AVoided Emissions and geneRation Tool (AVERT)

User Manual
Version 1.6

July 2017

U.S. Environmental Protection Agency
Office of Air and Radiation
Climate Protection Partnerships Division

Acknowledgments

AVERT was developed by Synapse Energy Economics, Inc., under contract to EPA's Climate Protection Partnerships Division and under the direction of Robyn DeYoung of EPA. EPA thanks the staff at Synapse who developed AVERT and the user manual, particularly Jeremy Fisher, Ph.D., Patrick Knight, Ariel Horowitz, Ph.D., Avi Allison, Elizabeth A. Stanton, Ph.D., and Bruce Biewald. Eastern Research Group, Inc. (ERG) provided production and logistical support. ERG and Synapse provided these services under EPA contracts #EP-BPA-12-H-0025 and #EP-BPA-12-H0036. EPA also thanks Abt Associates staff Kait Siegel and Jonathan Dorn, Ph.D., and Anna Belova, Ph.D., currently with Cognistx, who provided support for developing the $PM_{2.5}$ emission rates under contracts #EP-W-11-003 and #EP-W-17-009.

Contents

1. INTRODUCTION 1

THE CHALLENGE OF ESTIMATING DISPLACED EMISSIONS 2

Basic Method: eGRID Non-baseload Method 3

Basic Method: Capacity Factor Approach 4

Intermediate Method: Historical Hourly Method 4

Sophisticated Method: Energy Modeling 4

USING AVERT 5

Example Use A: Air Quality Planner Quantification of EE/RE Emissions Impacts for SIP Compliance 6

Example Use B: Stakeholder Review of Multiple EE Options for Emissions Impacts 6

Cautionary Note 6

BENEFITS OF USING AVERT 7

KEY ABBREVIATIONS 9

2. THE AVERT ANALYSIS STRUCTURE 10

LIMITATIONS AND CAVEATS 12

3. AVERT MAIN MODULE: AN OVERVIEW 15

AVERT REGIONS 15

EE/RE PROGRAM CHARACTERISTICS 17

DISPLACED EMISSIONS OUTPUT 19

4. AVERT MAIN MODULE: STEP-BY-STEP INSTRUCTIONS 22

AVERT WELCOME PAGE 22

STEP 1: LOAD REGIONAL DATA FILE 24

STEP 2: SET ENERGY EFFICIENCY AND RENEWABLE ENERGY DATA 26

Manual User Input 28

Reduce Generation by a Percent in Some or All Hours 28

Reduce Generation by Annual GWh 30

Reduce Each Hour by Constant MW 30

Renewable Energy Proxy 30

STEP 3: RUN DISPLACEMENT 30

STEP 4: DISPLAY OUTPUTS 32

Summary Tables 32

Charts and Figures 36

SMOKE Text File 41

Advanced Outputs 42

APPENDIX A: INSTALLATION INSTRUCTIONS **43**
MAIN MODULE 43
System Requirements *43*
Installation *43*
Launching AVERT's Main Module *44*
Technical Assistance *44*
STATISTICAL MODULE 44
System Requirements *44*
Installation and Launching *44*
Technical Assistance *44*
FUTURE YEAR SCENARIO TEMPLATE 45
System Requirements *45*
Installation *45*
Launching and Working with the Future Year Scenario Template *45*
Technical Assistance *45*
APPENDIX B: DATA **46**
APPENDIX C: PROXY RENEWABLE ENERGY HOURLY PROFILES **50**
APPENDIX D: OVERVIEW OF AVERT'S STATISTICAL MODULE **52**
PARSING GENERATION DEMAND INTO FOSSIL-FUEL LOAD BINS 52
COLLECTING STATISTICAL INFORMATION 55
Frequency of Operation by Fossil-Fuel Load Bin *55*
Generation Level by Fossil-Fuel Load Bin *55*
Heat Input and Emissions by Generation Level *58*
EXTRAPOLATION TO HIGHER AND LOWER FOSSIL-FUEL LOADS 58
Extrapolating the Probability of Operation *59*
Extrapolating the Generation Level *60*
STATISTICAL ANALYSIS 62
STATISTICAL OUTPUT 66
APPENDIX E: AVERT'S STATISTICAL MODULE: STEP-BY-STEP INSTRUCTIONS **68**
STEP 1: DETERMINE WINDOWS OPERATING ENVIRONMENT 68
STEP 2: DOWNLOAD THE STATISTICAL MODULE EXECUTABLE 68
STEP 3: DOWNLOAD CAMD DATABASE 69
STEP 4: INSTALL MATLAB COMPILER RUNTIME (MCR) 69
STEP 5: IF DESIRED, COMPLETE A FUTURE YEAR SCENARIO TEMPLATE 70
STEP 6: LAUNCH THE AVERT EXECUTABLE 70
STEP 7: CHOOSE A BASE YEAR FOR ANALYSIS 71
STEP 8: CHOOSE A BASE- OR FUTURE YEAR SCENARIO 71

STEP 9: CHOOSE REGION(S) OF INTEREST 72

APPENDIX F: AVERT'S FUTURE YEAR SCENARIO TEMPLATE 73

RETIREMENT OF EXISTING EGUS 73

ADDITION OF PROXY EGUS 73

POLLUTION-CONTROL RETROFITS 74

RUNNING FUTURE YEAR SCENARIOS IN AVERT 75

APPENDIX G: AVERT REGIONS AND INSTRUCTIONS FOR STATES THAT CROSS REGIONAL BOUNDARIES 76

APPENDIX H: FREQUENTLY ASKED QUESTIONS 79

RENEWABLE ENERGY AND ENERGY EFFICIENCY 79

AVERT OUTPUTS 82

AVERT STATISTICAL MODULE 83

FUTURE YEAR SCENARIOS 86

1. Introduction

The U.S. Environmental Protection Agency (EPA) recognizes that many states are adopting, implementing, and expanding cost-effective energy efficiency (EE) and renewable energy (RE) policies and programs. States are investing in EE/RE policies and programs to achieve benefits including lowered customer costs, improved electric supply reliability, and diversified energy supply portfolios. EE/RE can also reduce pollution of criteria air pollutants and greenhouse gases, especially on high-electricity-demand days that typically coincide with poor air quality.

EPA's *Roadmap for Incorporating Energy Efficiency/Renewable Energy Policies and Programs in State and Tribal Implementation Plans* describes basic, intermediate, and sophisticated methods for quantifying the emissions impacts of EE/RE programs.[1] Basic methods entail a simple calculation: multiplying the amount of generation or electricity consumption displaced by the EE/RE policy or program by the "non-baseload" emissions rate indicated for a specific pollutant in a region (e.g., eGRID subregion or electricity market area). Intermediate methods, like the AVERT tool described in this manual, are transparent, credible, free, and accessible tools. Sophisticated methods cannot be implemented without a detailed understanding of the electricity grid and electric generator dispatch dynamics, and/or energy modeling expertise. EPA is committed to helping state air quality planners calculate the emissions benefits of EE/RE policies and program so that these emissions reductions can be incorporated in Clean Air Act plans to meet National Ambient Air Quality Standards (NAAQS) and other clean air goals.

AVERT works by estimating the "displaced generation" from EE/RE programs—that is, the generation at fossil fuel power plants that will not take place because EE or RE is meeting consumers' energy needs. The quantification of EE/RE programs' "displaced emissions"—or emissions that would have been created by the generation that has been displaced—is unlike direct measurement of emissions at an electric generator's smokestack from stack controls. Emissions reductions from stack controls can be measured directly; emissions reductions due to demand reductions are indirect, or derived from model scenarios.

Electricity from numerous electric generators is dispatched onto a "grid" that immediately responds to changes in demand for power from residential, commercial, and industrial customers throughout a broad geographic area. Reducing consumption through EE/RE programs makes some fossil fuel generation unnecessary. Electric generating units (EGUs) that are not required to generate electricity are not "dispatched" as often, so some of their emissions are avoided.

Specific EE/RE programs and technologies have hourly load[2] profiles (hour-by-hour schedules of expected reductions in electricity demand or increases in electricity production for a year). Understanding the hour-by-hour relationship between specific EE/RE programs and the dispatch of fossil fuel EGUs (that is, which power plants are called on to generate electricity in a given hour) is essential to the estimation of the magnitude and location of emissions reductions from EE/RE.

EPA has developed a credible, free, user-friendly, and accessible tool to estimate emissions impacts of EE/RE policies and programs so that air quality planners can incorporate those impacts

[1] See Appendix I at https://www.epa.gov/sites/production/files/2016-05/documents/appendixi_0.pdf.
[2] "Load" is the term used throughout this manual to describe regional demand for electricity.

into their NAAQS SIPs.[3] The AVoided Emissions and geneRation Tool (AVERT) quantifies the displaced emissions of sulfur dioxide (SO_2), nitrogen oxides (NO_x), carbon dioxide (CO_2), and particulate matter with diameter of 2.5 microns or less ($PM_{2.5}$) associated with EE/RE policies and programs within the continental United States (Alaska, Hawaii, and U.S. Territories are not modeled). AVERT captures the actual historical behavior of EGUs' operation on an hourly basis to predict how EGUs will operate with additional EE/RE implemented.

AVERT users can analyze how different types of EE programs, as well as wind, solar and other renewable energy technologies, affect the magnitude and location—at the county, state, and regional level—of emissions. AVERT is a flexible modeling framework with a simple user interface designed specifically to meet the needs of state air quality planners and other interested stakeholders.

The Challenge of Estimating Displaced Emissions

Estimating the location of displaced generation and its associated emissions impacts presents several challenges:

- The balance of electricity supply and demand varies hour by hour and by season.
- Multiple EGUs are dispatched to supply demand for electricity over a broad region.
- Different EE/RE programs and technologies save or generate energy at varying times throughout the day and seasonally.

Within each region across the country, system operators decide when, how, and in what order to dispatch generation from each power plant in response to a) customer demand for electricity in each moment and b) the variable cost of production at each plant.[4] Electricity from the power plants that are least expensive to operate is dispatched first, and the most expensive plants are dispatched last. That is, given a cohort of EGUs, the lowest variable-cost units are brought online first; as the load increases through peak (high-demand) hours, increasingly expensive units are brought online. (Ideally, given no other constraints—e.g., transmission, voltage support, ramp rates, maintenance outages—EGUs will dispatch into an electric system in a regular economic order based on the cost of fuel, the units' heat rates, and other variable costs of production.) In this "economic dispatch" decision-making process, EE/RE resources generally have low variable costs or are considered "must-take" resources, the operation of which is determined by sun, wind, the flow of a river, or efficiency program designs.[5] EE/RE resources displace higher variable-cost, emission-producing fossil-fuel generation. While electricity planners typically think about a single "marginal" resource (that is, the highest-cost unit that is required to meet customer demand at any

---

[3] See Appendix I of the *Roadmap for Incorporating Energy Efficiency/Renewable Energy Policies and Programs* (https://www.epa.gov/sites/production/files/2016-05/documents/appendixi_0.pdf) for details on how this approach can be used in the different NAAQS SIP pathways.

[4] "Variable costs" are the costs realized in the hour-to-hour operation of a generator that vary with the amount of energy that the unit produces. They typically include the cost of fuel, maintenance costs that scale with output, and the cost of emissions. Power plants also have "fixed costs"—such as staffing and regular maintenance—that must be met regardless of whether or not their units are generating power.

[5] "Must-take" resources are so named because they cannot generally be centrally dispatched (i.e., a controller cannot determine when they provide power), and as such they must be taken when they provide power. These resources can be curtailed under unusual circumstances, such as during periods of excess supply. These periods are not the norm; for the most part, controllers operate dispatchable resources around the must-take resources.

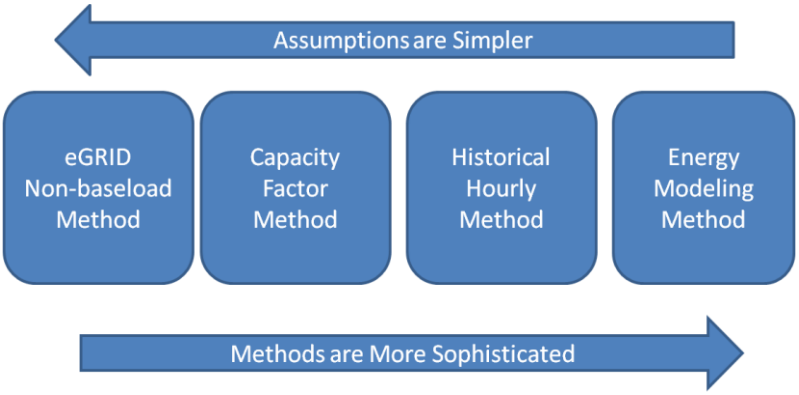
particular time), there are often several EGUs with similar variable costs that are simultaneously on or near the margin. EE load reductions and low-variable-cost RE generation can change the level of generation dispatched at multiple marginal EGUs at the same time across state boundaries.

Different EE/RE resources displace generation in different hours or seasons. EE load impact profiles describe the hourly changes in customer demand resulting from a program or measure, or the combined impact of a set of programs or measures. For example, load impact profiles can represent a portfolio of programs used to meet a policy target, such as the Energy Efficiency Resource Standards adopted by 27 states.[6] Generation profiles for RE technologies, such as wind or solar photovoltaic (PV), also vary by hour and season.

