RESOLVE
Capacity Expansion Model

User Manual Update

September 2021

Energy+Environmental Economics

RESOLVE
Capacity Expansion Model

User Manual Update

September 2021

Energy and Environmental Economics, Inc.
44 Montgomery Street, Suite 1500
San Francisco, CA 94104
415.391.5100
www.ethree.com

Table of Contents

Disclaimer

The core of the RESOLVE model is written in the Python scripting language. The E3 RESOLVE Model is free software under the terms of the GNU Affero General Public License as published by the Free Software Foundation, either version 3 of the License, or (at your option) any later version.

NO WARRANTY OF ANY KIND, IMPLIED, EXPRESSED, OR STATUTORY, INCLUDING BUT NOT LIMITED TO THE WARRANTIES OF NON-INFRINGEMENT OF THIRD PARTY RIGHTS, TITLE, MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE, AND FREEDOM FROM COMPUTER VIRUS, IS GIVEN WITH RESPECT TO THE RESOLVE SOFTWARE INCLUDING ITS PYTHON SCRIPTS, THE WEB PAGE HOSTING THE RESOLVE SOFTWARE OR HYPERLINKS TO OTHER INTERNET RESOURCES. E3 bears no responsibility for the consequences of any modifications to the model, including its Python scripts, whether intentional or unintentional.

1 Introduction

1.1 Overview

The purpose of this document is to provide users with the guidance needed to set up and run the RESOLVE model and to analyze the results of scenarios once they have been completed. RESOLVE is a linear program written in Python with Excel-based interfaces for scenario development and results processing.

RESOLVE is an optimal investment and operational model designed to inform long-term planning questions around renewables integration in systems with high penetration levels of renewable energy. The model is formulated as a linear optimization problem that co-optimizes investment and dispatch for a selected set of days over a multi-year horizon in order to identify least-cost portfolios for meeting renewable energy targets and other system goals.

RESOLVE incorporates a representation of neighboring regions to characterize transmission flows into and out of a main zone of interest endogenously. RESOLVE can solve for the optimal investments in renewable resources, energy storage technologies, demand response, energy efficiency, new gas plants, and retention of existing thermal plants. These least-cost decisions are subject to annual constraints on delivered renewable energy that reflects the RPS policy, annual constraints on greenhouse gas emissions, capacity adequacy constraints to maintain reliability, and constraints on the ability to develop specific renewable resources. RESOLVE simulates operations on sampled days and includes a linearized version of the unit commitment problem.

1.2 Structure of This Document

The remainder of this document is organized as follows:

- **Section 2. Setting Up RESOLVE**
  Describes system requirements for running RESOLVE and recommended installation instructions.
- **Section 3. Interacting with RESOLVE Interfaces**
  Overview of how to use the Excel-based user interfaces (Scenario Tool and Results Viewer). For users seeking only to run RESOLVE cases and view model outputs, this section provides the necessary background to do so.

2 Setting Up RESOLVE

2.1 System Requirements

2.1.1 OPERATING SYSTEM

The underlying Python code powering RESOLVE has been tested on Windows, macOS, and Ubuntu. Other Linux distributions will likely also be able to run the model.

The Excel interfaces used to interact with RESOLVE require access to Microsoft Excel (i.e., Windows or macOS). The RESOLVE interfaces been tested extensively on Windows. The interfaces will also open on Excel for Mac; however, the VBA buttons required to print out input files from the Scenario Tool and read in results into the Results Viewer do not work correctly.

2.1.2 PYTHON

RESOLVE is compatible with the latest **Python 3**, while also being backward compatible with Python 2. E3 currently uses Python 3.7.10 (64-bit). E3 recommends installing **Anaconda** to obtain Python, which also includes some of the mathematical packages needed to run RESOLVE.

RESOLVE relies on the open-source Python packages **numpy**, **pandas**, and **pyomo** to formulate the optimization model and process inputs/outputs. Both **numpy** and **pandas** are included when installing Anaconda. E3 currently uses **pyomo** version 5.6.9 or later.

2.1.3 SOLVERS

The default, open-source solver to use with RESOLVE is called **cbc**.[1] Download **cbc-win64.zip**, unzip, and move the executable (**cbc.exe**) to a folder of your choosing. The final step is to add the folder in which **cbc.exe** resides to your **PATH** system variable, which can be done by following **these instructions**. E3 has tested CBC version 2.9.9 (64-bit) on Windows 10. Executables for macOS, and Linux can also be obtained from the link in the footnote and added to the system **PATH** following the appropriate instructions for each operating system or via **conda**.

If users have licenses for other, commercially available solvers (such as **CPLEX** and **Gurobi**[2]), these can be used with RESOLVE and may provide significantly faster solution times than **cbc**. E3 recommends using a commercial solver if the user plans to run more than a handful of cases. Both CPLEX and Gurobi provide onsite and cloud licensing options and other commercial solver vendors may have similar options. As with CBC, to utilize a commercial solver, you will need to make sure the executable for the solver is added to your system **PATH**.

2.2 Installing Python and RESOLVE

In this user guide, we offer one set of installation instructions using the features of the **Anaconda distribution of Python**.

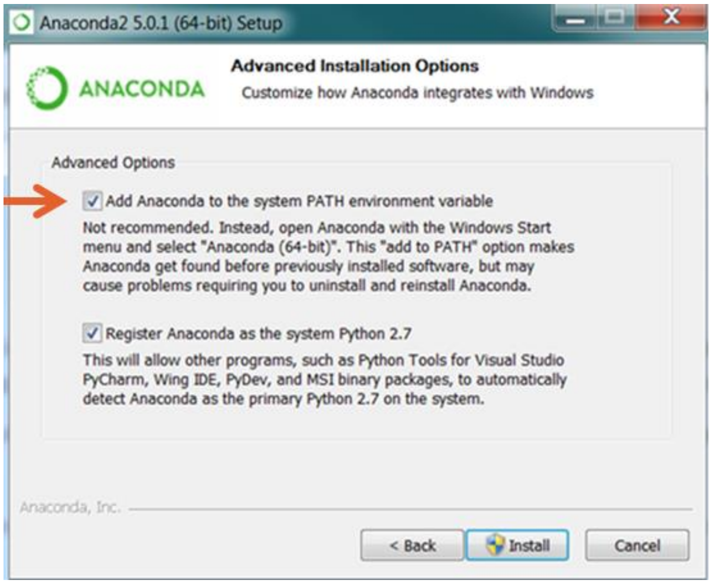
[1] A 64-bit compatible cbc executable compiled by AMPL Optimization, Inc. can be downloaded at the following link: https://ampl.com/products/solvers/open-source/

[2] E3 has tested Gurobi extensively and has observed that in specific instances Gurobi can have numerical issues when solving RESOLVE cases, resulting in longer runtimes than expected. Solver settings for Gurobi in **run_opt.py** address most of the numerical issues, but in certain circumstances the user may need to change solver settings to allow a case to solve with an acceptable runtime. If the user is experiencing numerical issues with Gurobi on a specific model run, modifying some of the Gurobi solver settings in **run_opt.py** frequently results in improved performance. Skipping the crossover phase (crossover = 0), and/or setting BarHomogeneous = 1 (in conjunction with Method = 2) may address runtime issues.

