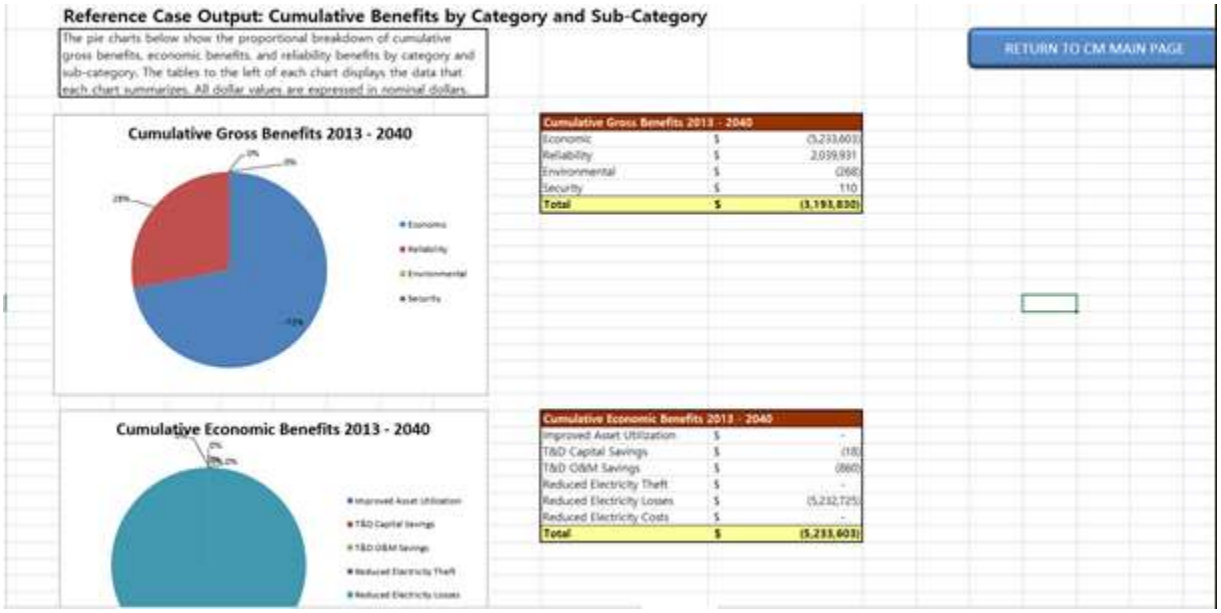


Figure 50 Result Charts (DOE SGCT)

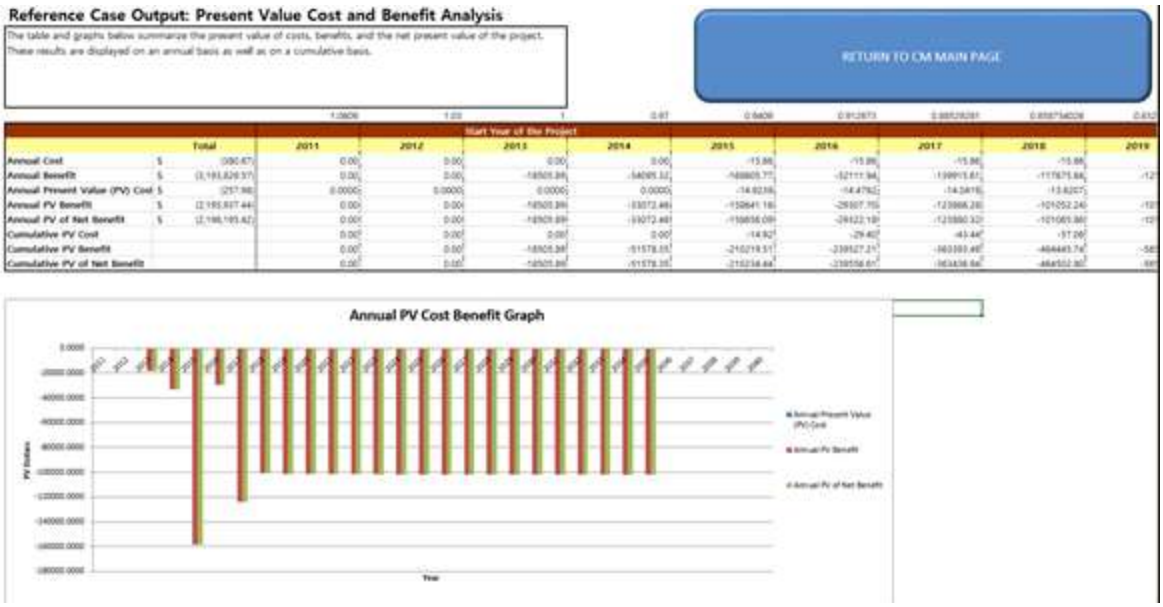


Figure 51 NPV Analysis (DOE SGCT)

Appendix I Overview of SGCT

A1.1 SGCT Framework and Work Flow

There are basically three modules in SGCT, which are: first the Project Characterization Module (PCM); second the Data Input Module (DIM); and third the Computational Module (CM), as shown in the figure below. The first module helps users determine the functionality of the projects by mapping the various assets provided by a smart grid project onto a standardized set of benefit categories. This module represents the first to fourth steps in EPRI's ten step approach. In the second module, users can input the required data to calculate the project's specific benefits. The list of anticipated benefits is derived from the first module and the list of inputs needed is dependent on the individual formulas of the various benefit calculations. This module represents the fifth, sixth and ninth steps of EPRI's ten step approach. The last module then calculates the project's costs and benefits. It also provides a mean of sensitivity analysis, by changing the range of some basic inputs, such as costumer number, electricity price, and various inputs for further benefit calculations.

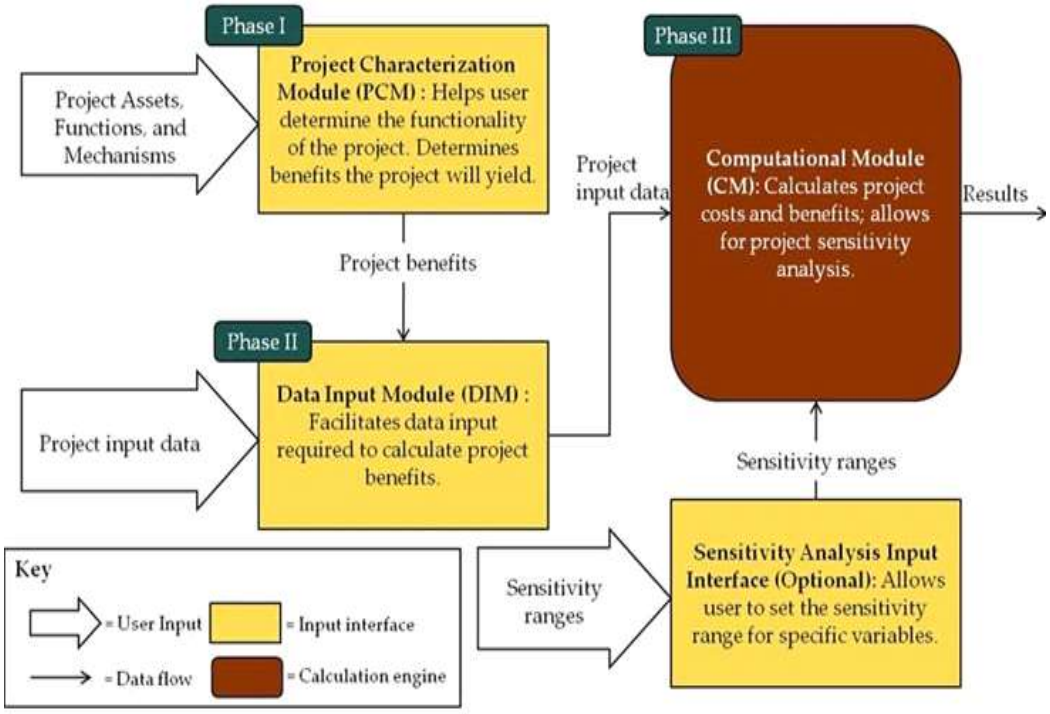


Figure 52SGCT Architecture

Source: Navigant, 2011

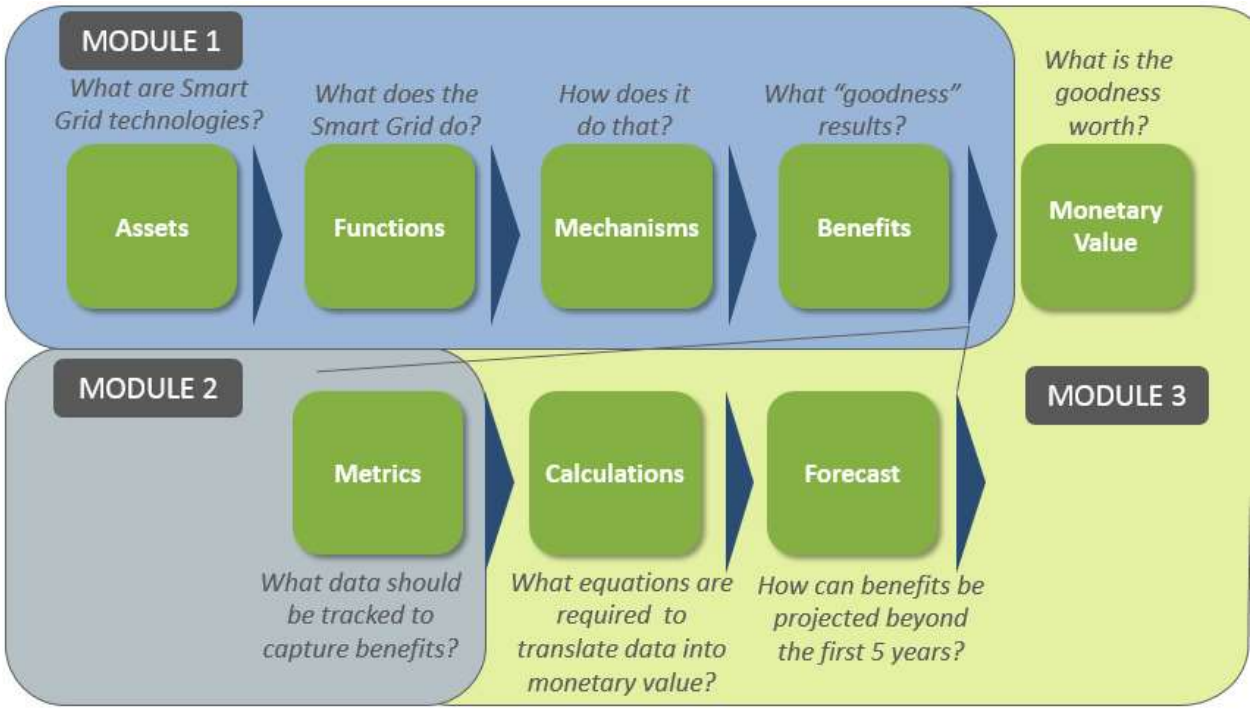


Figure 53 The Structure of SGCT

A1.2 Project Characterization Module (PCM)

This process takes up from phase one to phase two. The process done in the tool is explained by the figure below. It started from identification of Smart Grid technologies available (Assets) in the project. Then from those assets, the user must determine the functions those Assets can do. Each function would have several mechanisms, which in turn would provide some benefits, to the utility, consumer or society. Then based on the list of benefits that can be provided by a smart grid project, a monetized value is calculated.

Each process above will have its own standardized map. Figure below shows the illustration of Assets to Functions to Mechanisms to Benefits mapping in SGCT. It can be seen that the function can be mixed, such as that an asset can have several functions as well as a function can be done by several assets. The same goes for any of the mapping, up to mechanisms to benefits mapping.