Determining which cohorts of EGUs are most likely to be displaced during particular hours or under certain conditions is a complex endeavor. It is not possible to definitively predict how an EE/RE resource will affect any given power plant. There are, however, several ways to estimate which EGUs would be displaced when and by how much based on EE/RE resources' load impact profiles, and EGUs' historical operational behavior or projected information on cost and other factors affecting dispatch in each regional electricity market.

Methods for estimating projected displaced emissions range from basic to sophisticated (see Figure 1). The first three methods (two basic methods and the AVERT intermediate-complexity method described in this manual) use historical operations and profiles to estimate likely displaced emissions. The more sophisticated fourth approach predicts future electricity market conditions and emissions displacement. Each method attempts to identify the group of EGUs that would be displaced as a result of EE/RE programs or measures that vary in terms of their sizes, geographic areas, and timing during the day and the year.

Figure 1. Emissions quantification methods.



Basic Method: eGRID Non-baseload Method

This basic method calculates the average non-baseload emissions reductions of clean energy policies and programs in one of EPA's "eGRID" subregions.[7] Annual electricity generation or sales displaced by an EE/RE program or measure are multiplied by the "non-baseload" emissions rate for each pollutant in each eGRID subregion.[8] The non-baseload emissions rate for an eGRID subregion is the current average emissions rate for the EGUs most likely to be displaced by EE/RE.

---

[6] U.S. EPA Energy and Environment Guide to Action, Chapter 4.1 (2015), available at https://www.epa.gov/sites/production/files/2017-06/documents/gta_chapter_4.1_508_0.pdf.

[7] eGRID data can be found at https://www.epa.gov/energy/egrid.

[8] Grid loss factors approximates the line losses that occur between the electric generating facilities and the buildings that purchase the electricity. They should be included in this calculation.

Basic Method: Capacity Factor Approach

The capacity factor approach estimates emissions reductions for an EGU based on its current capacity factor (i.e., its production of electricity in the most recent year as a percentage of the maximum energy that it can produce).[9] The capacity factor is used as a proxy for the likelihood that any given EGU will be displaced by EE/RE. Infrequently dispatched EGUs with low capacity factors are more likely to be displaced than EGUs with higher capacity factors.

Intermediate Method: Historical Hourly Method

The AVERT method described here uses historical hourly emissions rates based on recent EPA data on EGUs' hourly generation and emissions reported through EPA's Acid Rain Program.[10] This method couples historical hourly generation and emissions with the hourly load reduction profiles of EE/RE resources to determine hourly marginal emissions rates and hourly emissions reductions. AVERT can be used to predict EE/RE-related emissions reductions in a current or near-future year—though it is based on historical behavior rather than predicted economic behavior and, therefore, does not use projections of future fuel or electricity market prices.

Sophisticated Method: Energy Modeling

The most sophisticated method, energy modeling, is the use of highly complex simulation models that predict individual EGU dispatch, commitment, and emissions based on economic dispatch.[11] Energy models that simulate unit-by-unit dispatch and attempt to replicate decisions made by controllers and operators are called "production-cost" models, and will often include operational and transmission constraints. Operating economic dispatch models require the modification and validation of extensive input datasets, significant expertise to operate proprietary models, and ultimately a fairly high cost to evaluate individual EE/RE scenarios.[12]

---

[9] See, for example, the eCALC model: Texas A&M Energy Systems Laboratory. 2004. Texas Emissions and Energy Calculator (eCALC). Documented at http://oaktrust.library.tamu.edu/handle/1969.1/2079.

[10] https://ampd.epa.gov/ampd/.

[11] Fisher, J., C. James. N. Hughes, D. White, R. Wilson, and B. Biewald. 2011. *Emissions Reductions from Renewable Energy and Energy Efficiency in California Air Quality Management Districts.* Available at http://uc-ciee.org/downloads/CAEmissionsReductions.pdf.

[12] A variety of utility-standard models that are available to estimate the impact of new EE/RE resources on dispatch. Generally, the models best suited for this purpose in near-term years are termed "production-cost" models, including such systems as Market Analytics - Zonal Analysis (http://new.abb.com/enterprise-software/energy-portfolio-management/market-analysis/zonal-analysis), PROMOD IV (http://new.abb.com/enterprise-software/energy-portfolio-management/market-analysis/promod-iv), and PLEXOS (http://www.energyexemplar.com). Other models are designed to optimize resource build-out (i.e., new capacity additions), and may be appropriate for examining long-term displacement of specific new resources. These "capacity expansion" models include such platforms as EGEAS (http://www.epri.com) and System Optimizer and Strategist (http://new.abb.com/enterprise-software/energy-portfolio-management/commercial-energy-operations/system-optimizer-strategist). These models are all proprietary and require either licensure or specific project contracts to operate for most users. Large-scale, integrated assessment models such as ICF's Integrated Planning Model (IPM; https://www.epa.gov/airmarkets/clean-air-markets-power-sector-modeling), the National Renewable Energy Laboratory's Regional Energy Deployment System (ReEDS; http://www.nrel.gov/analysis/reeds/) and the U.S. Department of Energy's National Energy Modeling System (NEMS; http://www.eia.gov/forecasts/aeo/) are appropriate for testing the implications of large-scale policies and initiatives over longer periods, but use highly simplified representations of electricity dispatch and generally aggregate units for computational efficiency.

Using AVERT

AVERT is a free tool that allows users with minimal electricity-system expertise to easily evaluate county-level emissions displaced by EE/RE programs. AVERT is primarily designed to estimate the impact of new EE/RE programs on emissions from large (greater than 25-megawatt [MW]), stationary fossil-fired EGUs. It uses public data, is accessible and auditable, and can be used for quantifying emissions impacts in NAAQS SIPs.[13]

To estimate displaced emissions using AVERT, users will need to know the type of EE/RE program or measure to be analyzed, or the program's load impact profile. An annual EE/RE load impact profile can be presented in 8,760 hourly intervals, or more coarsely in a few intervals (for example, peak, off-peak, and shoulder periods). For EE policies and programs, users will need the expected annual load reduction and an understanding of the temporal profile (e.g., would the EE program save energy throughout the year or primarily during peak periods). For RE programs, users will need to know the capacity of the solar or wind resource they are analyzing. These annual profiles are used to identify more precisely what specific generation resources are displaced by EE/RE programs or measures.[14] In the absence of specific data on the load impact, planners need to use their judgement to approximate the timing of impacts.

Using these inputs, AVERT automatically estimates emissions displacements in a region. The user then can view various outputs, maps, charts, and tables useful for many different types of analysis. Users can choose outputs that show regional-, state-, and county-level emissions impacts, with the option of highlighting high-electric-demand days. Expert air quality modelers assessing the benefits of $PM_{2.5}$, NO_x, and SO_2 emissions impacts can use the SMOKE (Sparse Matrix Operator Kernel Emissions) output function to produce hourly, EGU-specific air-dispersion-model-ready data.

AVERT is best suited to analyze the emissions impacts of state-wide or multi-state EE/RE policies and programs. Since AVERT modeling is conducted in one of 10 large regions that represent electricity markets and does not account for transmission constraints within each region, this tool is not recommended for estimating the emissions displaced by small local programs. Smaller programs can use AVERT-generated emission factors to estimate impacts within an AVERT region; these factors are available at www.epa.gov/avert. (See Appendix H for more details on determining the upper and lower bounds for EE/RE program sizes to be modeled in AVERT.) In addition, the tool is equipped to predict displacement in near-term future years by estimating each unit's generation, heat input, and emissions in the event that other EGUs are retired, newly brought online, or retrofitted with pollution controls.

AVERT provides useful information to both expert energy or air quality planners, and interested stakeholders.

[13] See EPA's Roadmap for Incorporating Energy Efficiency/Renewable Energy Policies and Programs in SIPs for details on other regulatory requirements.

[14] U.S. EPA. 2010. Assessing the Multiple Benefits of Clean Energy: A Resource for States. Chapter 3, page 64.

Example Use A: Air Quality Planner Quantification of EE/RE Emissions Impacts for SIP Compliance

Air quality planners can use AVERT to quantify the expected emissions of a new wind farm, solar initiative, or energy efficiency program for the purposes of NAAQS State Implementation Plan (SIP/TIP) compliance. For example, planners can evaluate a program that could displace NO_x during the summer ozone season, efforts to bolster a state wind energy program, or proposed additional incentives for an EE program that targets peak energy usage (e.g., high-efficiency air conditioner replacement).

Using AVERT, planners can input estimates for the amount of energy a wind farm of a particular size and output typical of the region can produce or the amount of energy that could be avoided from an EE program. Among other outputs, AVERT can estimate annual $PM_{2.5}$ emissions as well as ozone-season NO_x emissions reductions or a pounds (lbs)-per-day 10-day average of NO_x emissions in counties selected, allowing a comparison of the effectiveness of these programs against other SIP measures. Advanced AVERT users are able to incorporate expected retirements and changes in emissions rates expected in future years, and establish new baseline conditions. Since AVERT has the capability to output SMOKE-formatted emissions estimates for each EGU in the region in each hour of the year, planners can also assess the air quality improvements using an air dispersion model. Following EPA guidance, this information could be incorporated into a SIP.[15]

Example Use B: Stakeholder Review of Multiple EE Options for Emissions Impacts

A second use of AVERT is for stakeholders' development and testing of multiple types of energy efficiency programs in a state or group of states within an AVERT region to compare potential reductions in $PM_{2.5}$, NO_x, SO_2, or CO_2 emissions. Stakeholders can use AVERT to quickly test different types of energy efficiency load profiles and estimate the resulting displaced emissions. Users would modify input parameters to simulate baseload, peakload, or total EE portfolio reductions, or hour-by-hour load reduction profiles. This type of analysis allows stakeholders to review estimated emissions benefits from a wide variety of programs, to help consider adopting and/or implementing programs with the greatest improvements to air quality.

Cautionary Note

Please note that AVERT should only be used to assess EE/RE impacts—not to assess changes to an EGU fleet. For example, AVERT is not equipped to examine the changes in emissions that result from retirements, changes to heat rates, or specific fuel changes. AVERT uses data based on historical dispatch patterns and cannot credibly estimate emissions reductions resulting from changes to the overall pattern of dispatch.

[15] For more information on EPA's guidance, refer to EPA's *Roadmap for Incorporating Energy Efficiency/Renewable Energy Policies and Programs in SIPs/TIPs* at https://www.epa.gov/energy-efficiency-and-renewable-energy-sips-and-tips/energy-efficiencyrenewable-energy-roadmap.

Benefits of Using AVERT

AVERT combines historical hourly generation data with EE/RE load impact profiles, making it possible for users to:

- Compare the emissions benefits of different types of EE/RE programs or technologies.
- Incorporate EE/RE policies and programs into air quality models; public health impact tools, such as EPA's Co-Benefits Risk Assessment (COBRA) Screening Model; and SIPs to demonstrate Clean Air Act compliance.
- Estimate emissions impacts during peak energy demand periods in a historical year or near-term future year.

For example, wind and solar power have different hourly and seasonal operational profiles. AVERT can compare the emissions impacts between these two RE technologies at different times of the year. Similarly, various EE programs have different hourly load profiles. AVERT can also help users analyze different EE programs or portfolios of programs that offer different energy savings and emissions displacement throughout the year. Using this information, air quality planners could, for example, assess which EE programs provide the greatest air quality improvement on high ozone days. For smaller programs, users can use AVERT-generated emission factors to get a general estimate within an AVERT region. (See Appendix H for more details on determining the upper and lower bounds for EE/RE program sizes to be modeled in AVERT.)

Emission Factors from AVERT

EPA has used AVERT to produce marginal emission factors for each AVERT region and a weighted average for the nation for each year from 2007 to 2016. These emission factors are available at www.epa.gov/avert and can be used for quick estimates of avoided emissions, especially for very small EE/RE programs. They were calculated by assuming a 5% displacement of the existing regional demand and are divided into four categories: wind, utility PV, portfolio EE, and baseload EE.

AVERT is driven entirely by historical, publicly available data reported to EPA. It uses statistically driven "behavior simulation" to estimate near-term future emissions displacement based on the recorded historical behavior of existing EGUs in the recent past. Using this dataset alone, the model derives unit generation behaviors (i.e., how these EGUs respond to load requirements), EGUs that have a must-run designation,[16] and forced and maintenance outages. In addition, AVERT accurately represents the recent historical relationship between unit generation and emissions, with characteristics such as a decreasing heat rate (i.e., increasing efficiency) at higher levels of output, higher emissions from EGUs that are just warming up, and seasonally changing emissions for EGUs with seasonal environmental controls. The derivation of unit behavior and its application to AVERT is described in detail in Appendix D of this user guide.

[16] A must-run designation indicates that a unit is required to operate for reliability reasons, and often operate at minimum levels to maintain the ability to meet higher load in later hours.