2.2.1 INSTALLING ANACONDA

As previously discussed in **Section 2.1.2**, E3 recommends installing the **Anaconda distribution of Python**. *Users may skip this step if they have previously installed Anaconda or are choosing to use a different installation method not described in this user guide; however, the next step in this user guide assumes you have installed Anaconda.*

During the installation process, you should see "Add Anaconda to the system PATH environment variable" in the Advanced Installation Options (as shown in the screenshot below). This will allow us to find the installed Python easily when running RESOLVE.[3]



Advanced Installation Options

Customize how Anaconda integrates with Windows

Advanced Options

☑ Add Anaconda to the system PATH environment variable

Not recommended. Instead, open Anaconda with the Windows Start menu and select "Anaconda (64-bit)". This "add to PATH" option makes Anaconda get found before previously installed software, but may cause problems requiring you to uninstall and reinstall Anaconda.

☑ Register Anaconda as the system Python 2.7

This will allow other programs, such as Python Tools for Visual Studio PyCharm, Wing IDE, PyDev, and MSI binary packages, to automatically detect Anaconda as the primary Python 2.7 on the system.

Note: Users with prior installations of Python should be careful of the implications of installing another version of Python on their system if they have other Python scripts and dependencies.

[3] If you are not sure if it is in your PATH environment variable, open a Command Prompt window and type the command "`python`" and press Enter. If you see a message to the effect of, **`'python' is not recognized as an internal or external command`**, you will need to follow the instructions to add python to your PATH environment variable.

2.2.2 SETTING UP THE e3resolve CONDA ENVIRONMENT

Included in the RESOLVE CPUC IRP package is a file called **environment.yml**.[4] This file specifies the dependencies (i.e., other pieces of open-source code) that RESOLVE relies on. Whether this is the first time you are setting up RESOLVE on your machine or you have a previous setup, you will likely want to update your RESOLVE environment using this file.

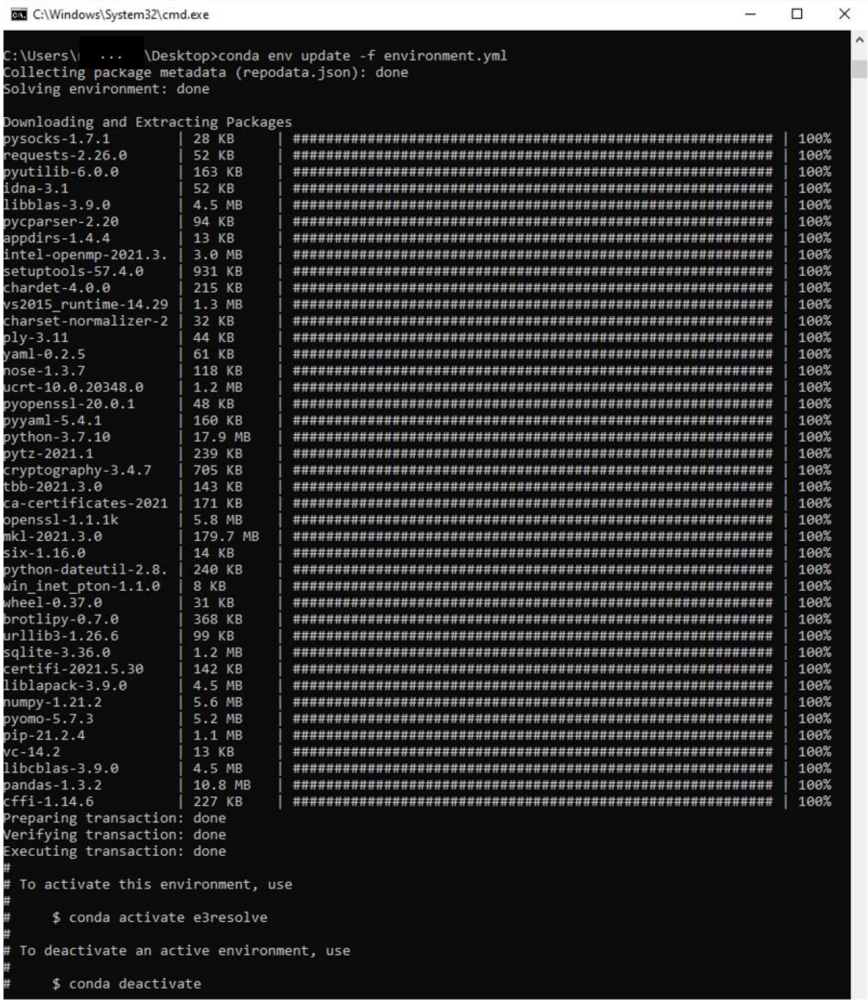
To set up and update the **e3resolve** conda environment, open a Command Prompt, navigate to the folder that contains the **environment.yml** file (in the case of Figure 2.1, the file is located on the Desktop), and use the command:

```
conda env update -f environment.yml
```

If successful, the Command Prompt should look something like Figure 2.1.