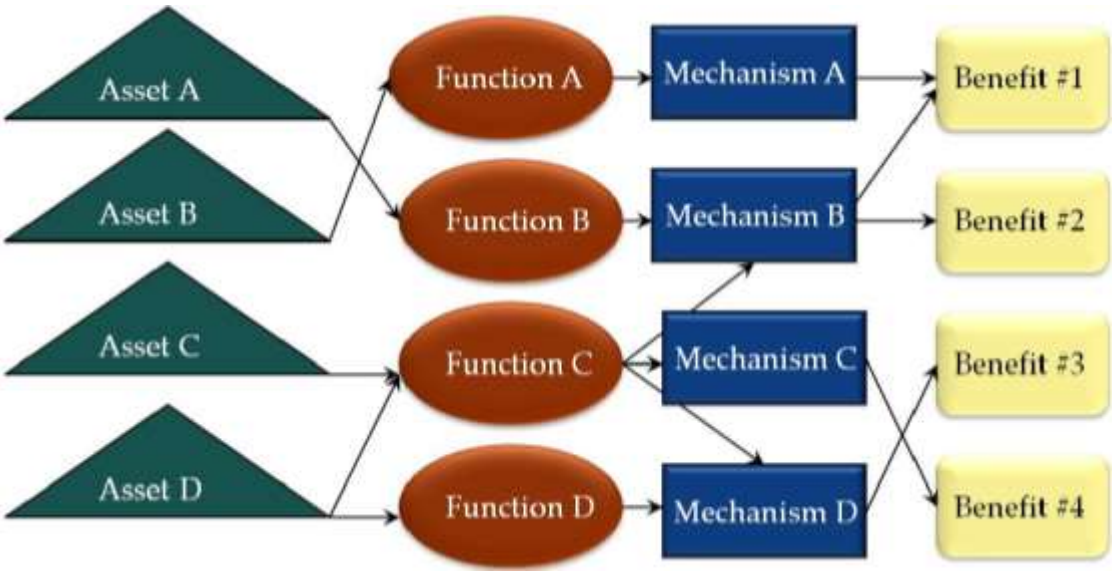


Figure 54 Illustration of Asset, Function, Mechanism, Benefit Mapping (Navigant, 2011)

Source: Navigant, 2011

Assets to Functions

There are 21 assets listed in the tools, which can be divided into five categories: Customer Assets, AMI Assets, Distribution Assets, Transmission Assets, and Other Assets. Please note that the listed assets here is different from the one in EPRI's Methodological Approach for Estimating the Benefits and Costs of Smart Grid Demonstration Projects (2011, Table 4-4 Linkage of Smart Grid Assets and Functions), which has 19 assets.

Table below shows the mapping of Assets to Functions in SGCT. There are 15 functions that are defined in the tools, starting from Fault Current Limiting to Distributed Production of Electricity. In EPRI (2010), the function is divided into two parts, which is called Functions and Enabled Energy Resources (due to Functions). Here the Enabled Energy Resources is just another part of Functions (as Other). Also, it must be noted that the PEV (Plug-in Electric Vehicle) and Distributed Generation in EPRI (2010) are combined together into Distributed Production of Electricity in DOE's SGCT.

Table 1 Mapping of Assets to Functions (DOE SGCT)

Smart Grid Assets	**Functions**		
	Delivery	Use	Other

	Fault Current Limiting	Wide Area Monitoring, Visualization and Control	Dynamic Capability Rating	Power Flow Control	Adaptive Protection	Automated Feeder and Line Switching	Automated Islanding and Reconnection	Automated Voltage and VAR Control	Diagnosis & Notification of Equipment Condition	Enhanced Fault Protection	Real-Time Load Measurement & Management	Real-Time Load Transfer	Customer Electricity Use Optimization	Storing Electricity for Later Use	Distributed Production of Electricity
Advanced Interrupting Switch										V					
AMI/Smart Meters								V			V		V		
Controllable/regulating Inverter							V	V							
Customer EMS/Display/Portal													V		
Distribution Automation					V	V	V	V				V			
Distribution Management System			V		V	V	V	V			V	V			
Enhanced Fault Detection Technology										V					
Equipment Health Sensor			V						V						
FACTS Device				V											
Fault Current Limiter	V														
Loading Monitor			V						V			V			
Microgrid Controller							V								
Phase Angle Regulating Transformer				V											
Phasor Measurement Technology		V	V	V	V		V	V		V					
Smart Appliances and Equipment (Customer)													V		
Software - Advanced Analysis/Visualization		V	V												
Two-way		V			V	V	V	V			V	V			

Communications (high bandwidth)															
Vehicle to Grid Charging Station													v		
Very Low Impedance (High Temperature Superconducing) cables				v											
Distributed Generator (diesel, PV, wind)								v							v
Electricity Storage device (e.g., battery, flywheel, PEV etc)								v						v	

Figure below shows the windows that show up in the process of executing DOE's SGCT. In this window user is required to choose the assets of its own smart grid project from various list of defined assets. It is classified into four class which are:

- ✓ Customer Assets
- ✓ AMI Assets
- ✓ Distribution Assets
- ✓ Transmission Assets
- ✓ Other Assets

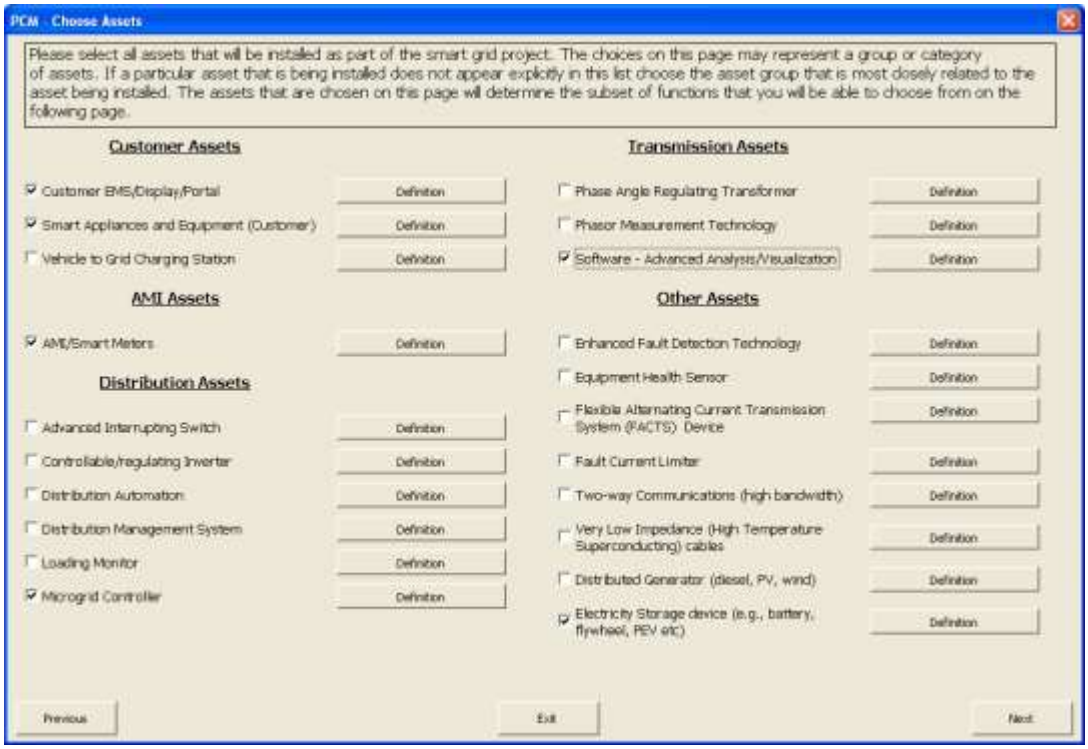


Figure 55 Choosing Assets in DOE's SGCT

The next step is choosing functions that can be enabled by the assets that already chosen in the previous step. Figure below shows the example of the window that showed up for that process.

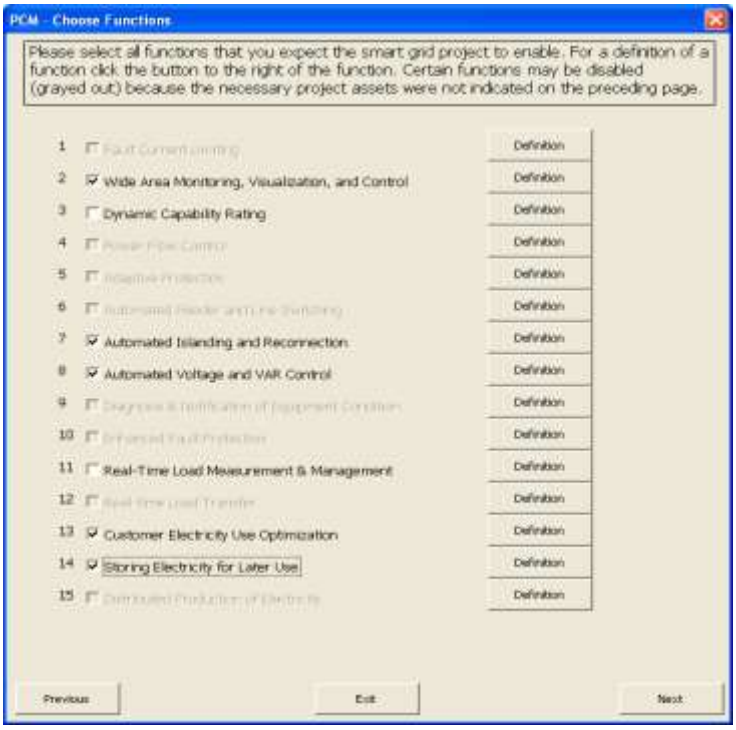


Figure 56 Choosing Functions in DOE's SGCT

In the macro code (Visual Basic for Applications, VBA), the mapping of function to asset can be found in object “Function to Asset Map” (sheet 16)

Functions to (Mechanisms to) Benefits

In the original EPRI’s Methodological Approach for Estimating the Benefits and Costs of Smart Grid Demonstration Projects (2010), there is only a mapping of Functions to Benefits, such as shown below. There are four categories of benefits: Economic, Reliability, Environmental and Security, which then translates into 22 types of benefits, starting from Optimized Generator Operation to Reduced Widescreen Blackouts.7

Table 2 Mapping of Functions to Benefits (with comparison to EPRI version)

EPRI: Stationary Electricity Storage + Plug-in Electric Vehicle

Benefits			Functions															
			Fault Current Limiting	Wide Area Monitoring, Visualization, and Control	Dynamic Capability Rating	Power Flow Control	Adaptive Protection	Automated Feeder and Line Switching	Automated Islanding and Reconnection	Automated Voltage and VAR Control	Diagnosis & Notification of Equipment Condition	Enhanced Fault Protection	Real-Time Load Measurement & Management	Real-time Load Transfer	Customer Electricity Use Optimization	Storing Electricity for Later Use	Distributed Production of Electricity
Economic	Improved Asset Utilization	Optimized Generator Operation		•												•	•
		Deferred Generation Capacity Investments													•	•	•
		Reduced Ancillary Service Cost		•						•			•		•	•	•
		Reduced Congestion Cost		•	•	•									•	•	•
	T&D Capital Savings	Deferred Transmission Capacity Investments	•	•	•	•									•	•	•
		Deferred Distribution Capacity Investments			•								•	•	•	•	•
		Reduced Equipment Failures	•		•						•	•					
	T&D O&M Savings	Reduced T&D Equipment Maintenance Cost									•						
		Reduced T&D Operations Cost						•		•							
		Reduced Meter Reading Cost											•				
	Theft Reduction	Reduced Electricity Theft											•				
	Energy Efficiency	Reduced Electricity Losses				•				•			•	•	•	•	•
	Electricty Cost Savings	Reduced Electricity Cost													•	•	•
Reliability	Power Interruptions	Reduced Sustained Outages					•	•	•		•	•	•			•	•
		Reduced Major Outages		•					•				•	•			
		Reduced Restoration Cost					•	•	•		•	•	•				
	Power Quality	Reduced Momentary Outages										•				•	
		Reduced Sags and Swells										•				•	
Environmental	Air Emissions	Reduced CO_2 Emissions				•		•		•	•		•	•	•	•	•
		Reduced SO_x, NO_x, and PM-10 Emissions				•		•		•	•		•	•	•	•	•
Security	Energy Security	Reduced Oil Usage (not monetized)						•			•		•			•	
		Reduced Widescale Blackouts		•	•							•					

Mapped in EPRI

In the SGCT, though, the concept of mechanisms is introduced as a linkage between functions and benefits. The complete mapping from functions to mechanisms to benefits is shown in the appendix.