AVERT has many advantages but requires several simplifying assumptions. Unlike traditional electricity system simulation dispatch or production cost models, AVERT does not use operating costs to estimate how and when an EGU dispatches to meet load requirements. As a result, there are important electric system dynamics that AVERT cannot capture: temporal characteristics (i.e., EGU minimum maintenance downtime and ramp-rates), changing economic conditions (i.e., rising or falling fuel or emissions prices), and explicit relationships between EGUs (i.e., units that substitute for one another). AVERT should not be used to assess these types of changes in the electric system or overall dispatch. These limitations are discussed in more depth in the "Limitations and Caveats" section on page 12 of this manual.

AVERT operates in a basic computer environment and leads users through the process step-by-step. Detailed instructions for the Excel version of the Main Module can be found in Section 4 of this guide or EPA's AVERT online tutorial.[17]

[17] AVERT's online tutorial provides video demonstrations and information about how to run AVERT. Visit https://www.epa.gov/statelocalenergy/avert-tutorial-homepage.

Key Abbreviations

- **AEO:** Annual Energy Outlook
- **AMPD:** Air Markets Program Data from CAMD
- **AVERT:** AVoided Emissions and geneRation Tool
- **CAMD:** EPA Clean Air Markets Division
- **CO_2:** carbon dioxide
- **DOE:** U.S. Department of Energy
- **EE:** energy efficiency
- **EE/RE:** energy efficiency and renewable energy
- **EGU:** electric generating unit
- **EPA:** U.S. Environmental Protection Agency
- **EWITS:** Eastern Wind Integration Transmission Study
- **GW:** gigawatt
- **GWh:** gigawatt-hour
- **ISO:** Independent System Operator
- **lb:** pound
- **MMBtu:** million metric British thermal units
- **MW:** megawatt
- **MWh:** megawatt-hour
- **NO_x:** nitrogen oxides
- $PM_{2.5}$: particulate matter with a diameter of 2.5 microns or less
- **PV:** photovoltaic
- **RE:** renewable energy
- **RTO:** Regional Transmission Organization
- **SMOKE:** Sparse Matrix Operator Kernel Emissions Model
- **SO_2:** sulfur dioxide
- **WWSIS:** Western Wind and Solar Integration Study

2. The AVERT Analysis Structure

AVERT has three components:

- The Excel-based **Main Module** allows users to estimate the displaced emissions likely to result from new EE/RE programs in reference to either a historical base-year or a future year scenario. In addition to inputs from the user, AVERT requires statistical data files generated by its Statistical Module. (See Sections 3 and 4 for a detailed description of the Main Module.)
- The MATLAB®-based **Statistical Module** performs statistical analysis on historical generation, heat input, and emissions data collected in the EPA Clean Air Markets Division's (CAMD's) Air Market Program Data (AMPD)[18] to produce the statistical data files used by AVERT's Main Module. The Statistical Module is available to users as a stand-alone executable. (See Appendices D and E for a detailed description of the Statistical Module.)
- The Excel-based **Future Year Scenario Template** allows users to modify base-year AMPD information with specified retirements and additions of power plants, as well as changes in emissions rates due to pollution controls. This modified data can be input into AVERT's Statistical Module to produce scenario-specific statistical data files, which are then fed into the Main Module. (See Appendix F for a detailed description of the Future Year Scenario Template.)

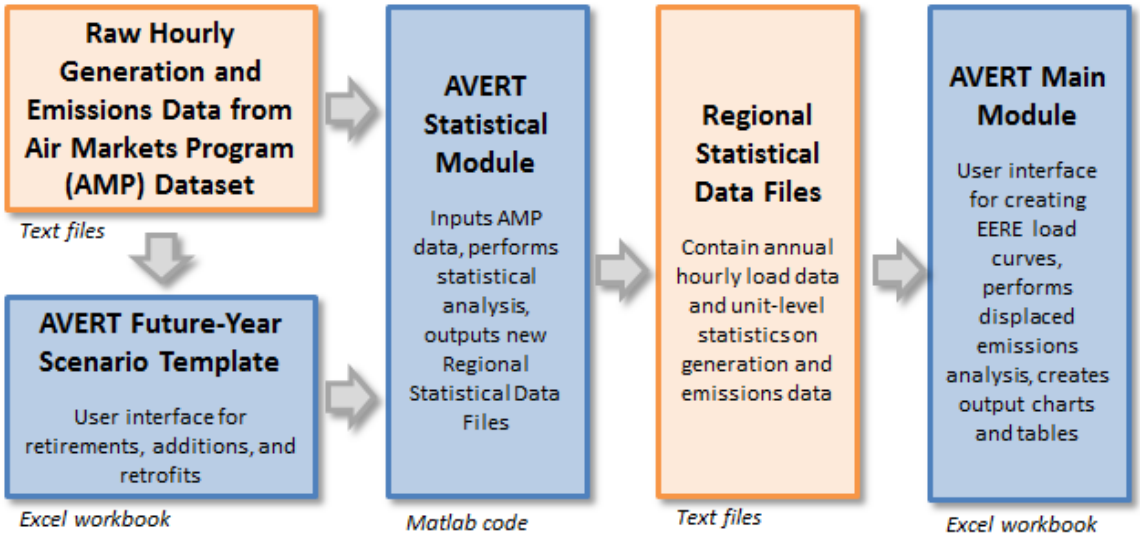
AVERT analyzes how hourly changes in demand in a user-selected historical base year change the output of fossil EGU.[19] Using detailed hourly data from AMPD, AVERT probabilistically estimates the operation and output of each EGU in a region based on a region's hourly demand for fossil-fired generation. This statistical information is used to predict EGUs' likely operation in response to load impacts from EE/RE resources. Figure 2, below, shows the flow of data from its source, through various processing tools, to its end-use in the Main Module.

In general, hourly "prepackaged" data from AMPD are input into AVERT's Statistical Module. Hourly generation, heat input, and emissions of $PM_{2.5}$, SO_2, NO_x, and CO_2 from each EGU reporting to AMPD (a requirement for fossil-fuel EGUs 25 MW and greater) are read from monthly or quarterly files.

[18] https://ampd.epa.gov/ampd/.

[19] AVERT's "base year" is modeled from recent, detailed hourly generation and emissions data collected by EPA for each U.S. fossil-fired generator with capacity greater than 25 MW. Base-year data is usually made available in the second quarter of the following year.

Figure 2. Schematic of AVERT.



AVERT's Statistical Module can analyze either raw data for a base year or modified data created in the AVERT's Future Year Scenario Template.[20] AVERT's Future Year Scenario Template allows users to create a scenario for a year in the near-future[21] by modifying data representing a historical year. Users designate existing fossil-fuel EGUs that will no longer be in operation or will have different emissions rates as a result of pollution-control retrofits, and add new fossil-fuel EGUs based on the characteristics of proxy existing EGUs. (See Appendix F for a more detailed description of AVERT's Future Year Scenario Template.)

After receiving either base- or future year scenario data, AVERT's Statistical Module performs a statistical analysis of how each EGU responds to variations in regional fossil load, and simulates the average generation, heat input, and emissions of each EGU across a range of possible load levels, from zero to the maximum coincident fossil capacity.[22] These EGU and load-level-specific averages are stored in the AVERT Regional Data Files, which are the input files used into AVERT's Main Module. (See Appendices D and E for a more detailed description of AVERT's Statistical Module.)

AVERT's Main Module allows users, regardless of their level of electricity modeling expertise, to quickly estimate the displaced emissions likely to result from EE/RE programs in a base or future year scenario. AVERT's Main Module provides a simple interface that guides users through inputting an EE/RE load impact profile depicting electricity demand in every hour of a year. The user is then prompted to launch automatic calculations that result in final output tables and charts for one of the 10 AVERT regions and, if desired, smaller areas within the region. In addition, AVERT's Excel-based Main Module also outputs SMOKE-formatted data for advanced air

[20] 2007 through 2016 data are provided with this version of AVERT. It is expected that data for future years will continue to be provided as additional data from CAMD are released.

[21] It is recommended that future year scenarios be designed for no more than five years forward from the base data year to account for changing emissions control technologies, changing fuel prices, and retirements and additions into the system. Caution should be exercised in reviewing future year scenarios to ensure reasonable results in light of known or expected system changes.

[22] Maximum coincident fossil capacity is equivalent to the sum of each and every fossil generator producing its maximum output in a single hour.

modeling applications. (See Sections 3 and 4 for a more detailed description of AVERT's Main Module and instructions for its use.)

Limitations and Caveats

There are several key limitations to the use of AVERT displaced emissions results.

- **Snapshot analysis:** AVERT provides a representation of the dynamics of electricity dispatch (i.e., which EGUs are put into operation in which hours) in a historical base year. However, it does not model changes in dispatch due to transmission resources, fuel prices, emissions allowances, demand for electricity, or the variable running cost of individual EGUs.[23] The use of AVERT to estimate forward-looking dispatch decisions is made more difficult when there are changes to the electrical grid (e.g., new transmission resources, EGU retirements, pollution control retrofits, or new EGUs), commodity prices (such as fuel or emissions allowances), or operational restrictions (e.g., "reliability must run" designations, curtailment due to new emissions caps). AVERT characterizes EGU retirements, pollution control retrofits, and new EGUs in its Future Year Scenario Template, but the scenarios created are only as good as the user's predictions of future conditions.
- **No explicit ramping or cycling:** AVERT does not model changes in ramping (periods when EGUs are changing to a new generation level) and cycling (fluctuating generation levels) behavior resulting from EE/RE programs, retirements, environmental controls, or new EGUs.[24] AVERT does not capture the changes in the frequency of ramping and cycling of fossil-fuel EGUs that can result from variability in wind- and sun-powered generation. In addition, it does not capture the ability of slow- or fast-cycling plants to respond to hour-to-hour changes in demand.
- **Average outcome:** AVERT generates an average outcome for each EGU, rather than a specific and precise trajectory. The default Regional Data Files produce generation and emissions levels that are averaged across 5,000 hypothetical scenarios of a recent past year. These levels are the statistically expected outcome, and should not be mistaken for an assertion of what did happen in a past year or what will happen in a future year.
- **Limited resolution for generation:** AVERT estimates regional displaced emissions. To do so it predicts the most likely generation levels for individual EGUs given a particular regional fossil-fuel load level and the most likely emissions rates for individual EGUs given a particular generation level. Results at the individual EGU level (and for counties containing small numbers of EGUs) have very limited "resolution"; the accuracy of the results is limited at small spatial and temporal scales.
- **Limited resolution for small EE/RE programs:** Due to the limited resolution of generation, when focusing on smaller-scale EE/RE programs, AVERT may return a higher level of "noise" in the displaced emissions results—that is, a greater divergence between desired reductions in generation and modeled reductions in generation. Small changes

[23] For example, new emissions controls may entail additional variable costs incurred by specific units. These additional costs could affect dispatch, but are not captured by AVERT.

[24] Models that do not capture ramping or cycling dynamics are generally referred to as having non-chronological dispatch—i.e., there is no explicit sense of time or timing built into the model.

may be swamped by random effects, such as historical non-economic forced outages and weather events, artifacts in the data, or even random perturbations in the Monte Carlo analysis. Users are encouraged to use emission factors pre-generated from AVERT for small-scale projects.[25] There is no hard limit on the smallest project that can or should be reviewed in AVERT, but results for EE/RE programs under several hundred MW in capacity should be reviewed carefully.[26] Appendix H discusses reasonable minimum levels of demand reduction for the purposes of obtaining useful results from AVERT.

- **Limited ability to capture dispatch implications of very large EE/RE programs:** AVERT is designed to review the impact of marginal changes in load requirements. Very large-scale energy efficiency and renewable energy programs may fundamentally change the way in which dispatchers operate a system. In particular, there is little precedent in the United States for understanding how high penetrations of variable renewable resources (such as wind and solar) impact other EGUs in a system. In some cases, very high penetrations of these resources may result in patterns that are not often observed in the historical dataset, such as the curtailment of slower-cycling coal plants, or an increase in the dispatch of fast-cycling peaking plants to smooth irregularities.[27] Appendix H discusses reasonable maximum levels of demand reduction for the purposes of obtaining useful results from AVERT.
- **Precision of results:** AVERT reports results rounded to the nearest 10 units (i.e., megawatt-hours [MWh], lbs of $PM_{2.5}$, SO_2, and NO_x, or tons[28] of CO_2). In general terms, users should consider the number of significant figures in their specified MW load reduction, and limit their use of AVERT results to that number of significant figures.
- **Non-communicating regions:** AVERT models one region at a time, assuming that each region generates sufficient electricity to meet its own requirements; imports and exports of electricity between regions are assumed to stay constant with changing load requirements). Similarly, displaced emissions are restricted to the confines of the AVERT region selected for the analysis. The basis of this assumption is that analyses on smaller-sized regions would risk missing important interdependencies between EGUs across larger, well-integrated regions. Using yet larger regions than those in AVERT, however, would spread the influence of load reductions too widely, making it difficult to ascribe load reductions to particular EGUs.

---

[25] Pre-generated emission factors for each year from 2007 to 2016 are available at www.epa.gov/avert.