[4] Read more about **conda** environments here

Figure 2.1. Screenshot of Command Prompt during conda environment setup process

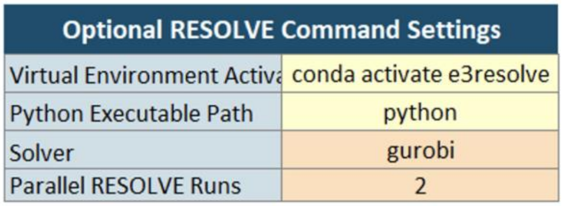


```
C:\Users\[redacted]\Desktop>conda env update -f environment.yml
Collecting package metadata (repodata.json): done
Solving environment: done

Downloading and Extracting Packages
pysocks-1.7.1        | 28 KB     | ########################################################### | 100%
requests-2.26.0      | 52 KB     | ########################################################### | 100%
pyutilib-6.0.0       | 163 KB    | ########################################################### | 100%
idna-3.1             | 52 KB     | ########################################################### | 100%
libblas-3.9.0        | 4.5 MB    | ########################################################### | 100%
pycparser-2.20       | 94 KB     | ########################################################### | 100%
appdirs-1.4.4        | 13 KB     | ########################################################### | 100%
intel-openmp-2021.3. | 3.0 MB    | ########################################################### | 100%
setuptools-57.4.0    | 931 KB    | ########################################################### | 100%
chardet-4.0.0        | 215 KB    | ########################################################### | 100%
vs2015_runtime-14.29 | 1.3 MB    | ########################################################### | 100%
charset-normalizer-2 | 32 KB     | ########################################################### | 100%
ply-3.11             | 44 KB     | ########################################################### | 100%
yaml-0.2.5           | 61 KB     | ########################################################### | 100%
nose-1.3.7           | 118 KB    | ########################################################### | 100%
ucrt-10.0.20348.0    | 1.2 MB    | ########################################################### | 100%
pyopenssl-20.0.1     | 48 KB     | ########################################################### | 100%
pyyaml-5.4.1         | 160 KB    | ########################################################### | 100%
python-3.7.10        | 17.9 MB   | ########################################################### | 100%
pytz-2021.1          | 239 KB    | ########################################################### | 100%
cryptography-3.4.7   | 705 KB    | ########################################################### | 100%
tbb-2021.3.0         | 143 KB    | ########################################################### | 100%
ca-certificates-2021 | 171 KB    | ########################################################### | 100%
openssl-1.1.1k       | 5.8 MB    | ########################################################### | 100%
mkl-2021.3.0         | 179.7 MB  | ########################################################### | 100%
six-1.16.0           | 14 KB     | ########################################################### | 100%
python-dateutil-2.8. | 240 KB    | ########################################################### | 100%
win_inet_pton-1.1.0  | 8 KB      | ########################################################### | 100%
wheel-0.37.0         | 31 KB     | ########################################################### | 100%
brotlipy-0.7.0       | 368 KB    | ########################################################### | 100%
urllib3-1.26.6       | 99 KB     | ########################################################### | 100%
sqlite-3.36.0        | 1.2 MB    | ########################################################### | 100%
certifi-2021.5.30    | 142 KB    | ########################################################### | 100%
liblapack-3.9.0      | 4.5 MB    | ########################################################### | 100%
numpy-1.21.2         | 5.6 MB    | ########################################################### | 100%
pyomo-5.7.3          | 5.2 MB    | ########################################################### | 100%
pip-21.2.4           | 1.1 MB    | ########################################################### | 100%
vc-14.2              | 13 KB     | ########################################################### | 100%
libcblas-3.9.0       | 4.5 MB    | ########################################################### | 100%
pandas-1.3.2         | 10.8 MB   | ########################################################### | 100%
cffi-1.14.6          | 227 KB    | ########################################################### | 100%
Preparing transaction: done
Verifying transaction: done
Executing transaction: done
#
# To activate this environment, use
#
#     $ conda activate e3resolve
#
# To deactivate an active environment, use
#
#     $ conda deactivate
```

2.2.3 CONFIGURING THE SCENARIO TOOL

RESOLVE Scenario Tool, users will find four options on the Dashboard tab (under the “Optional RESOLVE Command Settings” heading) for controlling how the VBA buttons call RESOLVE from the Scenario Tool:



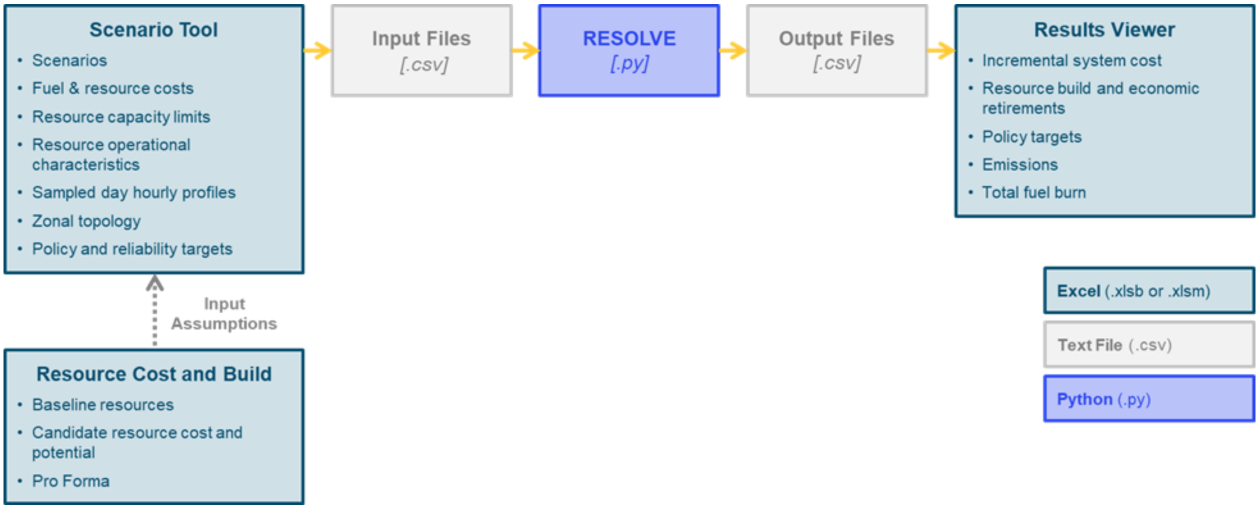
Optional RESOLVE Command Settings	
Virtual Environment Activa	conda activate e3resolve
Python Executable Path	python
Solver	gurobi
Parallel RESOLVE Runs	2

1. **Virtual Environment:**
   If you set up the `e3resolve` conda environment as described in the previous section, this cell should say `conda activate e3resolve`. If you choose not to use a conda environment, you will likely leave this cell blank.
2. **Python Path:**
   Copy the path you found in step (2) into the yellow input cell. By default, this cell should say `python`, and RESOLVE will use the default Python. By inputting a path to a different `python.exe` file here, you are telling the Scenario Tool to use that specific version of Python.
3. **Solver Name:**
   By default, this is set to **cbc** (which is a free open-source solver that can be used with RESOLVE, see **Section 2.1.3**). Other options (if the user has installed them) are **cplex** and **gurobi**, and advanced users could modify the Scenario Tool to use additional solvers if desired.
4. **Parallel Runs:**
   If your computer has enough CPU and RAM to handle multiple parallel runs, users can tell RESOLVE to run multiple cases in parallel. Otherwise, RESOLVE will solve cases listed under “Scenarios to Run” sequentially.

2.3 RESOLVE Package Organization

While users may wish to review the raw input and output files and Python scripts that constitute the core of RESOLVE, the RESOLVE package is designed to allow users to run scenarios and analyze results using only the Excel-based user interfaces for developing scenarios and viewing results. A schematic of the RESOLVE environment is shown in **Figure 2.2**.