Each function can have 1 to 13 mechanisms. Each mechanism, in turn, can lead to one to three benefits. Through these mechanisms to benefits mapping, the resulting functions to benefits mapping in SGCT will be exactly the same with the one from EPRI (2010)

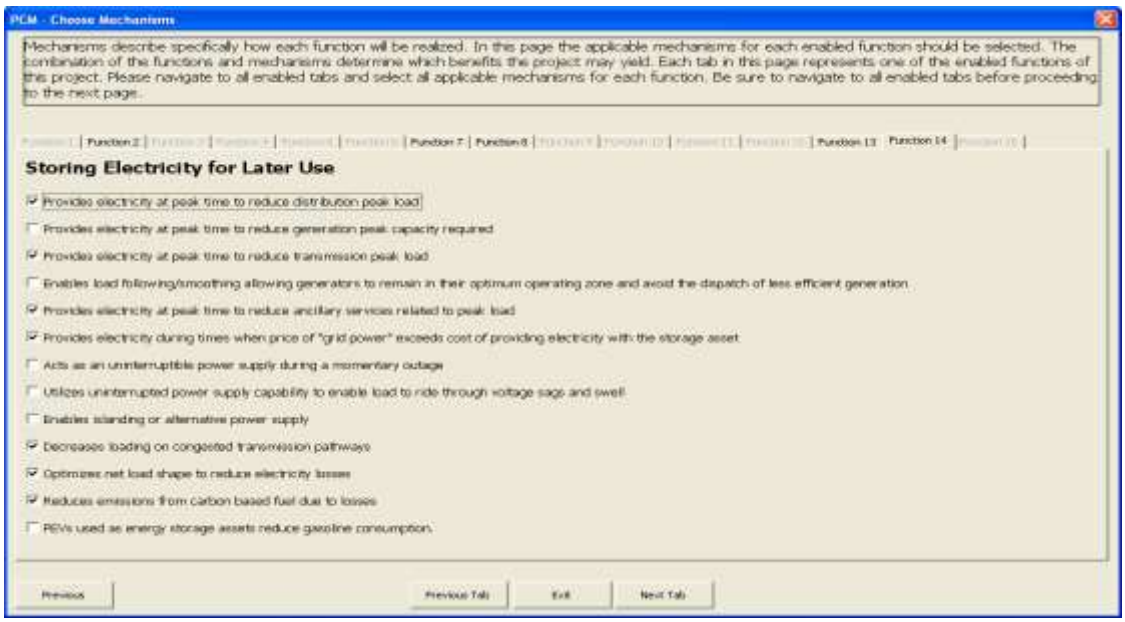


Figure 57 Choosing Mechanisms in DOE's SGCT

Figure above shows the process of choosing mechanism in DOE's SGCT. For each function that has been chosen from the previous step, there will be a unique tab with several pre-defined mechanisms. These mechanisms will lead to the benefits of smart grid. Once we choose all the mechanisms that could be realized by our Smart Grid project, the mechanism to benefit table will give the resulted benefits. Figure below shows the result, which is a function-benefit chart. The green cells show the relationship of function and benefit that can be realized by the Smart Grid project. After this, the next process in monetization of each benefit listed in the chart.

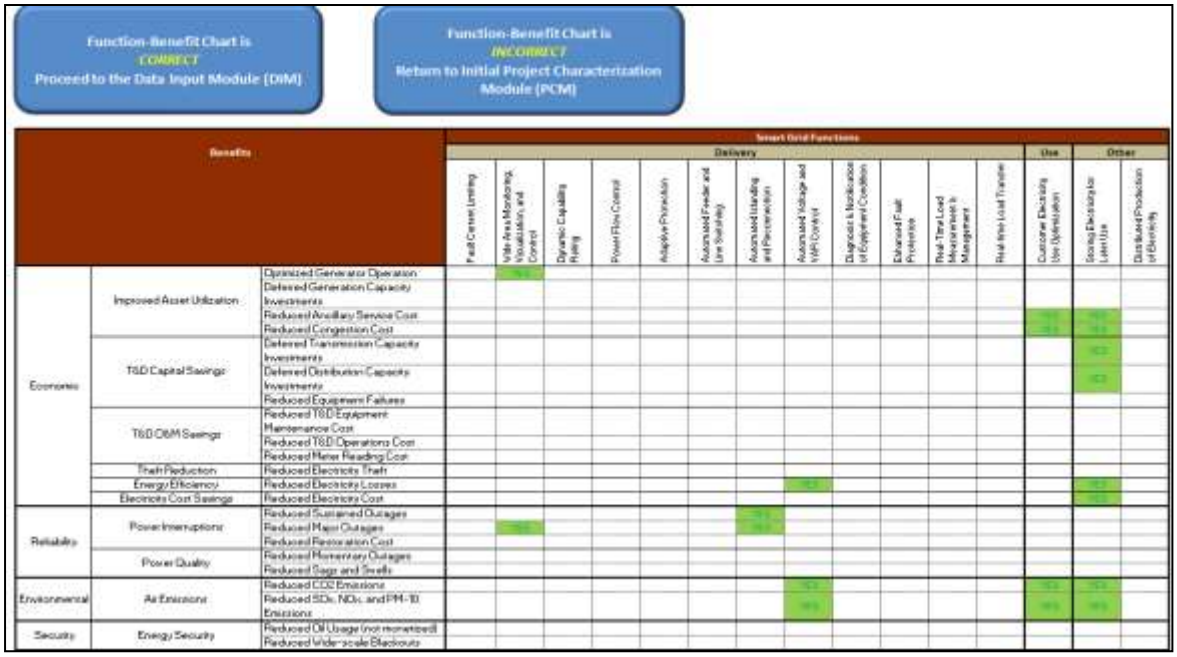


Figure 58 Function-Benefit Chartin DOE's SGCT

In macro code (VBA), these mappings can be examined in objects “Fxn_Benefit List” (Sheet 29), “Fxn-Mechanisms” (Sheet 47), “FxnMech to Benefits List” (Sheet 19), and “Function-Benefit Chart” (Sheet 25).

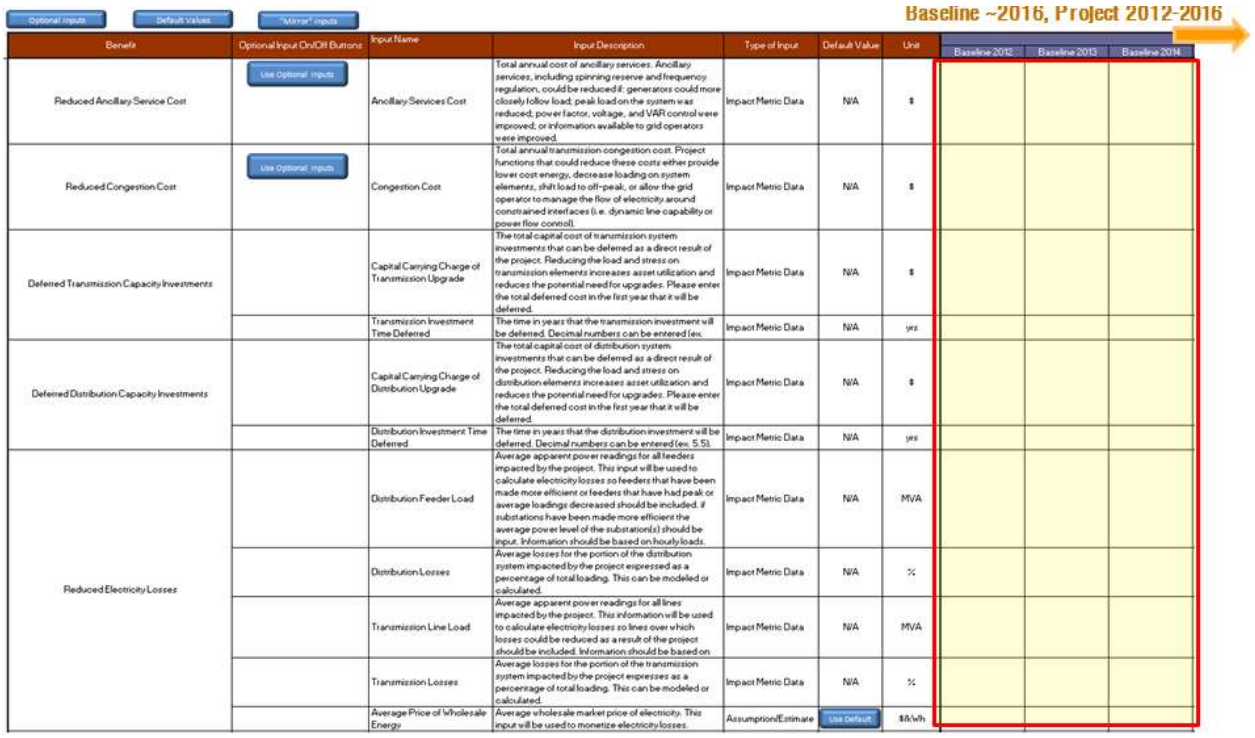
A1.3 Data Input Module (DIM)

Benefits Monetized Value

Once the list of benefits is produced, the SGCT then proceeds to the next step, calculating the monetized value of SG benefit. The complete calculations formula are explained Appendix A.1 Benefit Calculations of “User Guide for the US Department of Energy Smart Grid Computational Tool (SGCT): Guide for SGCT Public Version 1.3 (Navigant, 20100). Its summary can be examined in Table 9.

It must be noted that although in the previous processes a benefit can be achieved by various mechanisms of functions, the benefit calculation process itself does not necessarily need to be based on or contributed by those specific mechanisms. Some benefit calculation only considers the general picture of its benefit itself. In other words, the benefit is not calculated by adding each mechanism’s effect on creating the benefit.

Figure below shows the input sheet that is shown in the DOE's SGCT. In this sheet, a user must input all the data and parameters required to assess/monetize a specific benefit. There is an option to fill it with the default parameter, if available. Another option is provided to change the formula of benefit monetization. As discussed above, a benefit can be monetized following more than one formula. Choosing a formula would depend on the data availability.



Optional Inputs | Default Values | "Mirror" Inputs

Baseline ~2016, Project 2012-2016

Benefit	Optional Input On/Off Buttons	Input Name	Input Description	Type of Input	Default Value	Unit	Baseline 2012	Baseline 2013	Baseline 2014
Reduced Ancillary Service Cost	Use Optional Inputs	Ancillary Services Cost	Total annual cost of ancillary services. Ancillary services, including spinning reserve and frequency regulation, could be reduced if: generators could more closely follow load; peak load on the system was reduced; power factor, voltage, and VAR control were improved; or information available to grid operators were improved.	Impact Metric Data	N/A	$			
Reduced Congestion Cost	Use Optional Inputs	Congestion Cost	Total annual transmission congestion cost. Project functions that could reduce these costs either provide lower cost energy, decrease loading on system elements, shift load to off-peak, or allow the grid operator to manage the flow of electricity around constrained interfaces (i.e. dynamic line capability or power flow control).	Impact Metric Data	N/A	$			
Deferred Transmission Capacity Investments		Capital Carrying Charge of Transmission Upgrade	The total capital cost of transmission system investments that can be deferred as a direct result of the project. Reducing the load and stress on transmission elements increases asset utilization and reduces the potential need for upgrades. Please enter the total deferred cost in the first year that it will be deferred.	Impact Metric Data	N/A	$			
		Transmission Investment Time Deferred	The time in years that the transmission investment will be deferred. Decimal numbers can be entered (ex.	Impact Metric Data	N/A	yrs			
Deferred Distribution Capacity Investments		Capital Carrying Charge of Distribution Upgrade	The total capital cost of distribution system investments that can be deferred as a direct result of the project. Reducing the load and stress on distribution elements increases asset utilization and reduces the potential need for upgrades. Please enter the total deferred cost in the first year that it will be deferred.	Impact Metric Data	N/A	$			
		Distribution Investment Time Deferred	The time in years that the distribution investment will be deferred. Decimal numbers can be entered (ex. 5.5).	Impact Metric Data	N/A	yrs			
Reduced Electricity Losses		Distribution Feeder Load	Average apparent power readings for all feeders impacted by the project. This input will be used to calculate electricity losses so feeders that have been made more efficient or feeders that have had peak or average loadings decreased should be included. If substations have been made more efficient the average power level of the substation(s) should be input. Information should be based on hourly loads.	Impact Metric Data	N/A	MVA			
		Distribution Losses	Average losses for the portion of the distribution system impacted by the project expressed as a percentage of total loading. This can be modeled or calculated.	Impact Metric Data	N/A	%			
		Transmission Line Load	Average apparent power readings for all lines impacted by the project. This information will be used to calculate electricity losses so lines over which losses could be reduced as a result of the project should be included. Information should be based on	Impact Metric Data	N/A	MVA			
		Transmission Losses	Average losses for the portion of the transmission system impacted by the project expresses as a percentage of total loading. This can be modeled or calculated.	Impact Metric Data	N/A	%			
		Average Price of Wholesale Energy	Average wholesale market price of electricity. This input will be used to monetize electricity losses.	Assumption/Estimate	Use Default	$/kWh			

Figure 59 Benefit Calculation Input in DOE's SGCT

In the Macro code (VBA) the main object for benefit calculation can be seen in object “Calcs” (Sheet 38). Below is the screenshot of the sheet. This object is linked with other various objects in the Macro code. It must be noted that the input table in the previous table will also be linked with the object "Calcs" below.