[26] The smallest size that AVERT can resolve appropriately will vary by region and program, depending on how the program is distributed across time and the number of units that reduce output in response. AVERT allows users to review the impact of noise on expected outputs via a post-run diagnostic (discussed under "Signal-to-noise diagnostic" on page 40). In addition, AVERT rounds reductions from EE/RE programs to the closest 10 units (MWh, lbs of $PM_{2.5}$/SO_2/NO_x, or tons of CO_2); very small EE/RE programs will effectively report little or no specific reductions. Ultimately, the user must judge if the results return adequate information or appear reliable. For more information, see Appendix H.

[27] See Brown, P. 2012. *U.S. Renewable Electricity: How Does Wind Generation Impact Competitive Power Markets?* Congressional Research Service. R42818. Available at http://www.fas.org/sgp/crs/misc/R42818.pdf. See also National Renewable Energy Laboratory. 2011. *Eastern Wind Integration and Transmission Study.* Available at http://www.nrel.gov/docs/fy11osti/47078.pdf.

[28] In AVERT, all references to tons are short tons (2,000 lbs), not metric tons.

- **Unconstrained transmission:** AVERT looks at the dynamics of each region as a whole regardless of transmission constraints.[29] The model represents how the regional electricity system actually operated in the base year given the existing transmission infrastructure, but is completely insensitive to the physical location within a region of new EE/RE programs, as well as to the location within a region of retirements, environmental retrofits, and new EGUs modeled in the Future Year Scenario Template. In contrast, actual electricity dispatch decisions may be quite sensitive to the specific locations of resources, including (but not limited to) whether renewable resources are located close to consumers (at "load center") or in sparsely populated areas.
- **Limited capture of individual EGU dynamics:** Fossil-fuel EGUs, especially those using steam cycles, tend to operate at higher efficiencies and with lower emissions rates while in steady-state operation at or near their maximum output (although NO_x emissions in particular may be exacerbated by high-output operations). The AVERT approach does account for emissions rates appropriate to different levels of generation (which may be associated with periods of fast-ramping or cycling by fossil-fuel EGUs), but does not account for inefficiencies that may be associated with rapid cycling.

[29] Transmission is the infrastructure to transport electricity from generators to load centers (i.e., from the source of generation to electricity consumers). It can be "constrained" when the thermal (or other) limits prevent as much energy as is needed from moving across wires. When transmission is "bound" under these circumstances, dispatch begins to reflect local requirements, rather than regional requirements. In other words, generators may dispatch in a non-economic fashion when transmission is constrained.

3. AVERT Main Module: An Overview

This section bypasses technical details and how-to instructions to give a broad, simplified overview of key selections made by AVERT users (i.e., the region and other characteristics of the EE/RE program to be analyzed) and the displaced emissions results available to users. See Section 4 for detailed, step-by-step instructions and Appendix A for detailed installation instructions. Appendix D describes, in detail, how AVERT performs its calculations.

AVERT's Excel-based Main Module estimates the emissions displaced by EE/RE resources for every individual fossil-fuel EGU in a region and aggregates these displacements to the county level.[30] The Main Module uses two key pieces of information:

- **Expected emissions at every load level**—the likely generation level and emissions of all but the smallest fossil-fuel EGU in a region in a base- or future year scenario (as modeled in AVERT's Statistical Module and input automatically into the Main Module).
- **A change in load level for every hour of the year**—a user-created load impact profile depicting EE/RE-driven changes in the regional fossil-fuel load for every hour of the year.

The Main Module estimates how much each fossil-fuel EGU changes its generation output and emissions in response to an EE/RE program as compared to the base- or future year scenario without the program. The difference between emissions resulting from the base- or future year load curve and the emissions resulting from the same year adjusted to include the load impact profile of an EE/RE program is the "displaced emissions." The Main Module presents results in summary tables for quick comparison, and in graphs and maps for rapid visual assessment.

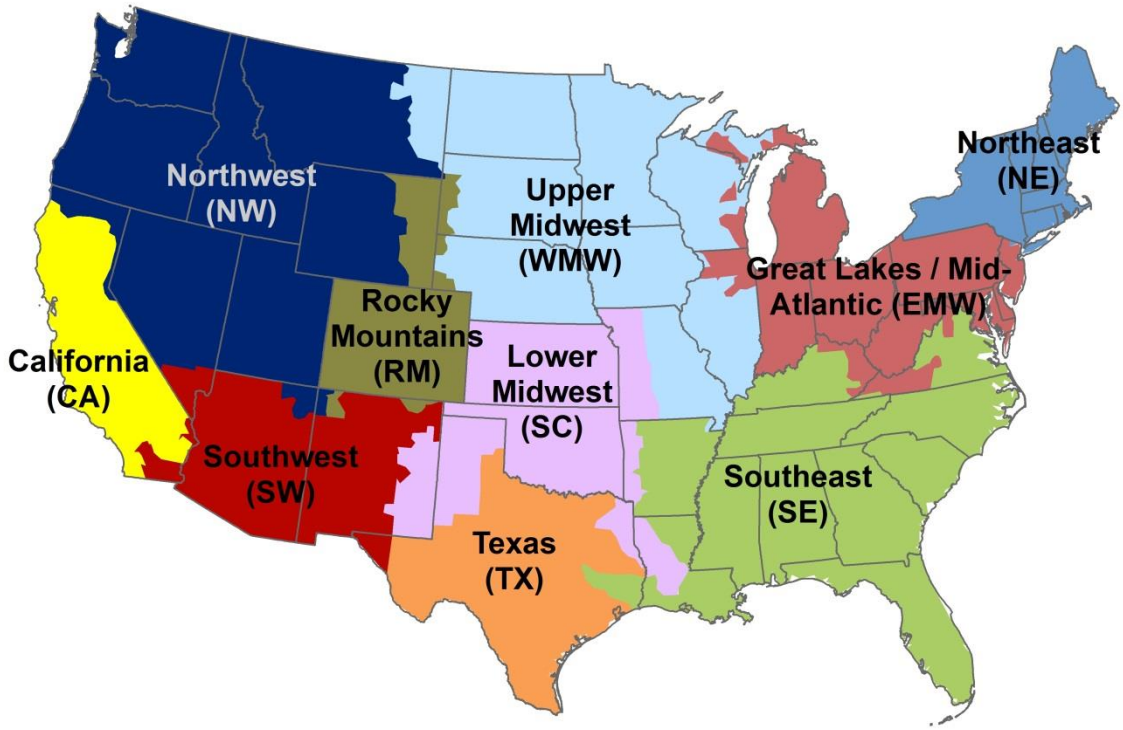
Section 4 presents detailed, step-by-step instructions on the process of identifying a region for analysis; obtaining and importing data; designing an EE/RE load impact profile; launching the automatic displaced emissions calculations; and accessing tables, graphs, and maps summarizing the output. Once an EE/RE load impact profile has been designed, typical processing takes 1 to 10 minutes depending on the size of the region of interest and the processing speed of the computer.

AVERT Regions

Because customers' electricity demand is met jointly by generation resources throughout a region, emissions displacements from EE/RE programs take place region-wide. All AVERT analysis, therefore, is conducted at a regional level. For users, designating one of the 10 AVERT regions of analysis is "Step 1" in using AVERT's Main Module. A map of these regions is shown in Figure 3.

[30] Excludes EGUs smaller than 25 MW that do not report to AMPD.

Figure 3. Map of AVERT's regions.



Twenty-six states and the District of Columbia each fall within a single region, while 22 states are split between two or more regions each. Table 1 describes each region in detail.

It is generally recommended that air quality managers for states that are split between more than one AVERT region evaluate the displaced emissions from regions in which 5 percent or more of their generation is located. Appendix G includes further discussion of the regions and more complete instructions for users analyzing EE/RE impacts in split states.

Table 1. AVERT regions, abbreviations, and states.

AVERT Region	Abbreviation	Full States	Partial States
Northeast	NE	Connecticut, Massachusetts, Maine, New Hampshire, New York, Rhode Island, and Vermont	New Jersey
Great Lakes / Mid-Atlantic	EMW	District of Columbia, Delaware, Indiana, and Maryland	Illinois, Kentucky, Michigan, New Jersey, Ohio, Pennsylvania, Virginia, Wisconsin, and West Virginia
Southeast	SE	Alabama, Florida, Georgia, North Carolina, South Carolina, and Tennessee	Arkansas, Kentucky, Louisiana, Missouri, Mississippi, Oklahoma, Texas, Virginia, and West Virginia
Lower Midwest	SC	Kansas	Arkansas, Louisiana, Missouri, New Mexico, Oklahoma, and Texas
Upper Midwest	WMW	Iowa, Minnesota, North Dakota, and Nebraska	Illinois, Missouri, Mississippi, Montana, South Dakota, and Wisconsin
Rocky Mountains	RM	Colorado	Wyoming

AVERT Region	Abbreviation	Full States	Partial States
Texas	TX		Oklahoma and Texas
Southwest	AZNM	Arizona	New Mexico, Nevada, and Texas
Northwest	NW	Idaho, Oregon, and Washington	Montana, Nevada, Utah, and Wyoming
California	CA		California and Utah

EE/RE Program Characteristics

AVERT users should understand the characteristics of the EE/RE program that they want to analyze in terms that can be input into the model; this is Step 2 in the AVERT Main Module. AVERT analyzes the difference in hourly load (regional electricity demand) between a baseline scenario and an EE/RE scenario. Starting with a baseline schedule of load for every hour of a reference year (the "load profile"),[31] the Main Module guides the user to create or input a load *impact* profile to represent their EE/RE program—i.e., the amount of load that will be reduced by the EE/RE program on an hourly basis. For details and instructions, refer to Step 2 in Section 4.

Designing future year scenarios is an advanced function of AVERT. Users can currently use 2007 through 2016 data as their baseline year.[32] Every AVERT user, however, must create or modify a load impact profile to represent a specific EE/RE program or group of programs. Advanced users can manually enter or cut and paste a load impact profile (i.e., an expected reduction for every hour of the year), but many users will use the Main Module's tools to create a load impact profile representing a set of EE/RE policies or programs.

Users are strongly encouraged to create and adopt their own load impact profiles, representing EE/RE programs specific to their interest or area of concern. The following load impact profiles are built into the Main Module:

- **Reduction of fossil-fuel generation by a chosen percent in some or all hours.** This option is recommended to represent a mix of energy efficiency programs that target some or all hours of the year, but preferentially target higher hours with greater demand.
- **Reduction of annual fossil-fuel generation by total gigawatt-hours (GWh) or by a constant MW each hour.** This option is recommended to represent a rough approximation of baseload-only reductions where the total number of GWh reduced over the course of a year is known and is expected to be equally distributed over all hours of the year.
- **Renewable energy proxy.** With this option, users can model wind, utility solar, and rooftop solar resources that are broadly representative of the selected region.

[31] Technically, within AVERT, the load profile represents aggregate fossil generation for a region, and not end use consumption.

[32] Future years will be released as data is made available through CAMD.

- **Combination of EE/RE programs.** Users can also mix and match from the above options, as well as combine the pre-set load reduction options with manually entered reductions

Note that this is not a comprehensive set of load reduction options. Rather, these are simple, illustrative examples.

AVERT combines all of the user's inputs to generate a single EE/RE profile with 8,760 hourly values.[33] This profile feeds into the calculations in the next step. Since the release of version 1.5 of AVERT's Main Module, AVERT adjusts the EE/RE profile to account for avoided transmission and distribution line losses associated with certain EE/RE resources: specifically, EE and distributed PV systems.[34] Hourly load reductions associated with each of these resources are adjusted upward by the following formula:

Adjusted load reduction = User's input / (1 – x),

where x is the regional average line loss percentage obtained from the most recent version of eGRID. AVERT currently uses the following line loss factors from eGRID 2014:

- 0.0497 for the Eastern Interconnect (AVERT regions: Great Lakes/Mid-Atlantic, Lower Midwest, Northeast, Southeast, and Upper Midwest)
- 0.0512 for Texas (ERCOT) (AVERT Texas region)
- 0.0479 for the Western Interconnect (AVERT regions: California, Northwest, Rocky Mountains, Southwest)

This adjustment has the effect of increasing displaced fossil load and displaced emissions associated with EE programs and with distributed RE generation. This adjustment provides more accurate results. Without this adjustment, AVERT would underestimate emissions. For example, AVERT without adjustments would assume that 100 MWh of EE or 100 MWh of onsite (distributed) PV generation avoids 100 MWh of fossil generation, whereas it actually avoids approximately 105 MWh of fossil generation after accounting for the additional power that would have been generated and lost during transmission in order to deliver 100 MWh to the end-user.

Once a load impact profile has been designed, the user is prompted to launch the automatic displaced emissions calculations in Step 3 of the AVERT Main Module.

[33] Or 8,784 in the case of leap years.

[34] AVERT treats wind and utility-scale PV as centralized resources that still require transmission and distribution to end-users; thus, while they displace fossil generation, a simple assumption is that they do not avoid any line loss.