Figure 2.2. Schematic of RESOLVE Modeling Components



The individual components of the RESOLVE modeling environment are described below:

1. **RESOLVE Resource Costs and Build Workbook**

   Excel workbook containing upstream information on baseline resources, candidate resource cost and potential, and the Pro Forma financial model. Data updates can be implemented in this workbook and manually copied over to corresponding sheets in the Scenario Tool.

2. **RESOLVE Scenario Tool**

   Excel workbook that includes a scenario management dashboard and input data worksheets. The Scenario Tool provides a simple interface to develop and run RESOLVE scenarios after setting up data inputs to the model.

3. **Input Files: `inputs/`**

   RESOLVE accepts scenario inputs as comma-delimited (.csv) files. These are created by the Scenario Tool and contain the minimal set of data needed to define scenario assumptions. The **`inputs`** directory contains scenario subdirectories with input files for each scenario.

4. **RESOLVE Python Scripts: `resolve_code/`**

   RESOLVE is written in Python and consists of multiple scripts that (1) read the raw input files, (2) formulates a linear programming optimization model to minimize total incremental system costs, and (3) exports the resulting optimal portfolio of investments and operations across the analysis time horizon. The **`resolve_code`** directory contains the RESOLVE Python scripts.

5. **Output Files: `results/`**
   RESOLVE prints out results in CSV files. These results files contain all results read by the Results Viewer, as well as other files that report detailed information. The **`results`** directory and scenario-specific subdirectories are created automatically upon running the RESOLVE code.

6. **Results Viewer**
   Excel workbook that is the interface through which users may review results of a completed RESOLVE run and compare results across runs. This workbook can be used to import and view summaries of the raw Output Files for a specific model. **Section 3.2** provides a summary of functionality included in the Results Viewer. Scenario-specific subdirectories in the **`results_summaries/`** directory containing result summaries for each scenario are created automatically when results are loaded into the Results Viewer.

7. **`setup.py`**
   Setup script that installs relevant dependencies to configure RESOLVE.

8. **`environment.yml`**

   Optional file used by **conda** to define a new virtual environment.

If the user is interested in reviewing inputs and outputs to the pre-built RESOLVE scenarios, the **Resource Cost and Build Workbook**, **Scenario Tool**, and **Results Viewer** provide can be used directly in Excel without installing Python or setting up RESOLVE.

2.3.1 RESOLVE PACKAGE FILE HASHES

File hashes for the current public release of RESOLVE are listed in **Table 2.1**.

Table 2.1. RESOLVE File Hashes

RESOLVE File	SHA-256 Hash
setup.py	771DA4BBA9EEAEBA06F05EBAA92BD970C3250477DAC9D21265C7B0A280CCC0B6
environment.yml	C3EACF2824EBE4D3DBEB5EF12A3DAB05B6B41855401 6CCB63E750694E00E29D2
resolve_code/create_results_summary.py	77F5F49833C4B1D2D769CFDF254E29A7873ADE1E0B261CBEF55C8E31F67E379A
resolve_code/export_results.py	25DF0AFEF4AA569D88FA24E3B698315C8D85EA6DD70511FA176FAE5388B249A2
resolve_code/fileio.py	76DEC107A04BA8D04DA91BC261FBB0517606FA44D13518C0D409B463F729B369
resolve_code/load_data.py	01260782875FCDB00EB1C7ED55F6A97DBD67A78088142188405FE807A40AF9B1
resolve_code/model_formulation.py	10E9002B9E39CE365081DFC8903D1D7F848DFDB96730647FDA5054EC1DB2C0AE
resolve_code/resolve_postprocessing.py	8ECEA568502A5A5F44515E07E77CDAD0DCFD5B16BD97A3E63F26511E8319DC76
resolve_code/runbatch.py	F4D9FF2BA098D134C549869060CFCAD6E342375AD808510E80B6C2E21B257485
resolve_code/run_opt.py	C9E4AD91E24310C6FDEEFC9499BAC97764E4B4DC46943C6D9C734651F3683408
resolve_code/run_reagg.py	580113050791A8B21779F3B2FC35E3B19751DA48A9178D08E52998843AC44F1C
resolve_code/util.py	DB192BDD91C2C7F2A040AE5DDDC18BB2F63B2AA18085669A420C5935D511B7EF
resolve_code/__init__.py	E3B0C44298FC1C149AFBF4C8996FB92427AE41E4649B934CA495991B7852B855

3 Interacting with RESOLVE

3.1 RESOLVE Scenario Tool

Cells throughout the Scenario Tool are color-coded to indicate how users should interact with them.

Table 3.1. RESOLVE Scenario Tool Cell Color Scheme

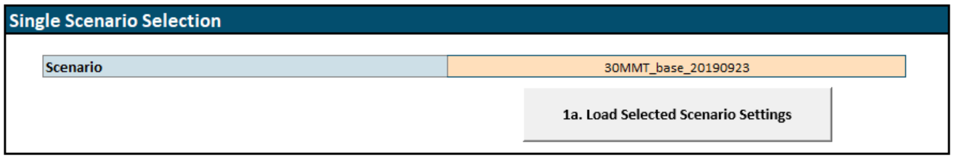
Cell Type	Notes
Inputs	Yellow cells indicate user-defined inputs. These can be changed by the user, although it is advised to choose from any of the existing options through the scenario toggles in the Dashboard tab.
Dropdown	Orange cells indicate values. These can be changed by the user but must adhere to a set of pre-defined options listed in the dropdown list. For example, True/False toggles or the names of available zones in the pre-defined cases. (Note: True/False toggles will change color from green to red to help indicate the toggle setting)
Results	Green cells indicate cells linked to other inputs via formulas. These should automatically update, and it is advised not to change the formulas to ensure links stay intact.
Fixed or Inactive	Grey cells indicate calculations that should not be changed or values that are inactive.
Labels	These are hard-coded labels indicating what the cell(s) adjacent to it should be used for.

3.1.1 RUNNING PRE-DEFINED SCENARIOS

The RESOLVE Scenario Tool comes with a set of predefined scenarios. Users can load and run a predefined scenario as follows:

1. The dropdown menu in cell **D6** of the Dashboard lists all predefined scenarios (stored on the Scenario Settings tab). You can use the **Single Scenario Selection** dropdown and **1a. Load Selected Scenario Settings** button (shown in **Figure 3.1**) to load a scenario's settings into the Dashboard for viewing.