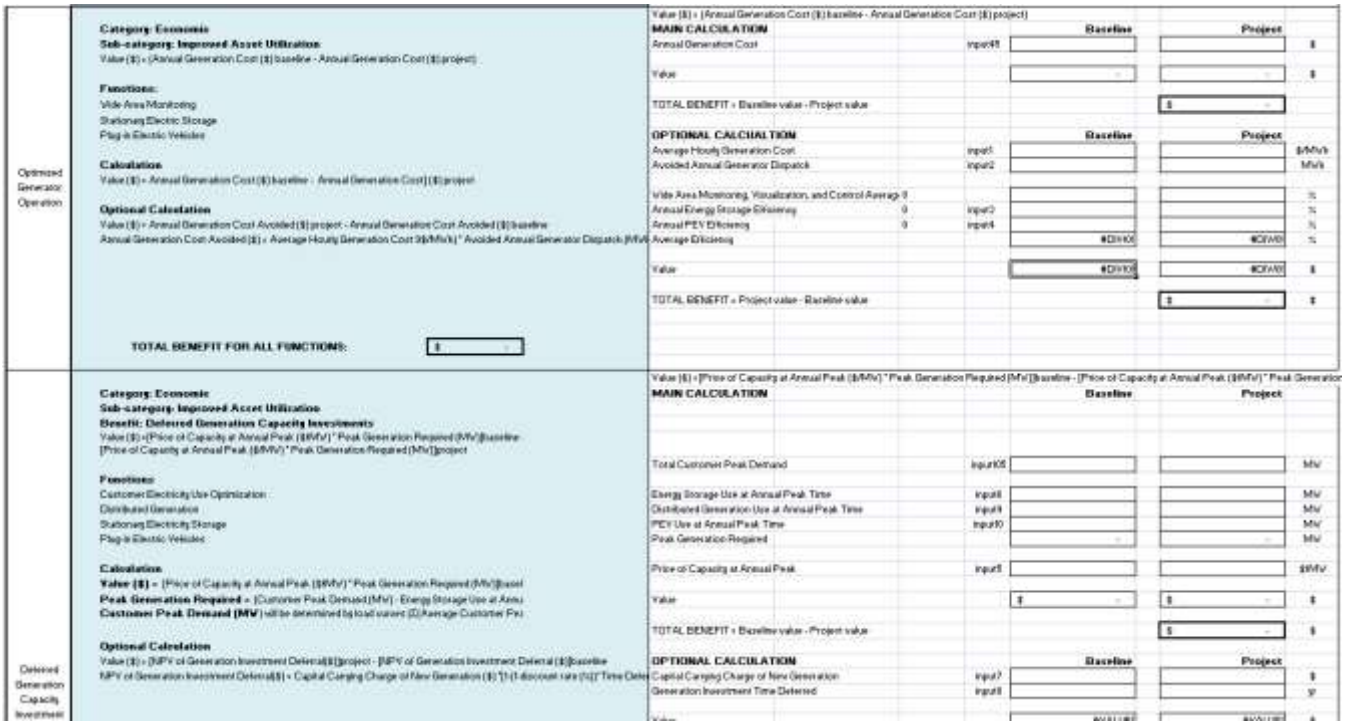


Figure 60 Calcs Object (Sheet 38) in Macro code

Cost Representation

In SGCT, the cost representation is somewhat simple. There are two types of cost schedule that can be inputted to the SGCT. The first is the user must directly enter a nominal cost schedule. But in this case there is no specific guideline from the manual regarding the minimum requirement or the details of the cost structure needed. Also the tools only need one representative cost (capital) for each year of project, as long as the cost spending is still needed by the project.

The second type of cost schedule input is an even more simplified version. The only user inputs that must be provided are: initial and final year of project spending, the total capital cost of the project, and interest rate. Based on those numbers, the SGCT then calculates the amortized yearly cost schedule. In other words, the tools will regard each year's spending of the project to be equal.

Both types of cost representative (as can be seen in the macro) is showed in figure below

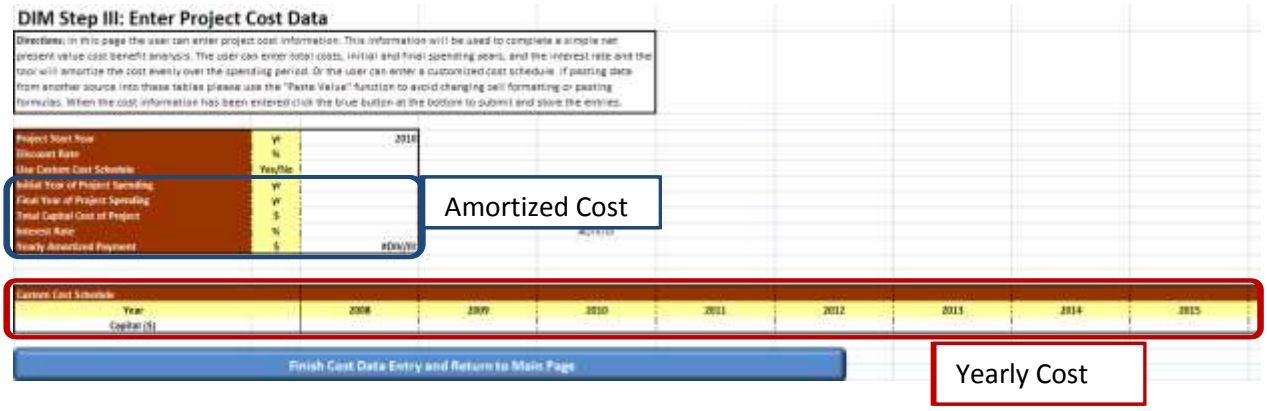


Figure 61 Cost Input in SGCT Macro

A1.4 Computational Module (CM)

The Computational Module is said to be the calculation engine of the SGCT (DOE, 2011). The primary purpose of the CM is totransform the input data either from the DIM default values or from user defined inputs into the costs and benefits of the smart grid project being analyzed. According to DOE (2011), default values are based on the following sources:

- ✓ EIA (Annual Energy Outlook 2009, Form 861, Form 411, etc.)
- ✓ Global Energy Decisions, Energy Velocity (FERC Form 714, etc.)
- ✓ SNL (FERC Form 1, etc.)
- ✓ Public filings, rate cases (PUC, FERC, ISO, etc.)

Then this computation module, CM, calculates costs and benefits on a yearly basis and presents summaries of these results to theuser in tabular and graphical formats.

Computational Module (CM) Main Page

Instructions

Welcome to the Computational Module (CM) phase of the Smart Grid Computational Tool. The CM is the calculation engine of the tool, it crunches the numbers and generates the output. The CM also allows the user to complete a sensitivity analysis if desired. Before running the CM the user can review their inputs and the first five years of projected inputs using the tables below. If the user wishes to change any inputs they can return to the PDIM by clicking the arrow to the right of this directions box.

Running the CM with Reference Inputs - To run the CM with the inputs that were entered in the DIM phase, simply click the button in the "Reference Case" section that says "Run CM with Reference Case Inputs". The CM will take about 20 seconds to complete the analysis. Once the analysis is complete the results can be viewed by clicking the "View Reference Case Results" button.

Running the a Sensitivity Analysis - Before running a sensitivity analysis the CM should be run with the reference case inputs by following the directions above. To run a sensitivity analysis first change the High and Low sensitivity ranges of the desired inputs by using the toggles that are to the right of every input. After all of the desired sensitivity ranges have been set click the button in the "Sensitivity Analysis" section that says "Run CM with Sensitivity Case Inputs". The CM will take about a minute to complete the analysis. Once the analysis is complete the results can be viewed by clicking the "View Sensitivity Results" button. All of the sensitivity ranges can be reset to 100% by clicking the button above the toggle switches that says "Reset all values to 100%".

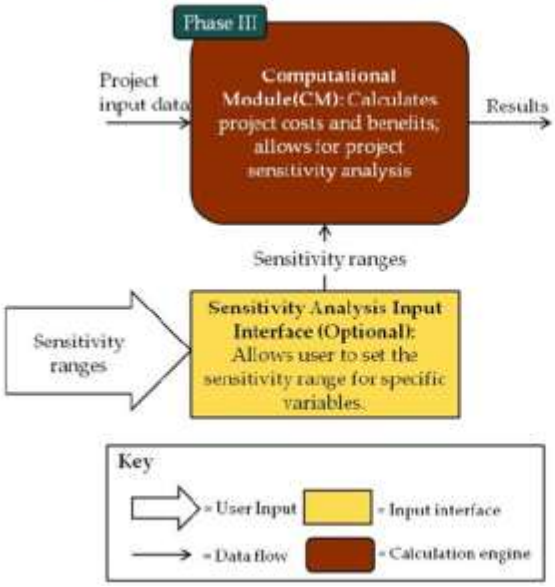


Figure 62 CM Main Page

Source: DOE (2011)

Reference Case

Run CM with Reference Case Inputs

View Reference Case Results

Sensitivity Analysis

Run CM with Sensitivity Case Inputs

View Sensitivity Results

Reset all values to 100%

Input Name	Unit	Select % using toggle		
		Low	Reference	High
Number of Customers Residential Rate Sub-Class 1	#	100%	100%	100%
Number of Customers Residential Rate Sub-Class 2	#	100%	100%	100%
Number of Customers Residential Rate Sub-Class 3	#	100%	100%	100%
Number of Customers Residential Rate Sub-Class 4	#	100%	100%	100%
Number of Customers Residential Rate Sub-Class 5	#	100%	100%	100%
Number of Customers All Residential Classes	#	100%	100%	100%
Number of Customers Commercial Rate Sub-Class 1	#	100%	100%	100%
Number of Customers Commercial Rate Sub-Class 2	#	100%	100%	100%
Number of Customers Commercial Rate Sub-Class 3	#	100%	100%	100%
Number of Customers Commercial Rate Sub-Class 4	#	100%	100%	100%
Number of Customers Commercial Rate Sub-Class 5	#	100%	100%	100%
Number of Customers All Commercial Classes	#	100%	100%	100%
Number of Customers Industrial Sub-Class 1	#	100%	100%	100%
Number of Customers Industrial Sub-Class 2	#	100%	100%	100%
Number of Customers Industrial Sub-Class 3	#	100%	100%	100%
Number of Customers Industrial Sub-Class 4	#	100%	100%	100%
Number of Customers Industrial Sub-Class 5	#	100%	100%	100%
Number of Customers All Industrial Classes	#	100%	100%	100%

Figure 63 Benefit Calculation Window

Source: DOE (2011)

Figure below shows the example of benefit calculation which is quite in detail. It can be seen that each function has its own monetization calculation. Thus the total monetized benefit of Optimized Generator Operation is the sum of Wide Area Monitoring, Visualization & Control monetization part and Stationary Electricity Storage and PEV monetization part.

Benefit	Functions & Enabled Energy Resources	Input Parameters	Monetization Calculation
Optimized Generator Operation	• Wide Area Monitoring, Visualization, and Control • Stationary Electricity Storage • Plug-in Electric Vehicles	• Hourly Generation Cost ($/MWh) • Annual Generator Dispatch (MWh) • Annual Energy Storage Efficiency (%)	For Wide Area Monitoring, Visualization, & Control: **Value ($)** = [Annual Generation Cost ($)]$_{Baseline}$ - [Annual Generation Cost ($)]$_{Project}$ For Stationary Electricity Storage and PEV: **Value ($)** = {[Hourly Generation Cost ($/MWh) * Annual Generator Dispatch (MWh)]$_{Baseline}$ – [Hourly Generation Cost ($/MWh) * Annual Generator Dispatch (MWh)]$_{Project}$}* Energy Storage Efficiency (%)
Deferred Generation Capacity Investments	• Customer Electricity Use Optimization • Distributed Generation • Stationary Electricity Storage • Plug-in Electric Vehicles	• Price of Capacity at Annual Peak ($/MW), • EER Use At Annual Peak (MW) • Capital Carrying Charge of New Generation ($/yr) • Time deferred (yrs)	**Value ($)** = [Price of Capacity at Annual Peak ($/MW) * EER Use or Customer Optimization at Annual Peak (MW)]$_{Baseline}$ - [Price of Capacity at Annual Peak ($/MW) * EER Use or Customer Optimization at Annual Peak (MW)]$_{Project}$ Or **Value ($)** = Capital Carrying Charge of New Generation ($/yr) * Time deferred (yrs)

Detailed

Figure 64 Example of Benefit Calculation which is Related to Its Functions

As mentioned above, the calculation of benefit is not necessarily in detailed case as previous case. Figure below shows the example of generalized and simplified benefit calculation. As can be seen, although the benefit of Reduced Wide-scale Blackouts can be realized through Wide Area Monitoring & Visualization, Dynamic Capability Rating, and Enhanced Fault Detection functions, the monetization calculation simply uses the number of events (Wide-scale Blackouts) times the estimated cost per event in baseline case and project case. Thus there is no "Dynamic Capability Rating-contributed benefit" or "Enhanced Fault Detection-contributed benefit".