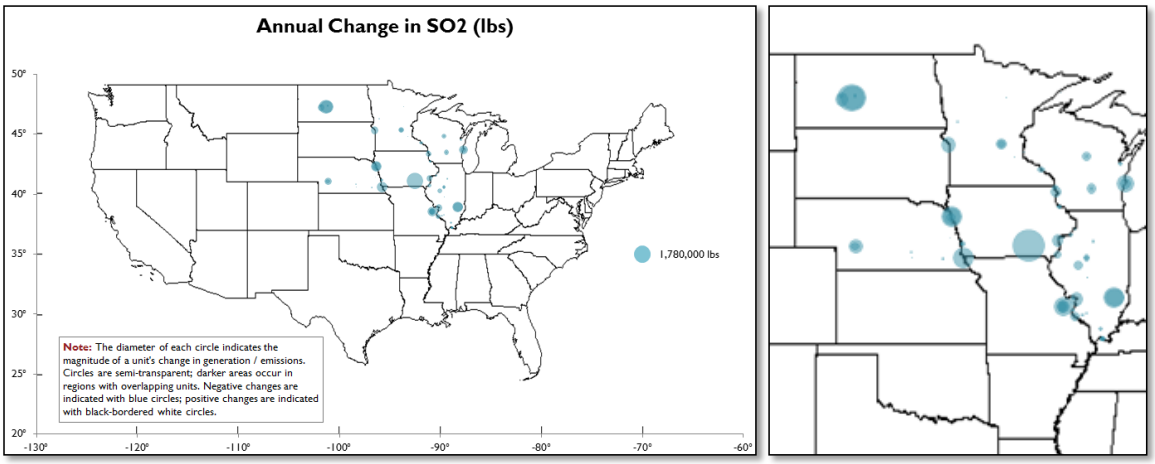
Displaced Emissions Output

Step 4 of AVERT's Main Module reports the difference between the baseline and EE/RE scenario through the following outputs:

- Summary tables:
  - Annual displaced generation and emissions
  - Displacement data for top 10 fossil-fuel generation days
  - Annual displacement data by county
  - Monthly displacement data by county
  - Daily NO_x displacement data by county
- Charts and figures:
  - Displaced generation and emissions map
  - Hourly displacements by week
  - Monthly displacements by selected geography (region, state, or county)
  - Signal-to-noise diagnostic
- SMOKE text file generation (for air quality modeling)

For assessing the air quality implications of EE/RE, the location of air emissions reductions resulting from load reduction programs can be critical. The example shown in Figure 4 represents a 2,000 MW wind program in the Upper Midwest AVERT region compared to 2012 base-year data. The map displays annual displaced SO_2 emissions from specific EGUs as blue circles; larger circles indicate greater displaced emissions. Where multiple EGUs overlap on the map (i.e., multiple units at one plant or several plants close together), the circles appear darker.

Figure 4. Map of annual SO_2 emissions reductions from an example wind program in the Upper Midwest region.

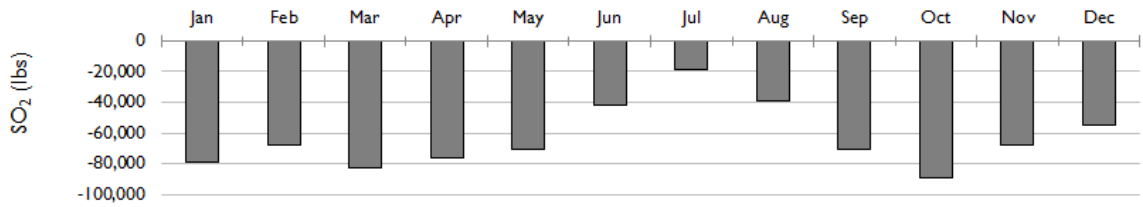


The diameter of each circle indicates the magnitude of an EGU's change in emissions. Circles are semi-transparent; darker areas occur in regions with overlapping EGUs. Emissions reductions are indicated with blue circles; increases in emissions are indicated with black-bordered white circles.

Increases in emissions are shown as black-bordered white circles. Increasing emissions may occur because higher load is programmed into AVERT (e.g., for testing a higher baseline if reviewing the impact of existing renewable portfolio standards (RPS), or if shifting load from peak to trough hours), or due to aberrations in the statistical dataset.[35]

Many users will be interested in displaced emissions results for smaller areas within a region. Monthly output can be displayed by region, state, or county. Figure 5 displays monthly SO_2 emissions displaced in a single county in Illinois, continuing the same example shown in Figure 4.

Figure 5. Monthly SO_2 emissions reductions for Madison County, Illinois, from an example wind program in the Upper Midwest region.



Some users may wish to view *hourly* displaced generation or emissions to understand the behavior of the system at a finer scale or during specific hours of the year. Using the same 2,000 MW of wind reduction program, Figure 6 displays the hour-by-hour fossil generation displaced in the week of August 1–7 in the Upper Midwest AVERT region from the wind project. Individual EGUs are color-coded along a gradient from dark blue (baseload EGUs) to light blue (peaking EGUs).[36] The EGUs' individual generation reductions are shown in stacked bar plots and the net total contribution is shown with a yellow line. The yellow line represents the hourly energy displaced by the wind project. Note that peaking (gas) EGUs are primarily displaced during daytime hours, while baseload (usually coal) EGUs are displaced during off-peak hours.

[35] Some units show increasing generation even as regional load decreases. This usually occurs with baseload units during trough hours. It is primarily explained by maintenance outages that occur during periods of low demand, but not necessarily at the lowest demand hour of the year. Statistically, these units appear likely to generate slightly more at the lowest-load hours than at medium-low-load hours. Therefore, reducing demand from a medium-low load to a very low load could appear to increase the output of these units.

[36] The color coding is illustrative only. It is not portrayed on an absolute scale, and is relative to all units in the region (i.e., if a region comprises 200 units, they will all be parsed along the gradient from light blue to dark blue. If a region comprises 1,000 units, they will similarly be parsed along the same gradient). Units are sorted based on annual capacity factor. Units with uniform generation across high and low load levels are closer to "high-capacity-factor" behavior, while units with high output at high load levels and none at low load levels are closer to "low-capacity-factor" behavior.

Figure 6. Hourly generation reductions in the week of August 1 from an example wind program in the Upper Midwest region.

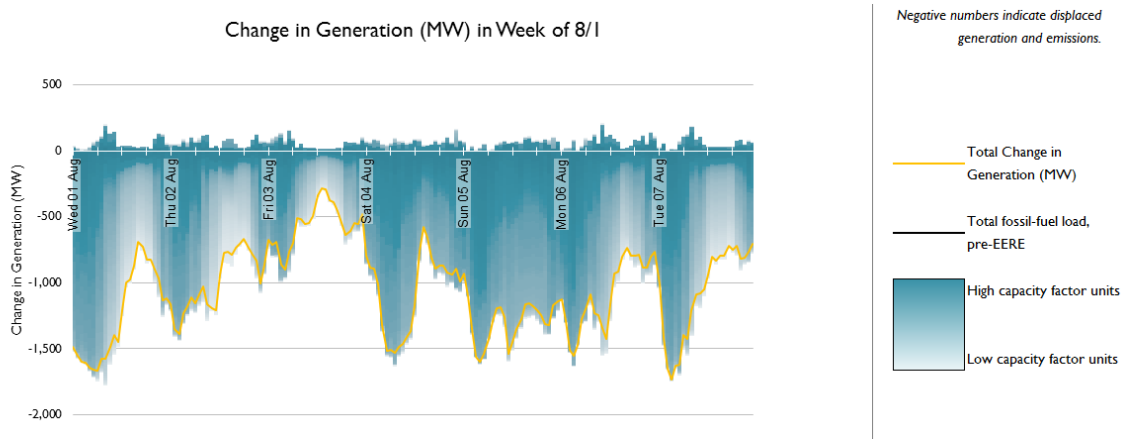
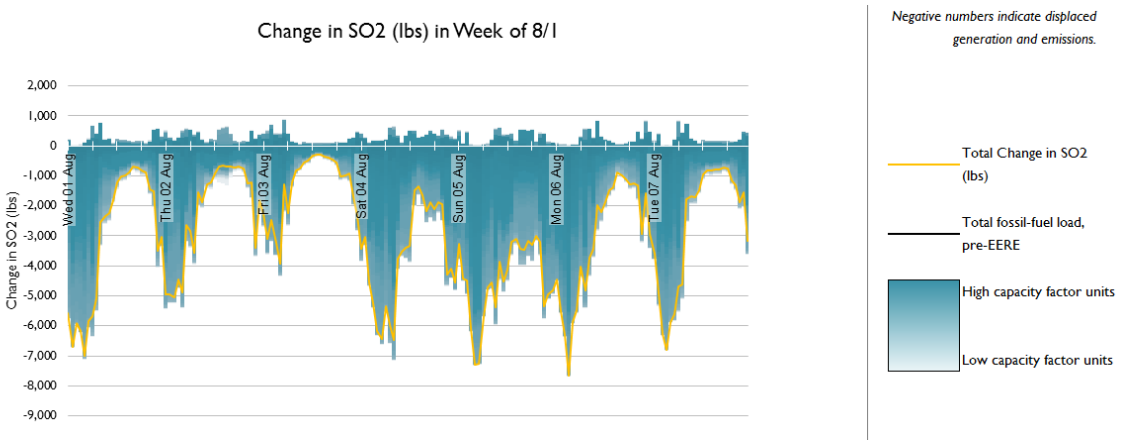


Figure 7 displays SO_2 emissions displaced in the same week from the same wind project. Note that almost all of the EGUs portrayed in this figure are dark blue in color; SO_2 reductions are primarily captured from reductions at high-capacity-factor coal EGUs, which are displaced during off-peak hours.[37]

Figure 7. Hourly emissions reductions in the week of August 1 from an example wind program in the Upper Midwest region.



[37] High-capacity-factor baseload units operate during most hours of the year, and are (by definition) the bulk of the units (or only units) online during offpeak hours, and therefore are the units that will be displaced in offpeak hours. This analysis indicates that baseload units are displaced during offpeak hours, but not during the daytime. During the day, gas plants (with no, or negligible, SO_2 emissions) are displaced, and therefore do not appear in this graphic.

4. AVERT Main Module: Step-by-Step Instructions

This section provides step-by-step instructions for using AVERT's Excel-based Main Module to estimate the emissions displaced by EE/RE resources.

To begin, download two files and save them to your computer:

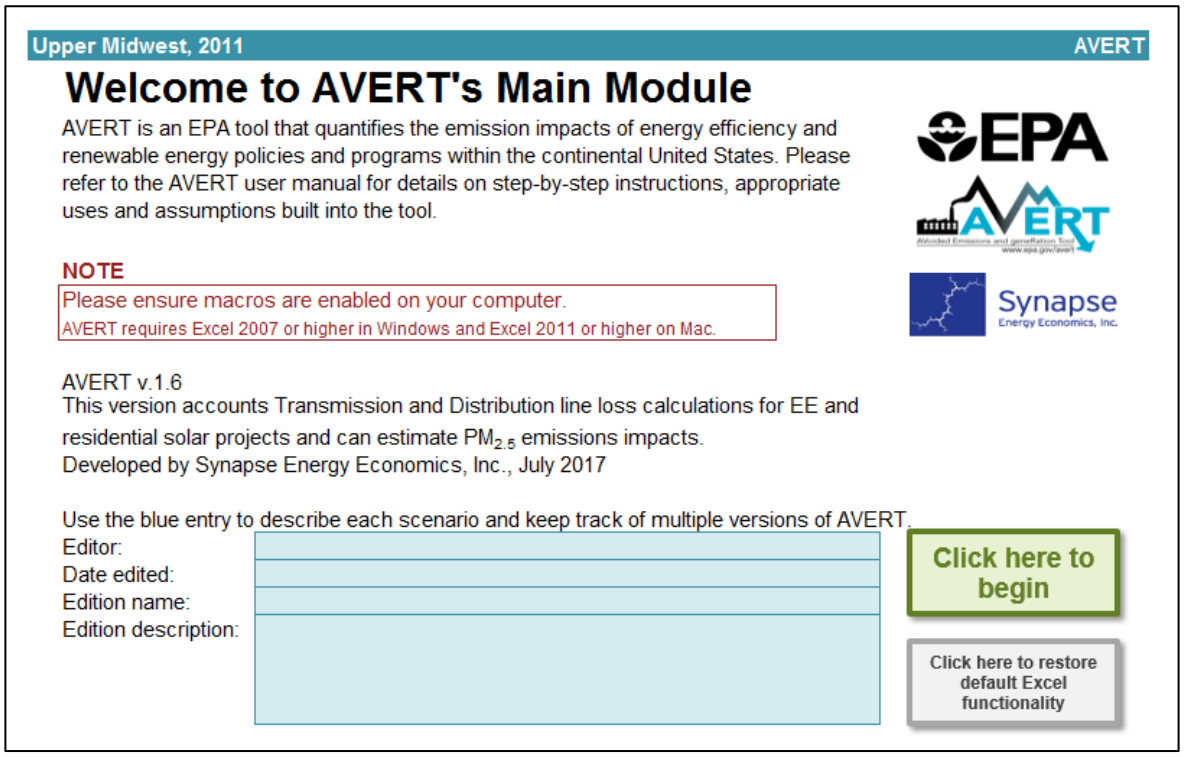
- The Main Module workbook: "AVERT Main Module.xlsx." Download the workbook at https://www.epa.gov/statelocalenergy/download-avert#Main.
- The Regional Data File for the region under analysis.
    - Default Regional Data Files developed for use by EPA are labeled "AVERT RDF [DataYear] BaseEPA ([Region]).xlsx"; they can be obtained at https://www.epa.gov/statelocalenergy/download-avert.
    - Regional analyses developed by advanced users using AVERT's Statistical Module will be saved, by default, in a folder of the Statistical Module titled "AVERT Output." These files use the following naming convention: "AVERT RDF [DataYear] [RunName] ([Region]) [RunDateTime].xlsx."