Figure 3.1. RESOLVE Single Scenario Selection Interface

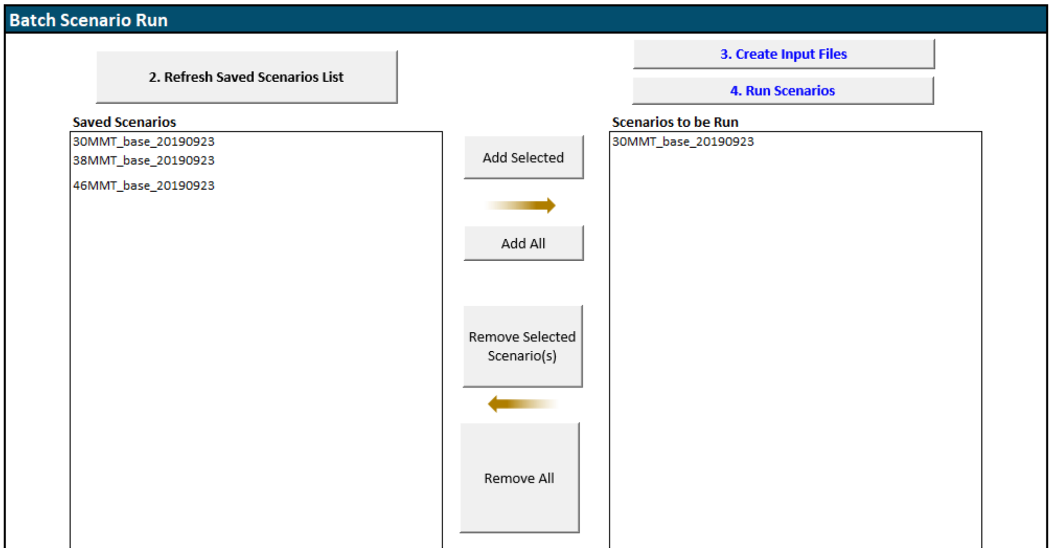


Single Scenario Selection

Scenario: 30MMT_base_20190923

2. To run scenarios, use the **Batch Scenario Run** section of the Dashboard to add/remove named scenarios (listed in the **Saved Scenarios** list). You may need to press the **2. Refresh Saved Scenarios List** button to update the list. To add selected scenarios, select the cells with the scenario names you are interested in running, then press the **Add Selected** button. The selected scenarios should appear in the **Scenarios to be Run** list to the right. The **Add All** button will add all scenarios in the **Saved Scenarios** list to the right side. The **Remove Selected/All** buttons works similarly.
3. Press the **3. Create Input Files** button, which will invoke VBA code that prints out the input data into the appropriate scenario-specific input files in an input subdirectory with the scenario's name.

Figure 3.2. RESOLVE Scenario Run Interface



Batch Scenario Run

Saved Scenarios
30MMT_base_20190923
38MMT_base_20190923
46MMT_base_20190923

Scenarios to be Run
30MMT_base_20190923

4. Press the **4. Run Scenarios** button to run RESOLVE. This will open a command prompt window and show text output as RESOLVE runs. RESOLVE runs can take anywhere from a few minutes to

many hours depending on specific scenario settings and which solver is being used. Note that the command prompt window will stay open even after RESOLVE has completed running.

3.1.1.1 Running RESOLVE via Command Line

There are a few reasons you may choose to run RESOLVE via the command line. For example, if you are running on a Linux or macOS machine, a machine without Excel installed, or a machine where you cannot use VBA macros, you will not be able to use the Scenario Tool to run RESOLVE.

To run RESOLVE via the command line, navigate in your selected command line terminal (e.g., Command Prompt, PowerShell, bash, etc.) to the **`resolve_code`** directory. This is generally done using the **`cd`** command (for change directory). For example, to switch to the directory where you have stored your **`resolve_code`** folder, you would use the command once, as shown below:

```
>> cd resolve_code
```

You will also want to activate the **`e3resolve`** conda environment using the command:

```
>> conda activate e3resolve
```

From within the **`resolve_code`** directory, you have two options for running RESOLVE cases.

1. The first is to run a single case using the **`run_opt.py`** script. There are two command line arguments that follow. The first argument is required, **`[scenario name]`**, and is the name of the single scenario you plan to run. This must correspond to the name of a directory in the inputs folder. The second argument is optional, **`[optional: solver name]`**, and is used to specify a different solver than the default CBC solver:

   ```
   >> python run_opt.py [scenario name] [optional: solver name]
   ```

   For example, to run the scenario **`full_run`** with and without the solver Gurobi, use the commands:

```
>> python run_opt.py full_run
>> python run_opt.py full_run gurobi
```

2. The second option is to run a batch of scenarios using the **runbatch.py** script by populating the CSV file called **cases_to_run.csv** with the list of scenarios you wish to run. **runbatch.py** runs all of the scenarios **cases_to_run.csv** in serial. The command line input is:

```
>> python runbatch.py [optional: solver name]
```

To run a batch of scenarios with and without the solver Gurobi, use the commands:

```
>> python runbatch.py gurobi
>> python runbatch.py
```