Benefit	Functions & Enabled Energy Resources	Input Parameters	Monetization Calculation
Reduced Oil Usage	• Automated Feeder Switching • Diagnosis & Notification of Equipment Condition • Real-Time Load Measurement & Management • Plug-in Electric Vehicles	• Number of Switching or Maintenance Operations Completed (# of events) • Average Miles Travelled per Operation (Baseline miles/operation) • Average Fuel Efficiency for Service Vehicle (gallons/mile) • kWh consumed (kWh) • Electricity to Fuel Conversion Factor	For Automated Feeder Switching, Diagnosis & Notification of Equipment Condition, & Real-Time Load Measurement & Management: **Value ($)** = {Operation (# of events) * Average Miles Travelled per Event (miles/event) *Average Fuel Efficiency for Service Vehicle (gallons/mile) * Oil Conversion Factor (barrels of oil/gallon of gasoline)}$_{Baseline}$ - {Operation (# of events) * Average Miles Travelled per Event (miles/event) *Average Fuel Efficiency for Service Vehicle (gallons/mile) * Oil Conversion Factor (barrels of oil/gallon of gasoline)}$_{Project}$ For PEVs: **Value ($)** = {Electricity consumed (kWh) * Gasoline Conversion Factor (gallons of gasoline/kWh) * Oil Conversion Factor (barrels of oil/gallon of gasoline)}$_{Baseline}$ - {Electricity consumed (kWh) * Gasoline Conversion Factor (gallons of gasoline/kWh) * Oil Conversion Factor (barrels of oil/gallon of gasoline)}$_{Project}$
Reduced Wide-scale Blackouts	• Wide Area Monitoring & Visualization • Dynamic Capability Rating • Enhanced Fault Detection	• Number of Events (# of events) • Estimated Cost per Event ($/event)	**Value ($)** = [Number of Events (# of events) * Estimated Cost per Event ($/event)]$_{Baseline}$ - [Number of Events (# of events) * Estimated Cost per Event ($/event)]$_{Project}$

Simplified

Figure 65 Example of Benefit Calculation which is Generalized and Simplified

In benefit calculation of SGCT, it is possible to have two types of calculation for each benefit, which is called standard and optional calculation. Each calculation will have different set of inputs that need to be provided by the user. For example, let's examine the calculation for Reduced Ancillary Service Cost. The standard calculation is:

**Value ($) =** [Ancillary Services Cost ($)]$_{Baseline}$ - [Ancillary Services Cost ($)]$_{Project}$

which only needs one type of input: Ancillary Service Cost ($).

The optional calculation for the same benefit is:

Value ($) = [Σ (Price of Ancillary Service ($/MW) * Purchases (MW))]$_{Baseline}$ - [Σ (Price of Ancillary Service ($/MW) *Purchases (MW))]$_{Project}$

which requires the user to provide these inputs:

- ✓ Average Price of Reserves ($/MW)
- ✓ Reserve Purchases (MW)
- ✓ Average Price of Frequency Regulation ($/MW)
- ✓ Frequency Regulation Purchases (MW)
- ✓ Average Price of Voltage Control ($/MVAR)
- ✓ Voltage Control Purchases (MVAR)

It can be noticed that in this case, the Ancillary Services that is considered in this calculation is Reserve Purchases, Frequency Regulation Purchases, and Voltage Control Purchases.

Since these key concepts can be very technical, it is advisable to examine closely Appendix B.2 Detailed Explanation of SGCT Inputs of the User Guide (2011).

Macro (VBA) Code

The SGCT is provided by DOE in form of Microsoft Excel's Macro. For a user who wants to execute Benefit Cost Analysis of a specific smart grid project, the tool can be utilized by following its step-by-step procedure. But it must be noted that to do so, the user needs to fully understand characteristics of its smart grid project (the assets, functions, and mechanisms). The user also needs to understand various concepts of those characteristics and other technical and economical key concepts and provide all the needed data inputs.

In order to understand how the inside of the macro works, a user needs to access and closely examine the macro code, which is written in Visual Basic for Application (VBA) environment. Once the access is granted, it can be seen that the code contains three parts:

- ➢ **Microsoft Excel Objects**

An object in VBA is something like a tool or a thing that has certain functions and properties, and can contain data. For example, an Excel Worksheet is an object, a cell in a worksheet is an object, range of cells is an object, a command button is an object, and a text box is an object. In SGCT, there are various sheets which range from all the mappings, user inputs, calculations, showing summaries, sensitivity analyses, results, etc. There are total 43 sheets listed in theSGCT VBA.

Figure below shows the list of Microsoft Excel Objects in the US_DOE_Smart_Grid_Computational_Tool_Public_Version_1.xlsb (excel basic) and an example of properties (sheet 11). These sheets are normally hidden, as can be seen in the last property, "Visible: 2 – xlSheetVeryHidden". In order to examine the sheet, the first thing that must be done is changing this property to "-1 – xlSheetVisible". After that, the corresponding sheet can be examined in the excel file.

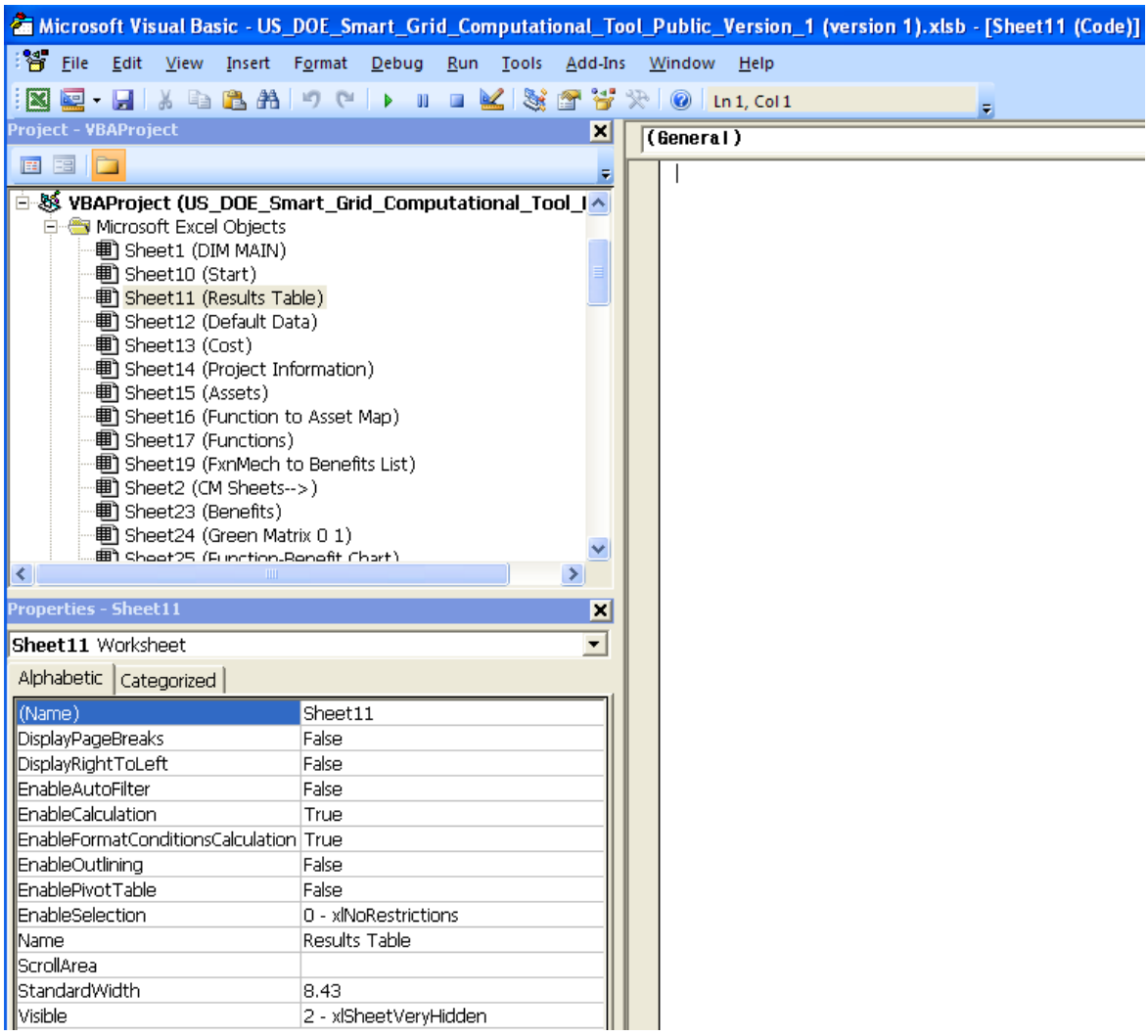


Figure 66 List of Microsoft Excel Object and an Example of Properties (Sheet 11)

- **Forms**

A user form in VBA is a kind of dialog/message box combined with various control properties. The user can input a text, choose from a bulleted list, open another message box, or move to another user form of worksheet. In SGCT, forms are used to display many dialog boxes and windows, such as for choosing assets, functions and mechanism, showing information about definitions or explanations of various key concepts, reminding user to fill out all needed input data, etc. There are total 13 forms listed in the SGCT VBA.

Figure below shows an example of form, which is the Choose Assets form. This form will be shown when a user start a new project in the excel macro file of SGCT.

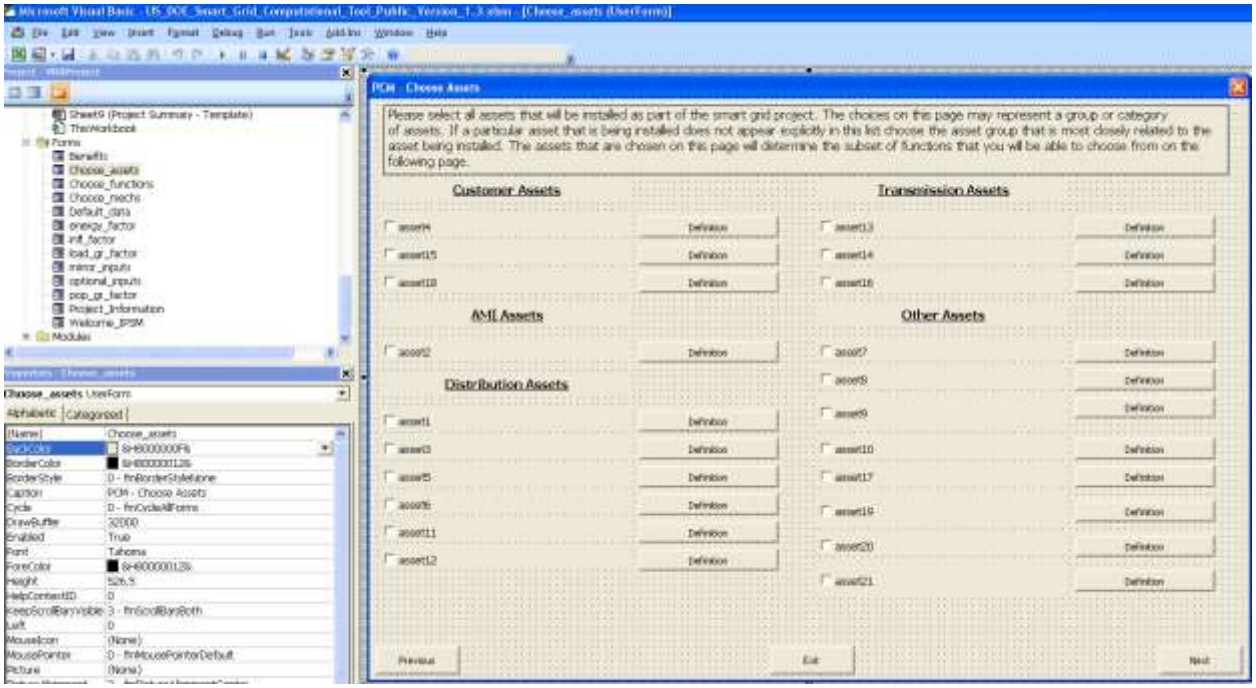


Figure 67 Example of Form (Choose Assets)

- **Modules**

Module is a collection of macros. Each macro is able to run a procedure which is composed of several lines of programming codes. The purpose of using macro is to build customized functions or solutions using Microsoft Excel. For example, it can handle the procedure for creating function mechanism table, inputting various data, filling in default input data, or protecting/unprotecting a sheet. There are 5 modules listed in the SGCT VBA:

- ✓ Module 1 contains all of the macros that helped create the tool and will help edit the tool
- ✓ Module 3 contains all of the codes that make the IPSM and DIM work and allow navigation through the tool.
- ✓ Module 4 contains all of the code for showing optional inputs.
- ✓ Module 5 contains all of the codes for filling in the default data inputs.