For more detailed installation instructions and model specifications, see Appendix A of this manual.

AVERT Welcome Page

When launched in Excel, the Main Module opens to its "Welcome" page as shown in Figure 8.

Figure 8. AVERT Main Module "Welcome" page.



The Main Module is primarily driven by macros to conserve memory and processing time.[38] Before making any selections or beginning calculations, macros must be enabled on your computer. This must be done first, before any other steps; if macros are not enabled before you load a Regional Data File (Step 1), you will need to close the workbook, re-open it, and then enable macros to continue.

To enable macros in Excel 2007 for Windows:

1. Click the Microsoft Office Button , then click “Excel Options.”
2. Click “Trust Center,” click “Trust Center Settings,” then click “Macro Settings.”
3. Click on “Enable all macros.”

To enable macros in Excel 2010 or later for Windows:

1. Click the “File” menu (Office Backstage), then click “Options” in the left sidebar.
2. Click “Trust Center” in the left sidebar, then click the “Trust Center Settings” button in the main window.
3. Click “Macro Settings” in the left sidebar.
4. Choose the “Enable all macros” option and hit “OK.”

To enable macros in Excel 2011 or later for Mac, select “Enable macros” in the dialog box that appears when opening the file.

Next, we recommend that you personalize the Welcome page with details about the user, the date of use, and the EE/RE program for which displacements are to be estimated. This version specification is very useful in keeping track of multiple versions of AVERT saved to the same drive. Please note that the version of AVERT available from EPA does not contain Regional Data File, and is thus fairly small in size (<6 MB). When a Regional Data File is loaded into AVERT and displacement is calculated, the program grows substantially to 60 to 100 MB.

A final note on the Welcome page: The Main Module has been designed with the goal of providing a clear user interface. While it is an Excel file, the tabs that drive the calculations for AVERT are hidden to enhance the usability and appearance of the tool, making it more similar to a web-based or executable program. For users who prefer full Excel functionality while using AVERT, there is a button at the lower right-hand side of the Welcome page that reads “Click here to restore default functionality.” You can complete the steps required to estimate displaced emissions regardless of whether or not full Excel functionality is visible.

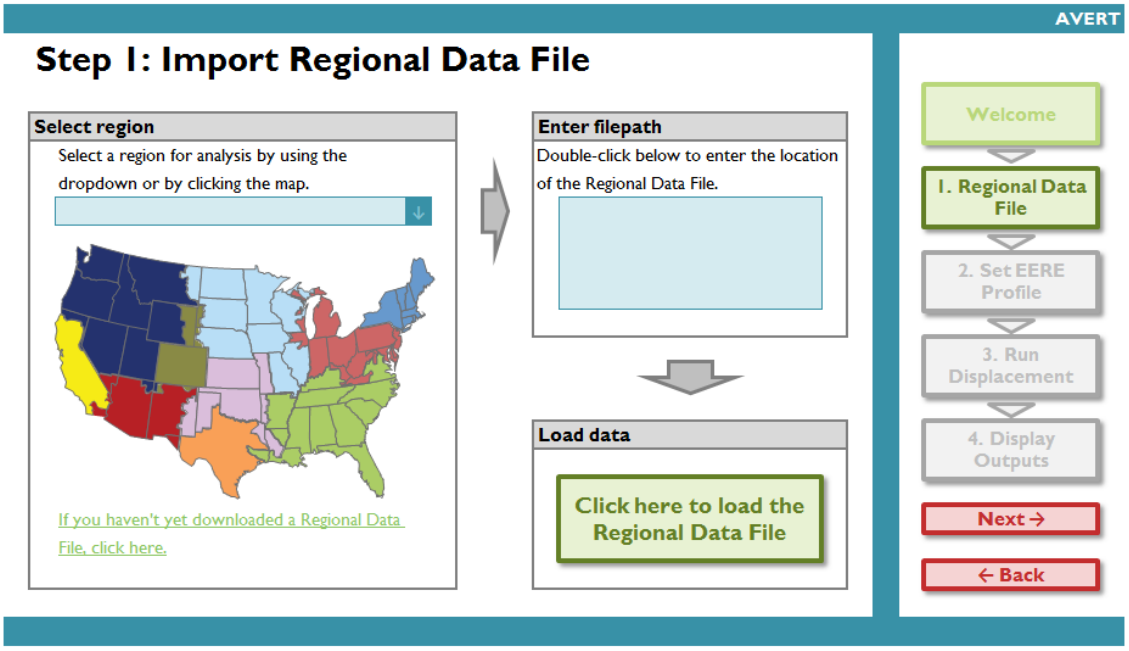
Click on the button labeled “Click here to begin” to move on to AVERT’s first step.

[38] Due to the large number of calculations—typically several hundred EGUs times 8,760 hours times five output variables, anywhere from 4 to 40 million complex calculations—storage in a dynamic Excel environment would be analytically burdensome and space-intensive. Therefore, most calculations are performed once in a Visual Basic environment, and are not stored in memory.

Step 1: Load Regional Data File

Next, choose the region of analysis in Step 1 (as shown in Figure 9) and load the corresponding Regional Data File. There are 10 AVERT regions to choose from, described in detail in Section 3. (For details on how the regions were developed, refer to Appendix B.)

Figure 9. Image of AVERT Main Module "Step 1: Import Regional Data File" page.



The choice of a region determines both which EGUs are included in the analysis and which default renewable resources are available for modeling the effects of EE/RE programs.

The 10 AVERT regions are:

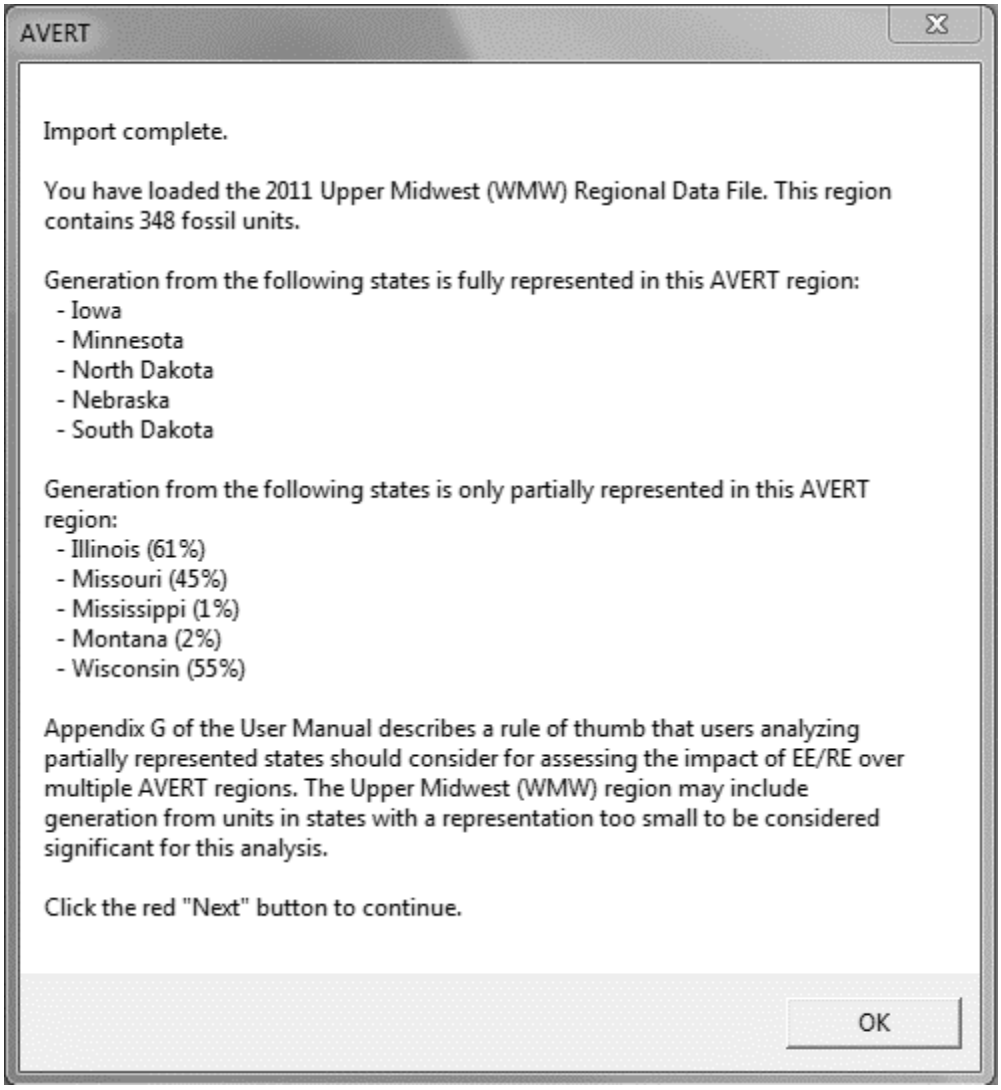
- California
- Great Lakes/Mid-Atlantic
- Lower Midwest
- Northeast
- Northwest
- Rocky Mountains
- Southeast
- Southwest
- Texas
- Upper Midwest

If you have not yet downloaded a Regional Data File, you can either select a region of interest from the dropdown menu or by clicking on the region in the map, then click the hyperlink in the bottom left of the page.

Then double-click on the filepath box and navigate to the folder where the Regional Data File has been saved. Once these steps have been completed, click on the green button labeled "Click here to load the Regional Data File." This step may take several minutes to complete, depending on the size of the region and the speed of the computer used. When the Regional Data File has been loaded, a pop-up box appears containing information about the loaded AVERT region and indicating "Import complete."

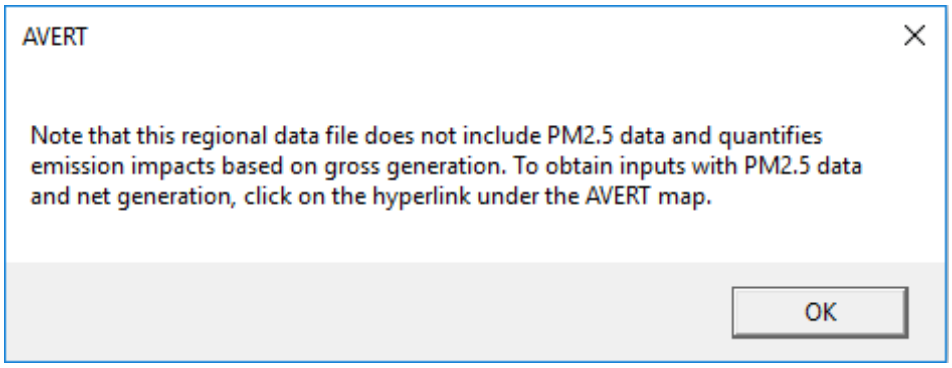
The pop-up box confirms the region and data year loaded by the user and indicates the number of reporting units in the analysis. The pop-up box also specifies the states that are fully represented and partially represented in a loaded AVERT region, as shown in Figure 10.

Figure 10. Regional Data File import pop-up box example for 2011 Upper Midwest AVERT region



Regional Data Files produced prior to summer 2017 do not contain $PM_{2.5}$ emission data, and they include generation data in “gross” rather than “net” (corrected for parasitic losses) terms. If you load a Regional Data File produced in 2016 or earlier, another pop-up box will alert you to these considerations and suggest that you download a newer Regional Data File from EPA’s website (Figure 11).

Figure 11. Regional Data File import pop-up example for data files produced prior to summer 2017.



Some states are divided by AVERT regions. For example, parts of Illinois are considered in the Upper Midwest Region, while other parts are in the Great Lakes / Mid-Atlantic Region.[39] Appendix G of this document describes the process that one should use to determine the impact of EE/RE programs in states that are partially represented in any one AVERT region. Users analyzing these states should assign the impact of EE or RE programs proportionally based on the fraction of the state's generation within each relevant AVERT region. These fractions are shown in Table 3 in Appendix G and, as a reminder and for clarity, in the pop-up box.

After you load a Regional Data File, the blue AVERT header bar will indicate the region and data year in the top left corner (e.g., "Upper Midwest, 2011"). The blue footer bar will also indicate the name of the AVERT run that has been loaded in the Regional Data File (e.g., "EPA_NetGen_PM25").[40] By default, the Regional Data Files provided by EPA are called "EPABase." When you run the Statistical Module, you will be able to give runs alternative names.

All four of AVERT's steps have a navigation panel on the right-hand side. You can click on any step or click "Next" or "Back" to move through the steps of the model. To move on to the next step, click "Next."