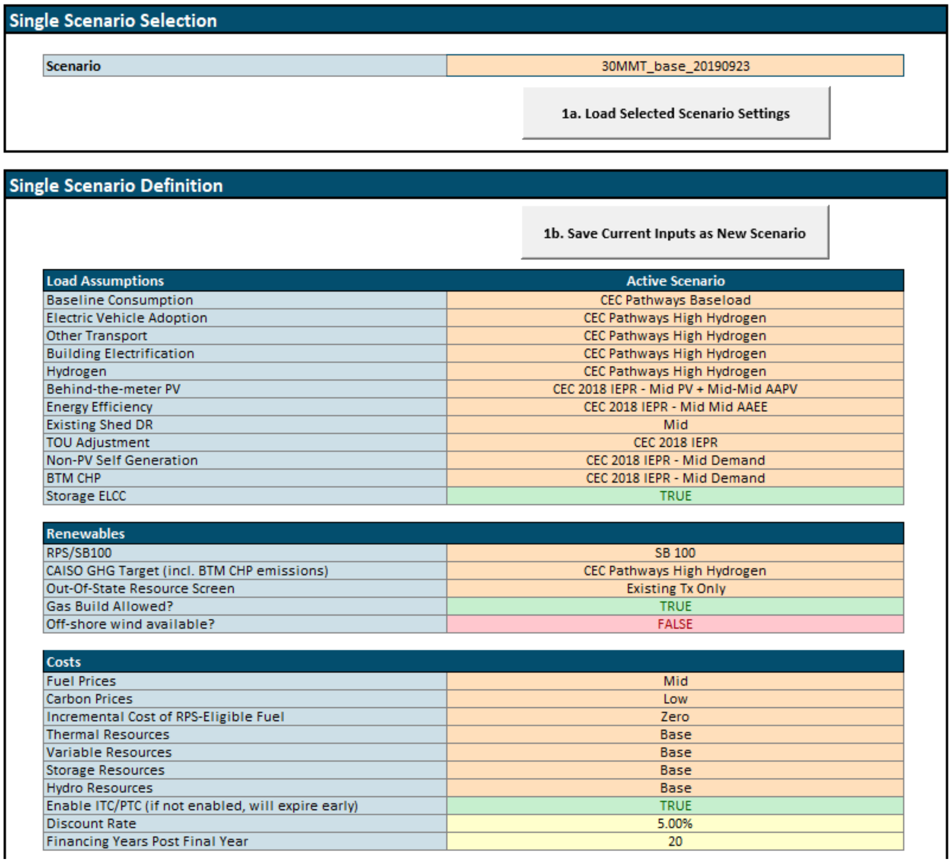
3.1.2 CREATING NEW SCENARIOS

Users may wish to create and run new scenarios based on existing input data, rather than the pre-defined scenarios. This can be done by adjusting the dropdowns in the Scenario Definition box on the RESOLVE Dashboard.

To create a new scenario:

0. (Optional) Select and load a scenario of interest in the **Single Scenario Selection** box
1. Customize the dropdown toggles in the **Single Scenario Definition** box (as shown in **Figure 3.3**). As indicated by the cell color, most of the inputs are dropdowns, but some (such as discount rate) are direct user inputs.

Figure 3.3. RESOLVE Dashboard Single Scenario Selection and Scenario Definition Interface


Single Scenario Selection
1a. Load Selected Scenario Settings
Single Scenario Definition
1b. Save Current Inputs as New Scenario

Scenario	30MMT_base_20190923

Load Assumptions	Active Scenario
Baseline Consumption	CEC Pathways Baseload
Electric Vehicle Adoption	CEC Pathways High Hydrogen
Other Transport	CEC Pathways High Hydrogen
Building Electrification	CEC Pathways High Hydrogen
Hydrogen	CEC Pathways High Hydrogen
Behind-the-meter PV	CEC 2018 IEPR - Mid PV + Mid-Mid AAPV
Energy Efficiency	CEC 2018 IEPR - Mid Mid AAEE
Existing Shed DR	Mid
TOU Adjustment	CEC 2018 IEPR
Non-PV Self Generation	CEC 2018 IEPR - Mid Demand
BTM CHP	CEC 2018 IEPR - Mid Demand
Storage ELCC	TRUE

Renewables	
RPS/SB100	SB 100
CAISO GHG Target (incl. BTM CHP emissions)	CEC Pathways High Hydrogen
Out-Of-State Resource Screen	Existing Tx Only
Gas Build Allowed?	TRUE
Off-shore wind available?	FALSE

Costs	
Fuel Prices	Mid
Carbon Prices	Low
Incremental Cost of RPS-Eligible Fuel	Zero
Thermal Resources	Base
Variable Resources	Base
Storage Resources	Base
Hydro Resources	Base
Enable ITC/PTC (if not enabled, will expire early)	TRUE
Discount Rate	5.00%
Financing Years Post Final Year	20

2. Save the new custom scenario by pressing the **1b. Save Current Inputs as New Scenario** button. A macro will prompt the user to enter a new scenario name and saves the scenario settings in the **Scenario Settings** tab. If a user would like to overwrite an existing scenario, they can do so by entering an existing scenario name in the dialog box. The macro will prompt you to confirm overwriting the scenario.
   Note that if a user changes any scenario toggles, they must be saved via the macro button for them to take effect in subsequent runs.

3. Press the **3. Create Input Files** button, which will invoke VBA code that prints out the input data into the appropriate scenario-specific input files in an input subdirectory with the scenario's name.

4. Press the **4. Run Scenarios** button to run RESOLVE. This will open a command prompt window and show text output as RESOLVE runs. RESOLVE runs can take anywhere from a few minutes to

many hours depending on specific scenario settings and which solver is being used. Note that the command prompt window will stay open even after RESOLVE has completed running.

3.1.3 INPUT DATA WORKSHEETS

The input data worksheets in the Scenario Tool are categorized into three high-level themes: system, loads, and resources. Brief summaries of each tab are included in **Table 3.2**. The cells in these data worksheets also adhere to the color-coding described at the start of **Section 3.1**.

Additional documentation of the contents of the data worksheets is provided in the Inputs & Assumptions documentation.

Table 3.2. Description of RESOLVE Scenario Tool Worksheets

Section	Tab	Description
DASHBOARD	Dashboard	*Contains a user interface to prepare and run scenarios. This is the main tab the user will interact with*
SCENARIOS	Scenario Settings	*Database with scenario settings that were saved through the user interface*
SYSTEM	Sys - Fuels	*Fuel cost assumptions and calculations*
	Sys - PRM	*Planning reserve margin assumptions and calculations*
	Sys - RPS GHG	*Renewable Portfolio Standard and greenhouse gas target assumptions*
	Sys - Reserves	*Operating reserves requirement assumptions*
	Sys - Tx	*Regional assumptions, such as transmission limits, hurdle rates, etc.*
	Sys - Inputs Passthrough	*Inputs to passthrough to the results (e.g., baseline costs)*
LOADS	Loads - Profiles	*Hourly load profiles by end-use*
	Loads - Forecasts	*Database of load forecasts*
	Loads - Hydrogen	*Inputs for hydrogen electrolysis feature*
	Loads – EE Optimization	*Inputs for EE investment feature*
	Loads_EV Calcs	*Electric vehicles assumptions and calculations*
	Loads - DR	*Assumptions for candidate demand response resources*
	Loads - Flexible	*Assumptions for flexible loads*
SUPPLY RESOURCES	Technologies	*Technology characteristics*
	Resources - Active	*Resource inputs and mapping to technologies*
	Resources - Candidate	*Inputs for resources that can be expanded*
	Resources - Variable	*Shapes for variable resources*
	Resources - Hydro	*Energy budgets and constraints for hydro resources*
	Resources - Maintenance	*Maintenance/derate schedules (if not defined, resource will be rated at 100%)*
	Resources - Options	*Additional constraints on resource operations & build (e.g., hydro operational constraints, annual min/max build rate constraints,*
	Resources - Scenarios	*Scenario combinations of cost and planned installed capacities*
	Resources - Scenario Costs	*Database of resource all-in fixed investment costs for expansion*
	Resources - Scenario Build	*Database of resource planned installed capacities*
	Resources - Forced In	
RAW INPUTS	Inputs2Write	*Calculation worksheet that converts inputs from all other tabs into model-ready input tables. Do not edit*
	Inputs2Write_Hourly	*Calculation worksheet that converts inputs from all other tabs into model-ready input tables. Do not edit*
LISTS	Lists	*Calculation worksheet with supporting lists and tables. Do not edit*