- ✓ Module 6 contains all of the code for the CM.

Figure below shows the example of Module three, which manages the IPSM (Initial Project Setup Module), DIM (Data Input Module), and navigation through the tool.

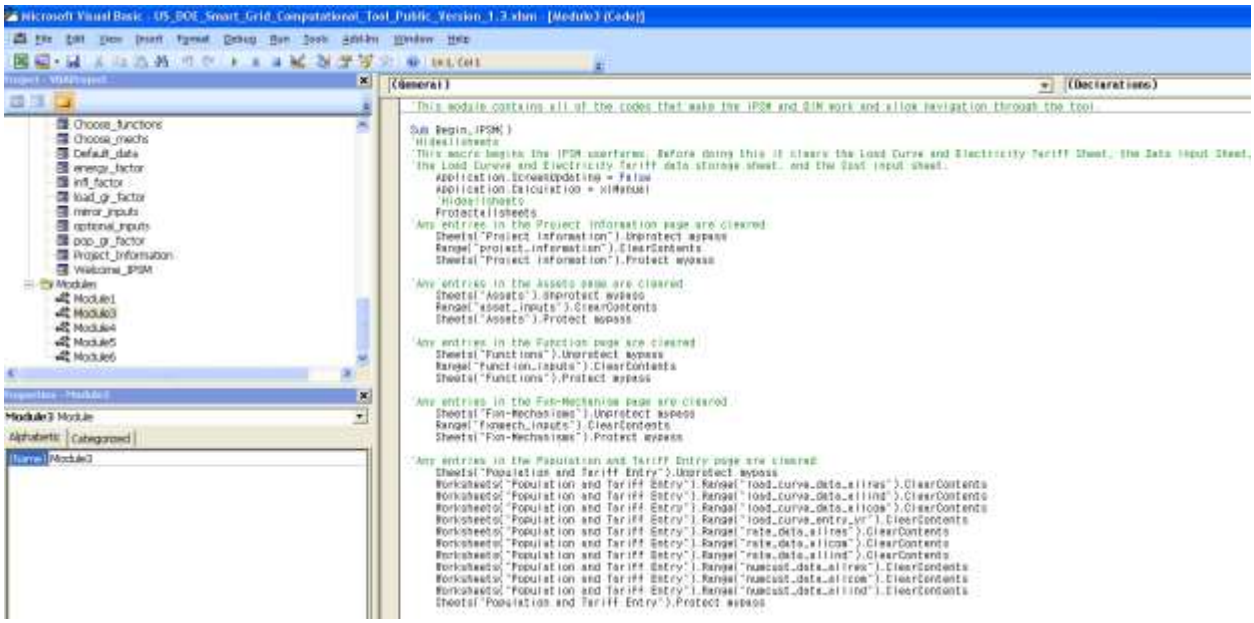


Figure 68 Example of Module (Module 3)

Appendix II Default Parameters in SGCT

Table 3 Average Hourly Generation Cost

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
NPCC	91.6	87.1	72.4	73.0	72.4	73.2	74.4	77.3	77.5	77.6	80.9	83.3	84.2	83.2	83.3	84.7	85.9	88.9	91.0	92.7	94.5	95.6	96.2
RFC	69.0	67.0	58.6	58.3	57.7	58.1	58.5	59.1	59.9	60.4	61.4	62.7	63.0	63.2	64.0	65.2	66.5	68.4	70.1	71.9	73.3	73.6	75.0
MRO	38.2	39.1	39.8	38.7	38.8	38.9	38.8	38.1	37.5	37.2	36.9	36.7	36.4	35.9	35.8	35.8	35.8	35.4	35.1	35.2	35.6	36.6	37.8
FRCC	87.5	91.6	80.0	83.2	85.3	85.4	85.4	85.8	86.1	86.0	86.6	88.4	90.7	90.7	90.6	90.8	91.6	92.9	94.7	96.8	98.0	99.0	99.6
SERC	56.7	57.4	54.0	53.3	52.6	52.1	51.5	50.9	51.0	51.2	51.6	51.6	51.7	51.7	52.1	52.5	53.6	54.8	56.1	57.5	58.4	59.3	60.0
SPP	56.9	60.0	54.5	55.8	53.5	53.7	53.7	53.7	54.5	54.9	55.4	56.0	56.0	55.6	55.8	56.4	57.5	58.9	60.0	61.5	62.4	63.3	64.1
TRE	76.7	74.0	62.2	62.0	61.5	64.0	64.9	64.9	66.4	69.6	71.8	75.4	77.9	78.4	79.5	80.7	81.9	84.6	88.0	91.5	93.7	94.6	95.5
WECC	63.2	64.4	59.8	57.7	55.5	54.2	53.4	53.3	53.9	55.2	55.9	56.7	56.7	56.2	56.0	58.1	59.4	60.7	62.4	63.8	65.0	66.3	67.2
ASCC	63.2	64.4	59.8	57.7	55.5	54.2	53.4	53.3	53.9	55.2	55.9	56.7	56.7	56.2	56.0	58.1	59.4	60.7	62.4	63.8	65.0	66.3	67.2
HI	63.2	64.4	59.8	57.7	55.5	54.2	53.4	53.3	53.9	55.2	55.9	56.7	56.7	56.2	56.0	58.1	59.4	60.7	62.4	63.8	65.0	66.3	67.2

Table 4 Price of Capacity at Annual Peak (1)

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
NPCC	46,829	46,829	50,144	39,137	29,167	35,958	50,224	63,772	63,466	63,136	62,831	64,199
RFC	40,150	40,150	40,150	40,150	39,194	50,795	64,377	66,021	70,702	75,091	79,833	84,813
MRO	95,700	95,700	95,700	95,700	95,700	95,700	95,700	95,700	95,700	95,700	95,700	95,700
FRCC	95,700	95,700	95,700	95,700	95,700	95,700	95,700	95,700	95,700	95,700	95,700	95,700
SERC	95,700	95,700	95,700	95,700	95,700	95,700	95,700	95,700	95,700	95,700	95,700	95,700
SPP	95,700	95,700	95,700	95,700	95,700	95,700	95,700	95,700	95,700	95,700	95,700	95,700
TRE	95,700	95,700	95,700	95,700	95,700	95,700	95,700	95,700	95,700	95,700	95,700	95,700
WECC	95,700	95,700	95,700	95,700	95,700	95,700	95,700	95,700	95,700	95,700	95,700	95,700
ASCC	95,700	95,700	95,700	95,700	95,700	95,700	95,700	95,700	95,700	95,700	95,700	95,700
HI	95,700	95,700	95,700	95,700	95,700	95,700	95,700	95,700	95,700	95,700	95,700	95,700

Table 5 Price of Capacity at Annual Peak (2)

	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
NPCC	76,909	89,004	100,504	100,478	100,472	100,484	100,510	100,475	100,454	100,513	100,509
RFC	96,727	102,203	110,401	114,992	114,133	105,800	105,515	109,794	114,412	119,436	124,817
MRO	95,700	95,700	95,700	95,700	95,700	95,700	95,700	95,700	95,700	95,700	95,700
FRCC	95,700	95,700	95,700	95,700	95,700	95,700	95,700	95,700	95,700	95,700	95,700
SERC	95,700	95,700	95,700	95,700	95,700	95,700	95,700	95,700	95,700	95,700	95,700
SPP	95,700	95,700	95,700	95,700	95,700	95,700	95,700	95,700	95,700	95,700	95,700
TRE	95,700	95,700	95,700	95,700	95,700	95,700	95,700	95,700	95,700	95,700	95,700
WECC	95,700	95,700	95,700	95,700	95,700	95,700	95,700	95,700	95,700	95,700	95,700
ASCC	95,700	95,700	95,700	95,700	95,700	95,700	95,700	95,700	95,700	95,700	95,700
HI	95,700	95,700	95,700	95,700	95,700	95,700	95,700	95,700	95,700	95,700	95,700

Table 6 Average Price of Reserves

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
NPCC	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
RFC	16.3	16.3	16.3	16.3	16.3	16.3	16.3	16.3	16.3	16.3	16.3	16.3	16.3	16.3	16.3	16.3	16.3	16.3	16.3	16.3	16.3	16.3	16.3
MRO	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3
FRCC	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3
SERC	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3
SPP	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3
TRE	12.8	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7
WECC	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4
ASCC	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3
HI	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3

Table 7 Average Price of Frequency Regulation

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
NPCC	33.4	33.4	34.1	34.8	35.5	35.6	35.7	35.7	35.8	35.8	35.8	35.9	35.9	35.9	36.0	36.0	36.1	36.2	36.2	36.3	36.3	36.4	36.5
RFC	36.9	40.2	40.2	40.6	41.0	41.1	41.2	41.2	41.3	41.4	41.5	41.6	41.7	41.8	41.9	41.9	42.0	42.1	42.1	42.2	42.2	42.3	42.3
MRO	26.1	28.5	28.5	28.8	29.0	29.1	29.1	29.2	29.3	29.3	29.4	29.5	29.5	29.6	29.7	29.7	29.7	29.8	29.8	29.9	29.9	29.9	30.0
FRCC	26.1	28.5	28.5	28.8	29.0	29.1	29.1	29.2	29.3	29.3	29.4	29.5	29.5	29.6	29.7	29.7	29.7	29.8	29.8	29.9	29.9	29.9	30.0
SERC	26.1	28.5	28.5	28.8	29.0	29.1	29.1	29.2	29.3	29.3	29.4	29.5	29.5	29.6	29.7	29.7	29.7	29.8	29.8	29.9	29.9	29.9	30.0
SPP	26.1	28.5	28.5	28.8	29.0	29.1	29.1	29.2	29.3	29.3	29.4	29.5	29.5	29.6	29.7	29.7	29.7	29.8	29.8	29.9	29.9	29.9	30.0
TRE	14.9	16.2	16.2	16.4	16.5	16.6	16.6	16.6	16.7	16.7	16.8	16.8	16.8	16.9	16.9	16.9	16.9	17.0	17.0	17.0	17.0	17.1	17.1
WECC	19.3	21.1	21.1	21.3	21.5	21.5	21.6	21.6	21.7	21.7	21.8	21.8	21.9	21.9	22.0	22.0	22.0	22.1	22.1	22.1	22.1	22.2	22.2
ASCC	26.1	28.5	28.5	28.8	29.0	29.1	29.1	29.2	29.3	29.3	29.4	29.5	29.5	29.6	29.7	29.7	29.7	29.8	29.8	29.9	29.9	29.9	30.0
HI	26.1	28.5	28.5	28.8	29.0	29.1	29.1	29.2	29.3	29.3	29.4	29.5	29.5	29.6	29.7	29.7	29.7	29.8	29.8	29.9	29.9	29.9	30.0

Table 8 Average Price of Voltage Control (1)