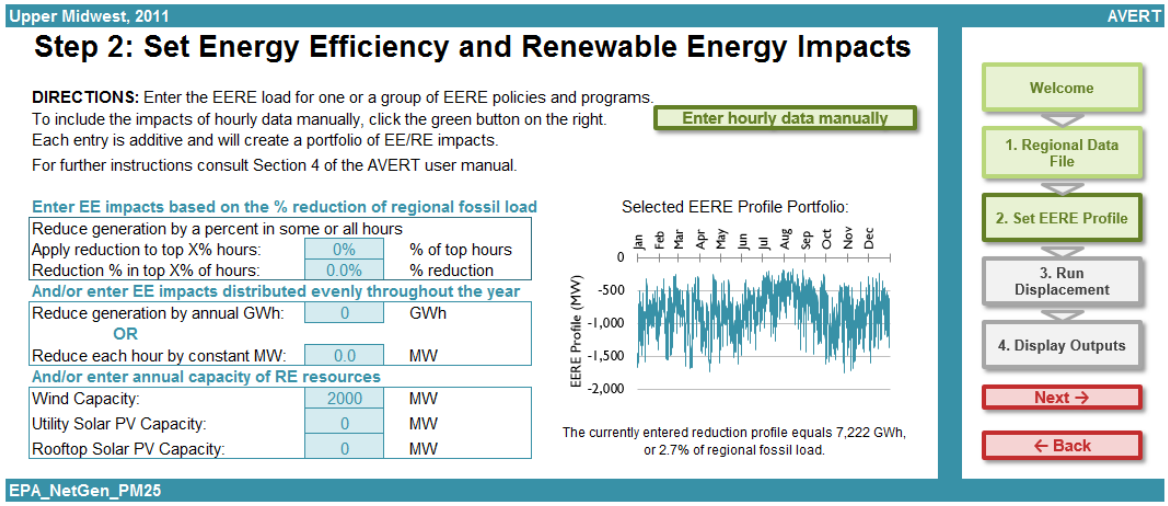
Step 2: Set Energy Efficiency and Renewable Energy Data

In this step, you will create a load impact profile (schedule of changes to electricity demand for every hour of a year) depicting the load reductions expected from an EE/RE program as shown in Figure 12. In this example, the user has input a 2,000 MW wind program, the displacement profile of which is being displayed in the chart in the bottom right hand corner

[39] This division in Illinois is primarily a function eastern part of the state falling under the PJM RTO, while the rest of the state falls into MISO.

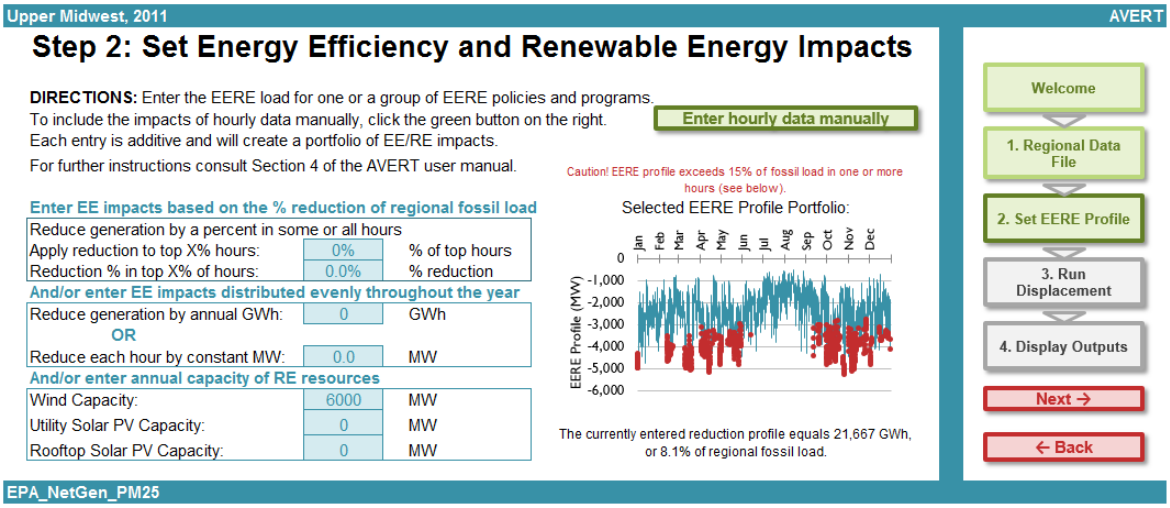
[40] Prior to summer of 2017, EPA used "EPABase" model runs to produce Regional Data Files. To recognize methodological changes, including the addition of $PM_{2.5}$ data and adjustment from gross to net generation values, EPA's default model runs are now named "EPA_NetGen_PM25."

Figure 12. Image of AVERT Main Module "Step 2: Set EE/RE Impacts" page



If you enter an EE/RE program that exceeds 15% of regional fossil load in any given hour, you will be shown an alert highlighting the hours of exceedance (Figure 13), but you can still proceed with the calculations.

Figure 13. Image of AVERT Main Module "Step 2: Set EE/RE Impacts" page with program size resulting in a more than 15% reduction in fossil load in some hours.



Since the release of AVERT's Main Module version 1.5, AVERT adjusts the EE/RE profile to account for avoided transmission and distribution line losses associated with certain EE/RE resources: specifically, EE and distributed PV systems.[41] This adjustment has the effect of increasing displaced fossil load and displaced emissions, which provides more accurate results. Without this adjustment, AVERT would underestimate emissions.

[41] AVERT treats wind and utility-scale PV as centralized resources that still require transmission and distribution to end-users; thus, while they displace fossil generation, a simplified assumption is that they do not avoid any line loss.

The Step 2 page allows you to estimate a load reduction from basic characteristics:

- Enter hourly data manually (see green button in right-hand corner)
- Reduce fossil-fuel generation by a percent in some or all hours
- Reduce fossil-fuel generation by total GWh (flat)
- Reduce each hour by a constant MW each hour
- Renewable energy proxy
- Combination of EE/RE programs including combining pre-set options with manual entry

Choose the option(s) that works best for your EE/RE resource and fill in the necessary data. Each option is described in more detail below. If you choose more than one option (including manual entry), the selected options will be combined into a portfolio of programs. For any program, or combination or programs, the Step 2 page returns a total annual energy reduction (in GWh) achieved by the EE/RE program(s). Total *hourly* reductions can be found in the manual input page.

Note that it is not recommended for EE/RE profiles to exceed 15 percent of fossil load in any given hour. If a user-entered EE/RE profile exceeds these recommended limits, a caution message will appear. The graph in the “Set EE/RE” section will also indicate the affected hours. Exceeding the 15 percent threshold does not prohibit the user from proceeding with the calculations.

Manual User Input

If the hourly load reductions expected from a particular EE/RE policy, program, or measure are known, a manual stream of load reduction values can be entered for every hour of the year (consisting of 8,760 hourly values for a non-leap year or 8,784 hourly values for a leap year). For example, you might use this approach to test the measured or modeled impacts of a particular known wind farm or EE program. To enter data manually or cut and paste data from another source, click on the green button that reads “Enter hourly data manually.” Data are entered as a single column of values from midnight on January 1 through 11 p.m. on December 31.

The last column on the manual input page shows the total aggregate hourly reduction from the programs input or selected by the user.

Reduce Generation by a Percent in Some or All Hours

To estimate the impacts of a broad-based energy efficiency or demand response program targeting high-cost peak fossil-consumption hours, enter two values: a) the fraction of hours to which load reduction is applied (with reductions applied to the highest fossil-fuel generation hours first) and b) the percent by which those hours should be reduced. For a broad-based efficiency program, the fraction of hours that experience reductions is very high; for a demand response program, it is very low.

Note that, when the percentage options are used, reductions are a share of *fossil-fuel generation* and not total system load (i.e., consumption). Therefore, using a 2 percent reduction per hour effectively reduces load by 2 percent of fossil-fired generation.

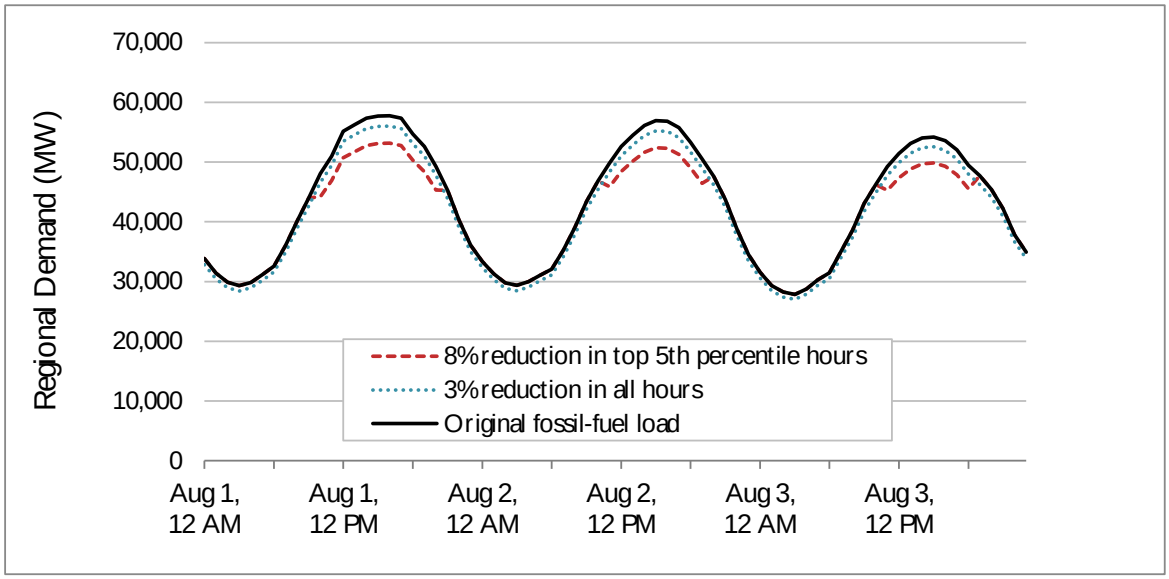
To simulate a broad-based efficiency program, enter 100 percent as the “% of top hours” and an estimated load reduction fraction in the cell labeled “% reduction.” A graph of the selected EE/RE

profile—which combines both manual entries and user selections made on the Step 2 page—is shown on this page.

To simulate a peak-reduction targeting program such as demand response, enter a fraction of high-demand hours that the program is expected to affect, and the load reduction (as a fraction of peaking load) that would be targeted in those hours. This type of scenario is recommended for programs that emphasize reductions in peak hours. Generally, reductions exceeding 20 percent of fossil-fired generation are not recommended.[42]

Figure 14 shows a baseline load impact profile (in black) and two example load reductions for three days in August. The blue, dotted line represents a 3 percent reduction in fossil-fired generation requirements in every hour of the year. The red, dashed line represents an 8 percent reduction in the 5 percent of hours with the highest demand for fossil-fired generation.

Figure 14. Examples of two load reduction programs as a percentage of some or all hours.



It is important to note that reducing load by a percent in some or all hours measures a reduction relative to hourly *fossil-fuel* load, and not system demand (i.e., consumption). It is important to ensure that the total reduction (in annual GWh) or peak reduction (in MW) comports with expectations of a reasonable fractional reduction. For example, if fossil-fuel load only accounts for 50 percent of regional generation, a user attempting to find the emissions impact of a *regional* load reduction of 3 percent should double the size of the reduction specified in AVERT's Main Module (i.e., to 6 percent) to scale from total fossil-fuel load to regional load. Similarly, to estimate the effect of a portfolio reduction (i.e., a percentage change) where you have an expectation of the total

[42] AVERT is designed to review marginal changes in a system, not large-scale changes. At some point, significant changes in load will result in non-marginal changes, such as the decommitment of units.

annual reduction (in MWh or GWh), find the correct percentage reduction such that the total amount of energy reduced is equal to the expected quantity.[43]

Reduce Generation by Annual GWh

You may have an estimate of the total amount of energy that is targeted or required to be reduced by a program in a given year, but lack information about the distribution of those reductions over the course of the year. "Reduce generation by annual GWh" simply distributes those savings evenly over all hours of the year. The user inputs a total number of GWh expected to be saved in a single year. This may be a highly erroneous assumption if savings are targeted from residential or commercial customers, for whom energy efficiency measures tend to target peak use reductions. However, an industrial or refrigeration efficiency program may be well represented by a constant reduction across most hours of the year. Use this option with close attention to the types of programs assumed in your analysis.

Reduce Each Hour by Constant MW

This option is identical in effect to the annual load reduction by total GWh above. The user selects a constant reduction for every hour of the year in MW.

Renewable Energy Proxy

This option allows you to use previously designed load impact profiles for region-specific wind, utility-scale solar PV, and rooftop-scale solar PV. Select the annual capacity (maximum potential electricity generation) for each type of resource, measured in MW. The model applies these values to "hourly capacity factors" that vary by resource type and region. Hourly capacity factors are the probability that a resource is generating at its full capacity in a given hour of the year. For example, solar panels might have a 90 percent or higher capacity factor on an August afternoon, but a 0 percent capacity factor at midnight any day of the year. Note that these are proxy load impact profiles for a year based on data from 2011– 2013 hourly wind speed datasets gathered from a variety of model locations across each AVERT region. These data do not represent actual or proposed projects. The data and methodology used to develop these capacity factors are described in Appendix C.