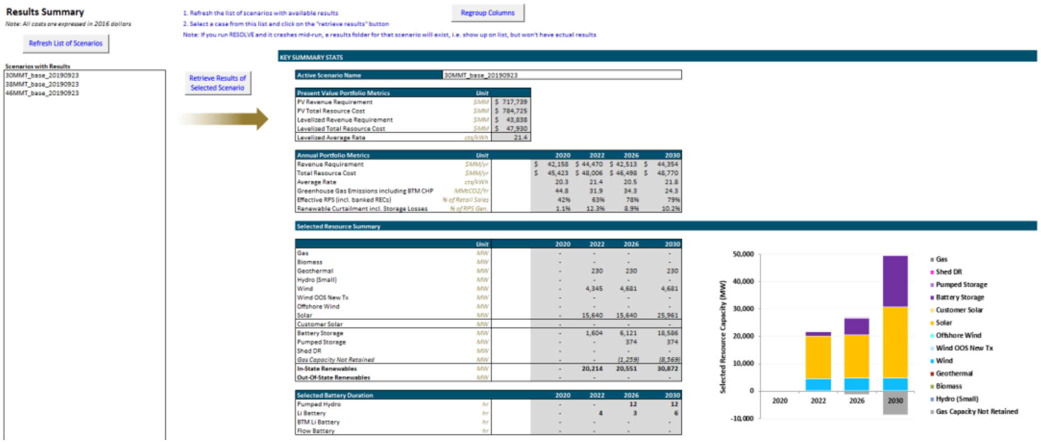
3.2 RESOLVE Results Viewer

The Results Viewer allows the user to look at the summary results of a scenario of interest. It contains four main worksheets: Dashboard, Portfolio Analytics, Scenario Comparison, and Lists. In addition, it contains “raw” summary results files for the scenario of interest.

3.2.1 DASHBOARD

The Dashboard worksheet is the main worksheet the user will interact with to look at the results of a single scenario.

Figure 3.4. Results Viewer Dashboard



Results Summary

Note: All costs are expressed in 2016 dollars

1. Refresh the list of scenarios with available results
2. Select a case from this list and click on the "retrieve results" button

Note: If you run RESOLVE and it crashes mid-run, a results folder for that scenario will exist, i.e. show up on list, but won't have actual results

Scenarios with Results

30MMT_base_20190923
38MMT_base_20190923
46MMT_base_20190923

KEY SUMMARY STATS

Active Scenario Name	30MMT_base_20190923

Present Value Portfolio Metrics	Unit	
PV Revenue Requirement	$MM	$ 717,739
PV Total Resource Cost	$MM	$ 784,725
Levelized Revenue Requirement	$MM	$ 43,838
Levelized Total Resource Cost	$MM	$ 47,930
Levelized Average Rate	cts/kWh	21.4

Annual Portfolio Metrics	Unit	2020	2022	2026	2030
Revenue Requirement	$MM/yr	$ 42,158	$ 44,470	$ 42,513	$ 44,354
Total Resource Cost	$MM/yr	$ 45,423	$ 48,006	$ 46,498	$ 48,770
Average Rate	cts/kWh	20.3	21.4	20.5	21.8
Greenhouse Gas Emissions including BTM CHP	MMtCO2/Yr	44.8	31.9	34.3	24.3
Effective RPS (incl. banked RECs)	% of Retail Sales	42%	63%	78%	79%
Renewable Curtailment incl. Storage Losses	% of RPS Gen.	1.1%	12.3%	8.9%	10.2%

Selected Resource Summary

	Unit	2020	2022	2026	2030
Gas	MW	-	-	-	-
Biomass	MW	-	-	-	-
Geothermal	MW	-	230	230	230
Hydro (Small)	MW	-	-	-	-
Wind	MW	-	4,345	4,681	4,681
Wind OOS New Tx	MW	-	-	-	-
Offshore Wind	MW	-	-	-	-
Solar	MW	-	15,640	15,640	25,961
Customer Solar	MW	-	-	-	-
Battery Storage	MW	-	1,604	6,121	18,586
Pumped Storage	MW	-	-	374	374
Shed DR	MW	-	-	-	-
Gas Capacity Not Retained	MW	-	-	(1,259)	(8,569)
In-State Renewables	MW	-	20,214	20,551	30,872
Out-Of-State Renewables	MW	-	-	-	-

Selected Battery Duration		2020	2022	2026	2030
Pumped Hydro	hr	-	-	12	12
Li Battery	hr	-	4	3	6
BTM Li Battery	hr	-	-	-	-
Flow Battery	hr	-	-	-	-

The Dashboard contains the following macro buttons:

5. The **“Refresh List of Scenarios”** macro lists all subdirectories that exist in the results directory. Note that if a RESOLVE run is interrupted mid-run, a results folder will be created but no results will be available. Consequently, the user will not be able to load results for that scenario until the simulation has completed running.

6. After selecting one of the scenarios from the list under “Scenarios with Results”, the **“Retrieve Results of Selected Scenario”** macro will load all summary results files into the appropriate worksheets (named raw_ + file name) for the selected scenario.

A common cause of errors is the **`fso.GetFolder()`** function in the VBA macro. If this function raises an error, go to Tools > References > find and tick 'Microsoft Scripting Runtime'.

The Dashboard worksheet contains key summary results for the CAISO zone, such as the resource buildout, portfolio costs, etc. The worksheet also includes graphs on the right side of the tables.

The year columns are grouped using Excel’s grouping functionality (see Data > Outline > Group), and can be expanded and minimized by clicking on the “+” or “-” signs in the columns sidebar, or by clicking on the numbers (1,2) on the top left of the spreadsheet. Note that expanding the grouped columns will interfere with the formatting of the charts. If the user has created a RESOLVE scenario that looks at a different set of years than the default case, the **“Regroup Columns”** macro will regroup the columns to show the representative set of years.