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
NPCC	2,187.5	2,220.3	2,253.6	2,287.4	2,321.7	2,356.6	2,391.9	2,427.8	2,464.2	2,501.2	2,538.7	2,576.8
RFC	2,187.5	2,220.3	2,253.6	2,287.4	2,321.7	2,356.6	2,391.9	2,427.8	2,464.2	2,501.2	2,538.7	2,576.8
MRO	2,187.5	2,220.3	2,253.6	2,287.4	2,321.7	2,356.6	2,391.9	2,427.8	2,464.2	2,501.2	2,538.7	2,576.8
FRCC	2,187.5	2,220.3	2,253.6	2,287.4	2,321.7	2,356.6	2,391.9	2,427.8	2,464.2	2,501.2	2,538.7	2,576.8
SERC	2,187.5	2,220.3	2,253.6	2,287.4	2,321.7	2,356.6	2,391.9	2,427.8	2,464.2	2,501.2	2,538.7	2,576.8
SPP	2,187.5	2,220.3	2,253.6	2,287.4	2,321.7	2,356.6	2,391.9	2,427.8	2,464.2	2,501.2	2,538.7	2,576.8
TRE	2,187.5	2,220.3	2,253.6	2,287.4	2,321.7	2,356.6	2,391.9	2,427.8	2,464.2	2,501.2	2,538.7	2,576.8
WECC	2,187.5	2,220.3	2,253.6	2,287.4	2,321.7	2,356.6	2,391.9	2,427.8	2,464.2	2,501.2	2,538.7	2,576.8
ASCC	2,187.5	2,220.3	2,253.6	2,287.4	2,321.7	2,356.6	2,391.9	2,427.8	2,464.2	2,501.2	2,538.7	2,576.8
HI	2,187.5	2,220.3	2,253.6	2,287.4	2,321.7	2,356.6	2,391.9	2,427.8	2,464.2	2,501.2	2,538.7	2,576.8

Table 9 Average Price of Voltage Control (2)

	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
NPCC	2,615.4	2,654.6	2,694.5	2,734.9	2,775.9	2,817.5	2,859.8	2,902.7	2,946.2	2,990.4	3,035.3
RFC	2,615.4	2,654.6	2,694.5	2,734.9	2,775.9	2,817.5	2,859.8	2,902.7	2,946.2	2,990.4	3,035.3
MRO	2,615.4	2,654.6	2,694.5	2,734.9	2,775.9	2,817.5	2,859.8	2,902.7	2,946.2	2,990.4	3,035.3
FRCC	2,615.4	2,654.6	2,694.5	2,734.9	2,775.9	2,817.5	2,859.8	2,902.7	2,946.2	2,990.4	3,035.3
SERC	2,615.4	2,654.6	2,694.5	2,734.9	2,775.9	2,817.5	2,859.8	2,902.7	2,946.2	2,990.4	3,035.3
SPP	2,615.4	2,654.6	2,694.5	2,734.9	2,775.9	2,817.5	2,859.8	2,902.7	2,946.2	2,990.4	3,035.3
TRE	2,615.4	2,654.6	2,694.5	2,734.9	2,775.9	2,817.5	2,859.8	2,902.7	2,946.2	2,990.4	3,035.3
WECC	2,615.4	2,654.6	2,694.5	2,734.9	2,775.9	2,817.5	2,859.8	2,902.7	2,946.2	2,990.4	3,035.3
ASCC	2,615.4	2,654.6	2,694.5	2,734.9	2,775.9	2,817.5	2,859.8	2,902.7	2,946.2	2,990.4	3,035.3
HI	2,615.4	2,654.6	2,694.5	2,734.9	2,775.9	2,817.5	2,859.8	2,902.7	2,946.2	2,990.4	3,035.3

Table 10 Average Price of Congestion

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
NPCC	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8
RFC	8.6	8.6	8.6	8.6	8.6	8.6	8.6	8.6	8.6	8.6	8.6	8.6	8.6	8.6	8.6	8.6	8.6	8.6	8.6	8.6	8.6	8.6	8.6
MRO	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2
FRCC	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SERC	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SPP	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TRE	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4
WECC	7.3	7.3	7.3	7.3	7.3	7.3	7.3	7.3	7.3	7.3	7.3	7.3	7.3	7.3	7.3	7.3	7.3	7.3	7.3	7.3	7.3	7.3	7.3
ASCC	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HI	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 11 Average Price of Wholesale Energy

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
NPCC	0.06	0.06	0.07	0.08	0.09	0.09	0.09	0.09	0.10	0.10	0.10	0.11	0.11	0.11	0.12	0.12	0.12	0.13	0.13	0.14	0.14	0.14	0.15
RFC	0.07	0.05	0.06	0.06	0.07	0.07	0.07	0.07	0.07	0.08	0.08	0.08	0.08	0.09	0.09	0.09	0.09	0.10	0.10	0.10	0.10	0.11	0.11
MRO	0.04	0.03	0.04	0.04	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.06
FRCC	0.09	0.07	0.08	0.09	0.11	0.11	0.11	0.10	0.11	0.11	0.11	0.11	0.12	0.12	0.13	0.13	0.13	0.13	0.14	0.14	0.14	0.14	0.15
SERC	0.06	0.04	0.05	0.06	0.07	0.06	0.06	0.06	0.06	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.08	0.08	0.08	0.08	0.08	0.09	0.09
SPP	0.06	0.04	0.05	0.06	0.07	0.07	0.07	0.06	0.07	0.07	0.07	0.07	0.07	0.08	0.08	0.08	0.08	0.08	0.09	0.09	0.09	0.09	0.10
TRE	0.08	0.05	0.06	0.07	0.08	0.08	0.08	0.08	0.08	0.09	0.09	0.10	0.10	0.11	0.11	0.11	0.12	0.12	0.13	0.13	0.14	0.14	0.14
WECC	0.06	0.05	0.06	0.06	0.07	0.07	0.06	0.06	0.07	0.07	0.07	0.07	0.07	0.08	0.08	0.08	0.08	0.09	0.09	0.09	0.09	0.10	0.10
ASCC	0.06	0.05	0.06	0.06	0.07	0.07	0.06	0.06	0.07	0.07	0.07	0.07	0.07	0.08	0.08	0.08	0.08	0.09	0.09	0.09	0.09	0.10	0.10
HI	0.06	0.05	0.06	0.06	0.07	0.07	0.06	0.06	0.07	0.07	0.07	0.07	0.07	0.08	0.08	0.08	0.08	0.09	0.09	0.09	0.09	0.10	0.10

Table 12 Inflation Factor

	Residential	Commercial	Industrial
NPCC	2.20	282.00	15.30
RFC	2.20	282.00	15.30
MRO	2.20	282.00	15.30
FRCC	2.20	282.00	15.30
SERC	2.20	282.00	15.30
SPP	2.20	282.00	15.30
TRE	2.20	282.00	15.30
WECC	2.20	282.00	15.30
ASCC	2.20	282.00	15.30
HI	2.20	282.00	15.30
Empty	2.20	282.00	15.30

Table 13 Restoration Cost per Event (1)

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
NPCC	3,000.0	3,081.0	3,081.0	3,164.2	3,164.2	3,249.6	3,249.6	3,337.4	3,337.4	3,427.5	3,427.5	3,520.0
RFC	3,000.0	3,063.0	3,063.0	3,127.3	3,127.3	3,193.0	3,193.0	3,260.0	3,260.0	3,328.5	3,328.5	3,398.4
MRO	3,000.0	3,063.0	3,063.0	3,127.3	3,127.3	3,193.0	3,193.0	3,260.0	3,260.0	3,328.5	3,328.5	3,398.4
FRCC	3,000.0	3,087.0	3,087.0	3,176.5	3,176.5	3,268.6	3,268.6	3,363.4	3,363.4	3,461.0	3,461.0	3,561.3
SERC	3,000.0	3,072.0	3,072.0	3,145.7	3,145.7	3,221.2	3,221.2	3,298.5	3,298.5	3,377.7	3,377.7	3,458.8
SPP	3,000.0	3,063.0	3,063.0	3,127.3	3,127.3	3,193.0	3,193.0	3,260.0	3,260.0	3,328.5	3,328.5	3,398.4
TRE	3,000.0	3,069.0	3,069.0	3,139.6	3,139.6	3,211.8	3,211.8	3,285.7	3,285.7	3,361.2	3,361.2	3,438.5
WECC	3,000.0	3,072.0	3,072.0	3,145.7	3,145.7	3,221.2	3,221.2	3,298.5	3,298.5	3,377.7	3,377.7	3,458.8
ASCC	3,000.0	3,078.0	3,078.0	3,158.0	3,158.0	3,240.1	3,240.1	3,324.4	3,324.4	3,410.8	3,410.8	3,499.5
HI	3,000.0	3,000.0	3,000.0	3,000.0	3,000.0	3,000.0	3,000.0	3,000.0	3,000.0	3,000.0	3,000.0	3,000.0

Table 14 Restoration Cost per Event (2)

	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
NPCC	3,520.0	3,615.1	3,615.1	3,712.7	3,712.7	3,812.9	3,812.9	3,915.8	3,915.8	4,021.6	4,021.6
RFC	3,398.4	3,469.8	3,469.8	3,542.6	3,542.6	3,617.0	3,617.0	3,693.0	3,693.0	3,770.5	3,770.5
MRO	3,398.4	3,469.8	3,469.8	3,542.6	3,542.6	3,617.0	3,617.0	3,693.0	3,693.0	3,770.5	3,770.5
FRCC	3,561.3	3,664.6	3,664.6	3,770.9	3,770.9	3,880.2	3,880.2	3,992.8	3,992.8	4,108.6	4,108.6
SERC	3,458.8	3,541.8	3,541.8	3,626.8	3,626.8	3,713.8	3,713.8	3,803.0	3,803.0	3,894.2	3,894.2
SPP	3,398.4	3,469.8	3,469.8	3,542.6	3,542.6	3,617.0	3,617.0	3,693.0	3,693.0	3,770.5	3,770.5
TRE	3,438.5	3,517.6	3,517.6	3,598.5	3,598.5	3,681.3	3,681.3	3,766.0	3,766.0	3,852.6	3,852.6
WECC	3,458.8	3,541.8	3,541.8	3,626.8	3,626.8	3,713.8	3,713.8	3,803.0	3,803.0	3,894.2	3,894.2
ASCC	3,499.5	3,590.5	3,590.5	3,683.8	3,683.8	3,779.6	3,779.6	3,877.9	3,877.9	3,978.7	3,978.7
HI	3,000.0	3,000.0	3,000.0	3,000.0	3,000.0	3,000.0	3,000.0	3,000.0	3,000.0	3,000.0	3,000.0

Table 15 Average Fuel Efficiency for Truck Roll Vehicle

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
NPCC	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3
RFC	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3
MRO	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3
FRCC	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3
SERC	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3
SPP	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3
TRE	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3
WECC	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3
ASCC	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3
HI	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3
Empty	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3	20.3

Table 16 CO2 Emissions per Gallon of Fuel

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021-'30
NPCC	0.0097	0.0097	0.0097	0.0097	0.0097	0.0097	0.0097	0.0097	0.0097	0.0097	0.0097	0.0097	0.0097	null
RFC	0.0097	0.0097	0.0097	0.0097	0.0097	0.0097	0.0097	0.0097	0.0097	0.0097	0.0097	0.0097	0.0097	null
MRO	0.0097	0.0097	0.0097	0.0097	0.0097	0.0097	0.0097	0.0097	0.0097	0.0097	0.0097	0.0097	0.0097	null
FRCC	0.0097	0.0097	0.0097	0.0097	0.0097	0.0097	0.0097	0.0097	0.0097	0.0097	0.0097	0.0097	0.0097	null
SERC	0.0097	0.0097	0.0097	0.0097	0.0097	0.0097	0.0097	0.0097	0.0097	0.0097	0.0097	0.0097	0.0097	null
SPP	0.0097	0.0097	0.0097	0.0097	0.0097	0.0097	0.0097	0.0097	0.0097	0.0097	0.0097	0.0097	0.0097	null
TRE	0.0097	0.0097	0.0097	0.0097	0.0097	0.0097	0.0097	0.0097	0.0097	0.0097	0.0097	0.0097	0.0097	null
WECC	0.0097	0.0097	0.0097	0.0097	0.0097	0.0097	0.0097	0.0097	0.0097	0.0097	0.0097	0.0097	0.0097	null
ASCC	0.0097	0.0097	0.0097	0.0097	0.0097	0.0097	0.0097	0.0097	0.0097	0.0097	0.0097	0.0097	0.0097	null
HI	0.0097	0.0097	0.0097	0.0097	0.0097	0.0097	0.0097	0.0097	0.0097	0.0097	0.0097	0.0097	0.0097	null
Empty	0.0097	0.0097	0.0097	0.0097	0.0097	0.0097	0.0097	0.0097	0.0097	0.0097	0.0097	0.0097	0.0097	null

Table 17 Value of CO2

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
NPCC	20	20	20	20	20	20	20	20	20	20	20	20	20	20.4	20.8	21.2	21.6	22.1	22.5	23.0	23.4	23.9	24.4
RFC	20	20	20	20	20	20	20	20	20	20	20	20	20	20.4	20.8	21.2	21.6	22.1	22.5	23.0	23.4	23.9	24.4
MRO	20	20	20	20	20	20	20	20	20	20	20	20	20	20.4	20.8	21.2	21.6	22.1	22.5	23.0	23.4	23.9	24.4
FRCC	20	20	20	20	20	20	20	20	20	20	20	20	20	20.4	20.8	21.2	21.6	22.1	22.5	23.0	23.4	23.9	24.4
SERC	20	20	20	20	20	20	20	20	20	20	20	20	20	20.4	20.8	21.2	21.6	22.1	22.5	23.0	23.4	23.9	24.4
SPP	20	20	20	20	20	20	20	20	20	20	20	20	20	20.4	20.8	21.2	21.6	22.1	22.5	23.0	23.4	23.9	24.4
TRE	20	20	20	20	20	20	20	20	20	20	20	20	20	20.4	20.8	21.2	21.6	22.1	22.5	23.0	23.4	23.9	24.4
WECC	20	20	20	20	20	20	20	20	20	20	20	20	20	20.4	20.8	21.2	21.6	22.1	22.5	23.0	23.4	23.9	24.4
ASCC	20	20	20	20	20	20	20	20	20	20	20	20	20	20.4	20.8	21.2	21.6	22.1	22.5	23.0	23.4	23.9	24.4
HI	20	20	20	20	20	20	20	20	20	20	20	20	20	20.4	20.8	21.2	21.6	22.1	22.5	23.0	23.4	23.9	24.4
Empty	20	20	20	20	20	20	20	20	20	20	20	20	20	20.4	20.8	21.2	21.6	22.1	22.5	23.0	23.4	23.9	24.4

Table 18 SOx Emissions per Gallon of Gas

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021-'30
NPCC	2.2E-07	2.2E-07	2.2E-07	2.2E-07	2.2E-07	2.2E-07	2.2E-07	2.2E-07	2.2E-07	2.2E-07	2.2E-07	2.2E-07	2.2E-07	null
RFC	2.2E-07	2.2E-07	2.2E-07	2.2E-07	2.2E-07	2.2E-07	2.2E-07	2.2E-07	2.2E-07	2.2E-07	2.2E-07	2.2E-07	2.2E-07	null
MRO	2.2E-07	2.2E-07	2.2E-07	2.2E-07	2.2E-07	2.2E-07	2.2E-07	2.2E-07	2.2E-07	2.2E-07	2.2E-07	2.2E-07	2.2E-07	null
FRCC	2.2E-07	2.2E-07	2.2E-07	2.2E-07	2.2E-07	2.2E-07	2.2E-07	2.2E-07	2.2E-07	2.2E-07	2.2E-07	2.2E-07	2.2E-07	null
SERC	2.2E-07	2.2E-07	2.2E-07	2.2E-07	2.2E-07	2.2E-07	2.2E-07	2.2E-07	2.2E-07	2.2E-07	2.2E-07	2.2E-07	2.2E-07	null
SPP	2.2E-07	2.2E-07	2.2E-07	2.2E-07	2.2E-07	2.2E-07	2.2E-07	2.2E-07	2.2E-07	2.2E-07	2.2E-07	2.2E-07	2.2E-07	null
TRE	2.2E-07	2.2E-07	2.2E-07	2.2E-07	2.2E-07	2.2E-07	2.2E-07	2.2E-07	2.2E-07	2.2E-07	2.2E-07	2.2E-07	2.2E-07	null
WECC	2.2E-07	2.2E-07	2.2E-07	2.2E-07	2.2E-07	2.2E-07	2.2E-07	2.2E-07	2.2E-07	2.2E-07	2.2E-07	2.2E-07	2.2E-07	null
ASCC	2.2E-07	2.2E-07	2.2E-07	2.2E-07	2.2E-07	2.2E-07	2.2E-07	2.2E-07	2.2E-07	2.2E-07	2.2E-07	2.2E-07	2.2E-07	null
HI	2.2E-07	2.2E-07	2.2E-07	2.2E-07	2.2E-07	2.2E-07	2.2E-07	2.2E-07	2.2E-07	2.2E-07	2.2E-07	2.2E-07	2.2E-07	null
Empty	2.2E-07	2.2E-07	2.2E-07	2.2E-07	2.2E-07	2.2E-07	2.2E-07	2.2E-07	2.2E-07	2.2E-07	2.2E-07	2.2E-07	2.2E-07	null

Table 19 NOx Emissions per Gallon of Gas

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
NPCC	0.00017	0.00017	0.00017	0.00017	0.00017	0.00017	0.00017	0.00017	0.00017	0.00017	0.00017	0.00017	0.00017	null
RFC	0.00017	0.00017	0.00017	0.00017	0.00017	0.00017	0.00017	0.00017	0.00017	0.00017	0.00017	0.00017	0.00017	null
MRO	0.00017	0.00017	0.00017	0.00017	0.00017	0.00017	0.00017	0.00017	0.00017	0.00017	0.00017	0.00017	0.00017	null
FRCC	0.00017	0.00017	0.00017	0.00017	0.00017	0.00017	0.00017	0.00017	0.00017	0.00017	0.00017	0.00017	0.00017	null
SERC	0.00017	0.00017	0.00017	0.00017	0.00017	0.00017	0.00017	0.00017	0.00017	0.00017	0.00017	0.00017	0.00017	null
SPP	0.00017	0.00017	0.00017	0.00017	0.00017	0.00017	0.00017	0.00017	0.00017	0.00017	0.00017	0.00017	0.00017	null
TRE	0.00017	0.00017	0.00017	0.00017	0.00017	0.00017	0.00017	0.00017	0.00017	0.00017	0.00017	0.00017	0.00017	null
WECC	0.00017	0.00017	0.00017	0.00017	0.00017	0.00017	0.00017	0.00017	0.00017	0.00017	0.00017	0.00017	0.00017	null
ASCC	0.00017	0.00017	0.00017	0.00017	0.00017	0.00017	0.00017	0.00017	0.00017	0.00017	0.00017	0.00017	0.00017	null
HI	0.00017	0.00017	0.00017	0.00017	0.00017	0.00017	0.00017	0.00017	0.00017	0.00017	0.00017	0.00017	0.00017	null
Empty	0.00017	0.00017	0.00017	0.00017	0.00017	0.00017	0.00017	0.00017	0.00017	0.00017	0.00017	0.00017	0.00017	null

Table 20 Value of SOx

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
NPCC	520	520	520	520	520	520	520	520	520	520	520	520	520	531	542	553	565	577	589	601	614	627	640
RFC	520	520	520	520	520	520	520	520	520	520	520	520	520	531	542	553	565	577	589	601	614	627	640
MRO	520	520	520	520	520	520	520	520	520	520	520	520	520	531	542	553	565	577	589	601	614	627	640
FRCC	520	520	520	520	520	520	520	520	520	520	520	520	520	531	542	553	565	577	589	601	614	627	640
SERC	520	520	520	520	520	520	520	520	520	520	520	520	520	531	542	553	565	577	589	601	614	627	640
SPP	520	520	520	520	520	520	520	520	520	520	520	520	520	531	542	553	565	577	589	601	614	627	640
TRE	520	520	520	520	520	520	520	520	520	520	520	520	520	531	542	553	565	577	589	601	614	627	640
WECC	520	520	520	520	520	520	520	520	520	520	520	520	520	531	542	553	565	577	589	601	614	627	640
ASCC	520	520	520	520	520	520	520	520	520	520	520	520	520	531	542	553	565	577	589	601	614	627	640
HI	520	520	520	520	520	520	520	520	520	520	520	520	520	531	542	553	565	577	589	601	614	627	640
Empty	520	520	520	520	520	520	520	520	520	520	520	520	520	531	542	553	565	577	589	601	614	627	640

Table 21 Value of NOx

	2008-'12	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
NPCC	3000	3063.0	3127	3193	3260	3329	3398	3470	3543	3617	3693
RFC	3000	3063.0	3127	3193	3260	3329	3398	3470	3543	3617	3693
MRO	3000	3063.0	3127	3193	3260	3329	3398	3470	3543	3617	3693
FRCC	3000	3063.0	3127	3193	3260	3329	3398	3470	3543	3617	3693
SERC	3000	3063.0	3127	3193	3260	3329	3398	3470	3543	3617	3693
SPP	3000	3063.0	3127	3193	3260	3329	3398	3470	3543	3617	3693
TRE	3000	3063.0	3127	3193	3260	3329	3398	3470	3543	3617	3693
WECC	3000	3063.0	3127	3193	3260	3329	3398	3470	3543	3617	3693
ASCC	3000	3063.0	3127	3193	3260	3329	3398	3470	3543	3617	3693
HI	3000	3063.0	3127	3193	3260	3329	3398	3470	3543	3617	3693
Empty	3000	3063.0	3127	3193	3260	3329	3398	3470	3543	3617	3693

Table 22 Value of PM-2.5

	2008-'20	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
NPCC	36000	36756.0	37527.9	38316.0	39120.6	39942.1	40780.9	41637.3	42511.7	43404.4	44315.9
RFC	36000	36756.0	37527.9	38316.0	39120.6	39942.1	40780.9	41637.3	42511.7	43404.4	44315.9
MRO	36000	36756.0	37527.9	38316.0	39120.6	39942.1	40780.9	41637.3	42511.7	43404.4	44315.9
FRCC	36000	36756.0	37527.9	38316.0	39120.6	39942.1	40780.9	41637.3	42511.7	43404.4	44315.9
SERC	36000	36756.0	37527.9	38316.0	39120.6	39942.1	40780.9	41637.3	42511.7	43404.4	44315.9
SPP	36000	36756.0	37527.9	38316.0	39120.6	39942.1	40780.9	41637.3	42511.7	43404.4	44315.9
TRE	36000	36756.0	37527.9	38316.0	39120.6	39942.1	40780.9	41637.3	42511.7	43404.4	44315.9
WECC	36000	36756.0	37527.9	38316.0	39120.6	39942.1	40780.9	41637.3	42511.7	43404.4	44315.9
ASCC	36000	36756.0	37527.9	38316.0	39120.6	39942.1	40780.9	41637.3	42511.7	43404.4	44315.9
HI	36000	36756.0	37527.9	38316.0	39120.6	39942.1	40780.9	41637.3	42511.7	43404.4	44315.9
Empty	36000	36756.0	37527.9	38316.0	39120.6	39942.1	40780.9	41637.3	42511.7	43404.4	44315.9

Table 23 Average Fuel Efficiency

	Feeder Service Vehicle	Diagnosis/Notification Service Vehicle	Real Time Load Measurement/Management Service Vehicle
NPCC	20.3	20.3	20.3
RFC	20.3	20.3	20.3
MRO	20.3	20.3	20.3
FRCC	20.3	20.3	20.3
SERC	20.3	20.3	20.3
SPP	20.3	20.3	20.3
TRE	20.3	20.3	20.3
WECC	20.3	20.3	20.3
ASCC	20.3	20.3	20.3
HI	20.3	20.3	20.3
Empty	20.3	20.3	20.3

Table 24 Electricity to Fuel Conversion Factor

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021-'30
NPCC	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	null
RFC	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	null
MRO	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	null
FRCC	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	null
SERC	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	null
SPP	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	null
TRE	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	null
WECC	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	null
ASCC	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	null
HI	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	null
Empty	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	null

Table 25 Escalation Factors

	Population Growth*	Load Growth**	Inflation***	Energy Price***
NPCC	0.002	0.008	0.027	0.033
RFC	0.003	0.014	0.021	0.025
MRO	0.004	0.023	0.021	0.015
FRCC	0.020	0.026	0.029	0.025
SERC	0.009	0.022	0.024	0.018
SPP	0.004	0.018	0.021	0.014
TRE	0.016	0.022	0.023	0.039
WECC	0.013	0.016	0.024	0.022
ASCC	0.011	0.022	0.026	0.025

HI	0.60	0.013	0.028	0.072

* Source: U.S. Census Bureau, Population Division, Interim State Population Projections, 2005. http://www.census.gov/population/www/projections/projectionsagesex.html 11

** Source: 1990 - 2008 Retail Sales of Electricity by State by Sector by Provider (EIA-861), http://www.eia.doe.gov/cneaf/electricity/epa/epa_sprdshts.html

*** Source: US Bureau of Labor and Statistics CPI Database, All Urban Consumers (Current Series) (Consumer Price Index - CPI), All Items, http://www.bls.gov/cpi/#tables

**** Source: 1990 - 2008 Average Price by State by Provider (EIA-861), Industry Sector Category = Full-Service Providers, http://www.eia.doe.gov/cneaf/electricity/epa/epa_sprdshts.html