3.2.2 PORTFOLIO ANALYTICS

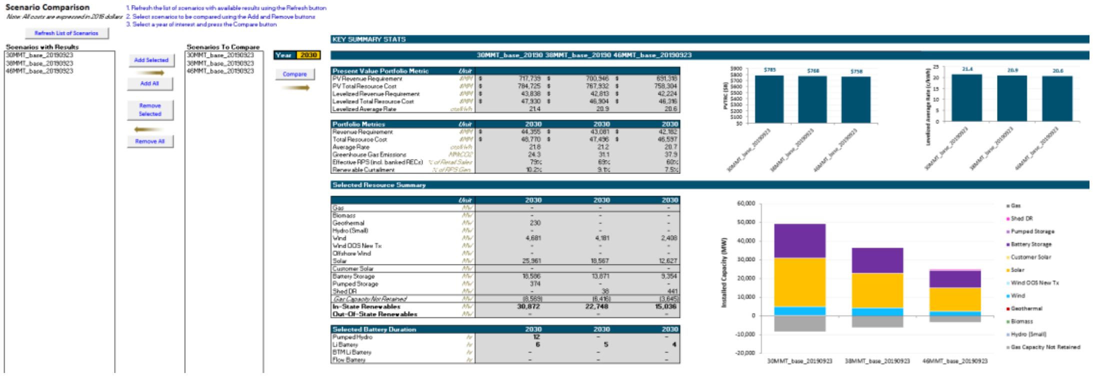
This worksheet contains more detailed summary tables that are pulled from the raw summary results worksheets and processed where necessary.

The results are grouped using Excel’s grouping functionality (see Data > Outline > Group), and can be expanded and minimized by clicking on the “+” or “-” signs in the rows/columns sidebar, or by clicking on the numbers (1,2) on the top left of the spreadsheet. If the user has created a RESOLVE scenario that looks at a different set of years than the default case, the **“Regroup Columns”** macro will regroup the columns to show the representative set of years.

3.2.3 SCENARIO COMPARISON

This worksheet is set up so the user can compare summary results of multiple scenarios. It allows the user to select scenarios of interest and to compare the summary results of these scenarios for a year of interest. The summary results are the same as those shown on the Dashboard for an individual scenario.

Figure 3.5. Results Viewer - Scenario Comparison Worksheet



Scenario Comparison

Note: All costs are expressed in 2016 dollars

1. Refresh the list of scenarios with available results using the Refresh button
2. Select scenarios to be compared using the Add and Remove buttons
3. Select a year of interest and press the Compare button

Scenarios with Results

30MMT_base_20190923
38MMT_base_20190923
46MMT_base_20190923

Scenarios To Compare

30MMT_base_20190923
38MMT_base_20190923
46MMT_base_20190923

Year: 2030

KEY SUMMARY STATS

Present Value Portfolio Metric	Unit	30MMT_base_20190	38MMT_base_20190	46MMT_base_20190923
PV Revenue Requirement	$MM	$ 717,739	$ 700,946	$ 691,318
PV Total Resource Cost	$MM	$ 784,725	$ 767,932	$ 758,304
Levelized Revenue Requirement	$MM	$ 43,838	$ 42,813	$ 42,224
Levelized Total Resource Cost	$MM	$ 47,930	$ 46,904	$ 46,316
Levelized Average Rate	cts/kWh	21.4	20.9	20.6

Portfolio Metrics	Unit	2030	2030	2030
Revenue Requirement	$MM	$ 44,355	$ 43,081	$ 42,182
Total Resource Cost	$MM	$ 48,770	$ 47,496	$ 46,597
Average Rate	cts/kWh	21.8	21.2	20.7
Greenhouse Gas Emissions	MMtCO2	24.3	31.1	37.9
Effective RPS (incl. banked RECs)	% of Retail Sales	79%	69%	60%
Renewable Curtailment	% of RPS Gen	10.2%	9.1%	7.5%

Selected Resource Summary

	Unit	2030	2030	2030
Gas	MW	-	-	-
Biomass	MW	-	-	-
Geothermal	MW	230	-	-
Hydro (Small)	MW	-	-	-
Wind	MW	4,681	4,181	2,408
Wind OOS New Tx	MW	-	-	-
Offshore Wind	MW	-	-	-
Solar	MW	25,961	18,567	12,627
Customer Solar	MW	-	-	-
Battery Storage	MW	16,586	13,871	9,354
Pumped Storage	MW	374	-	-
Shed DR	MW	-	38	441
Gas Capacity Not Retained	MW	(8,569)	(6,416)	(3,645)
In-State Renewables	MW	**30,872**	**22,748**	**15,036**
Out-Of-State Renewables	MW	-	-	-

Selected Battery Duration		2030	2030	2030
Pumped Hydro	hr	12	-	-
Li Battery	hr	6	5	4
BTM Li Battery	hr	-	-	-
Flow Battery	hr	-	-	-

To compare a set of scenarios, follow the steps below:

1. Refresh the list of available scenarios by pressing **"Refresh List of Scenarios"**. This macro lists all subdirectories that exist in the results directory. Results files must be present for all scenarios for the scenario comparison function to work.

2. [*Optional*] If necessary, remove any scenarios you don't want to compare from the "Scenarios to Compare" list by using the **"Remove Selected"** or **"Remove All"** Button.

    a. The **"Remove Selected"** macro will remove the selected scenario from the list of scenarios listed under "Scenarios to Compare". Note that in this context, selected scenario means the cell that is selected within the "Scenarios to Compare". If a cell outside of this box is selected, a warning will pop up and the macro will stop.

    b. The "**Remove All"** macro will remove all scenarios listed under "Scenarios to Compare".

3. Add scenarios of interest to the "Scenarios to Compare" list using the **"Add Selected"** or **"Add All"** buttons.
    a. The **"Add Selected"** macro will add the selected scenario to the list of scenarios listed under "Scenarios to Compare". Note that in this context, selected scenario means the cell that is selected within the "Saved Scenarios Menu" box (not the value in cell D8). If a cell outside of this box is selected, a warning will pop up and the macro will stop.
    b. The **"Add All"** macro will add all scenarios listed under "Saved Scenarios" to the list of scenarios listed under "Scenarios to Compare".

4. Select a year of interest in cell I8 (shaded yellow). Please ensure that this is a year for which there are RESOLVE results.

5. Compare all selected scenarios by pressing the **"Compare"** macro button. This macro will load the summary results for each of the scenarios listed under "Scenarios to Compare" to the Dashboard, and then copy the results for the year of interest to the Scenario Comparison table. It can take a few minutes to compare the results of many scenarios because the **"Retrieve Results of Selected Scenario"** macro on the Dashboard is called upon many times in a row.

3.2.4 RAW SUMMARY RESULTS

The set of worksheets that start with "raw_" contain a copy of the raw summary results files for the scenario of interest. Whenever the macro **"Retrieve Results of Selected Scenario"** is run, these worksheets are updated. Note that while the user should be able to find all the information needed in the first three tabs, if there is interest in investigating the "raw_" tabs to filter or edit any specific data, rerunning the **"Retrieve Results of Selected Scenario"** macro will overwrite any changes that have made. In that case, make sure to press the **"Retrieve Results of Selected Scenario"** button twice to ensure all the "raw_" tabs are fully refreshed.

3.2.5 LISTS

This worksheet contains a set of lists to support the functions in this workbook. The user should not change anything in this worksheet.