After the EE/RE load impact profile has been designed, click "Next" to move on to the next step.

Step 3: Run Displacement

Step 3 launches the automatic calculation of hourly displaced generation, heat input, and emissions for each EGU in the region as shown in Figure 15.

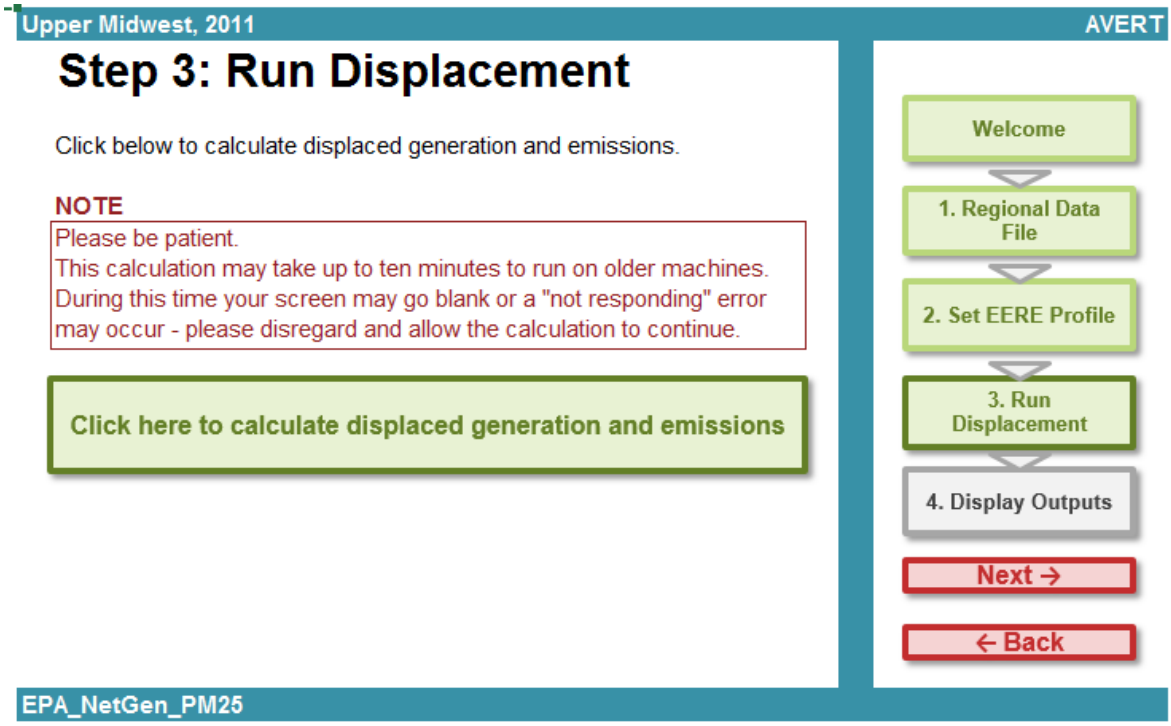
---

[43] For a program expected to accomplish an annual target reduction through a portfolio efficiency program, the user should find the percent reduction that will accomplish this target. For example, using Texas data from 2012, a portfolio EE program expected to reach 10,000 GWh of annual reduction (E_{req}) would require a fractional reduction of 3.79 percent in all hours of the year (F_{req}). To find this percentage value (F_{req}), the user can choose an arbitrary estimated fraction (e.g., 2 percent, F_{est}), and review the text below the graphic on the Step 2 page indicating the GWh reduction (E_{est}). Divide the required annual reduction (E_{req}) by the achieved estimated reduction (E_{est}), then multiply this value by the estimated fraction (F_{est}). The resulting value is the percentage that should be entered into the "% reduction" box to achieve the desired energy reduction. Check to ensure that the new total energy reduction value (in the text below the graphic) is consistent with the desired results.

Click on the box labeled “Click here to calculate displaced generation and emissions.” Because of the large amount of data being processed, this calculation may take several minutes to complete depending on the size of the region and the processing speed of the computer. A status bar in the lower left corner indicates the share of processing completed.

A pop-up box that reads “Calculation complete” will appear once the calculations are complete. Click “Next” to move on to the final step.

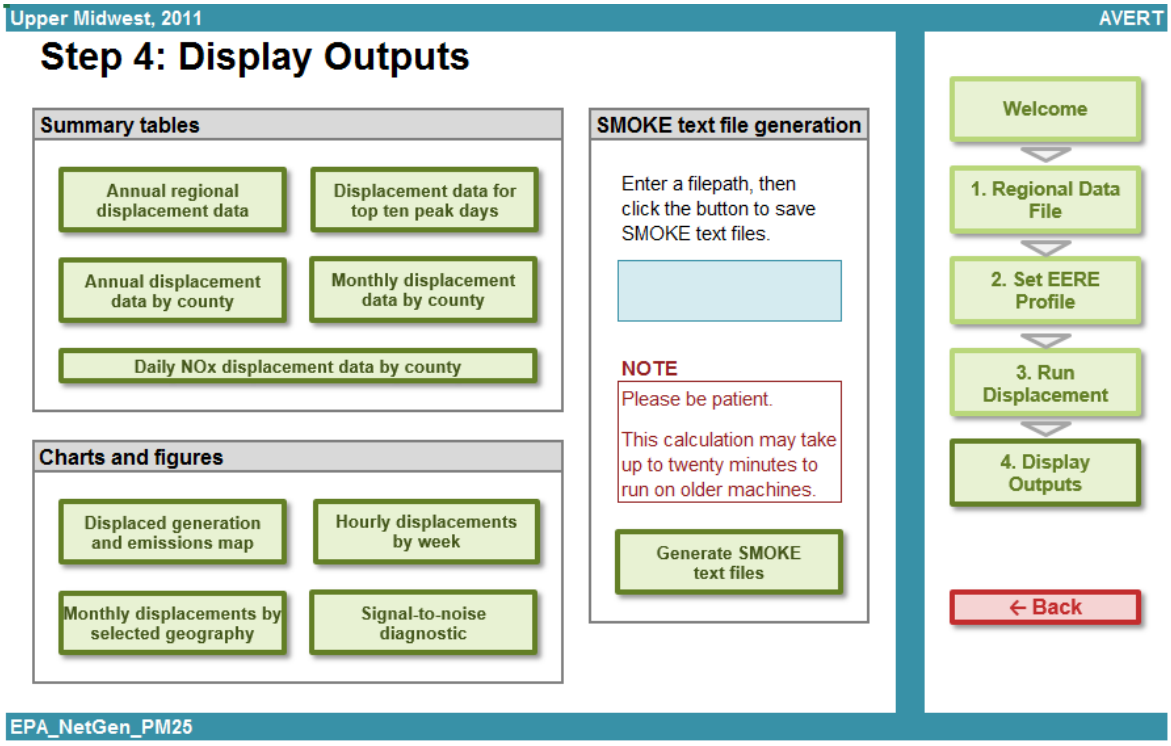
Figure 15. Image of AVERT Main Module “Step 3: Run Displacement” page.



Step 4: Display Outputs

Step 3 of AVERT's Main Module generates raw data in the form of hourly estimated reductions in generation, heat input, and emissions of $PM_{2.5}$, SO_2, NO_x, and CO_2 for each EGU in the region. These data are aggregated in charts and tables, which are then accessed through the "Step 4: Display Outputs" page, as shown in Figure 16.

Figure 16. Image of AVERT Main Module "Step 4: Display Outputs" page.



To display outputs, click on each of the green boxes under the headings: summary tables, charts and figures, advanced outputs, and SMOKE text file generation. The sample tables and figures shown below use the same example of a 2,000 MW wind installation in the Upper Midwest AVERT region.

Summary Tables

Annual displacement summary

Figure 17 shows a high-level summary of the results of the analysis. This table displays the total annual generation and emissions from the region's fossil generation fleet as reported in the base year ("Original") and as calculated by AVERT's Main Module after the EE/RE reduction ("Post-EERE"). The difference between these two scenarios is the total annual expected reduction from the user-specified EE/RE program. The chart also calculates total annual average fossil-fuel emissions rates for $PM_{2.5}$, SO_2, NO_x, and CO_2 before and after the EE/RE program.

All numerical results are shown rounded to the nearest 10 unit.[44] Dashes ("–") indicate that AVERT reported a value greater than zero, but lower than the level of reportable significance. True zeros are reported as zero (0) values. Increasing an EE/RE program size will increase the amount of output above the reportable significance level (i.e., reduce the number of dashes in the output datasets).

Figure 17. Image of annual displacement summary table for an example wind program in the Upper Midwest region.

Upper Midwest, 2011 AVERT

Output: Annual Regional Displacements

Click here to return to Step 4: Display Outputs

	Original	Post-EERE	Impacts
Generation (MWh)	267,436,050	260,240,200	-7,195,850
Total Emissions from Fossil Generation Fleet			
SO_2 (lbs)	1,301,793,140	1,268,694,580	-33,098,570
NO_x (lbs)	540,761,980	527,072,950	-13,689,030
CO_2 (tons)	300,935,610	293,707,130	-7,228,480
$PM_{2.5}$ (lbs)	43,319,100	42,280,340	-1,038,760
Fossil Generation Fleet Emission Rates			
SO_2 (lbs/MWh)	4.868	4.875	
NO_x (lbs/MWh)	2.022	2.025	
CO_2 (tons/MWh)	1.125	1.129	
$PM_{2.5}$ (lbs/MWh)	0.162	0.162	

Negative numbers indicate displaced generation and emissions.

All results are rounded to the nearest ten. A dash ("—") indicates a result greater than zero, but lower than the level of reportable significance.

Annual displacement data by county

Figure 18 shows a summary of the displaced generation and emissions for each of the counties from each of the states in the region. The Upper Midwest region, for example, contains EGUs in Illinois, Iowa, Michigan, Minnesota, Missouri, Montana, Nebraska, North Dakota, South Dakota, and Wisconsin. A line for each county containing an EGU is displayed.

For each county, the following annual output statistics are given:

[44] Data are reported by AMPD in integer units of MWh (generation), lbs (NO_x and SO_2), tons (CO_2), and MMBtu (heat input). Output data in AVERT are rounded to the closest 10 MWh, lbs $PM_{2.5}$, NO_x and SO_2, tons CO_2, and MMBtu fuel input.

- **Peak Net Generation Post-EE/RE (MW):** The peak (maximum) hourly generation produced by an EGU in the base- or future year scenario after EE/RE programs have been applied.[45]
- **Annual Net Generation Post-EE/RE (MWh):** The total annual generation of an EGU in the base- or future year scenario after EE/RE programs have been applied.
- **Capacity Factor (Calculated Post-EE/RE):** The capacity factor of an EGU in the base- or future year scenario after EE/RE programs have been applied. The capacity factor is the annual generation divided by the product of 8,760 and the peak generation level.
- **Annual Change in Generation (MWh):** The EGU's estimated change in generation from baseline conditions to post-EE/RE conditions over a full year (i.e., the annual displaced generation of this unit).
- **Annual Change in Heat Input/$PM_{2.5}$/SO_2/NO_x/CO_2 (MMBtu, lbs, or tons):** The EGU's estimated change in heat input or emissions from baseline conditions to post-EE/RE conditions over a full year (i.e., the annual displaced heat input or emissions of this unit).
- **Ozone Season Change in SO_2/NO_x/$PM_{2.5}$ (lbs):** The EGU's estimated change in emissions from baseline conditions to post-EE/RE during the ozone season (May to September, inclusive).
- **Ozone Season, 10 Peak Days Change in SO_2/NO_x/$PM_{2.5}$ (lbs):** The EGU's estimated change in emissions from baseline conditions to post-EE/RE during the 10 highest fossil generation days in the ozone season (May to September, inclusive).
- **Daily NO_x (lbs) Displacement Data by County:** Users can select from one to 10 days of a given year to display the pounds of NO_x for each day. The tool automatically calculates the daily total for dates of interest and the average across those dates in every county within one AVERT region.

All results (except for peak generation) are shown rounded to the nearest 10. Dashes ("—") indicate results greater than zero, but lower than the level of reportable significance.

[45] Note that, as of summer 2017, generation is counted on a "net" basis. Generation at the level of the boiler, prior to parasitic use by the plant or generator, is corrected to "net" generation exported to the grid using technology-specific loss factors. Parasitic use may include use for fans, pumps, and heating and cooling, and emissions control equipment. AVERT uses different parasitic loss factors for natural gas-fired combined cycle units, combustion turbines, and coal-fired steam units with and without controls for sulfur emissions.

Figure 18. Annual displacement data by county for an example wind program in the Upper Midwest region.

Upper Midwest, 2011

Output: Annual Displacement Data by County

Click here to return to Step 4: Display Outputs

State	County	Peak Gross Generation, Post-EERE (MW)	Annual Gross Generation, Post-EERE (MWh)	Annual Displaced Generation (MWh)	Annual Displaced SO_2 (lbs)	Annual Displaced NO_x (lbs)	Annual Displaced CO_2 (tons)
IA	Allamakee	222	1,292,900	-60,810	-461,920	20,200	-70,380
IA	Appanoose	6	2,080	-310	-390	-3,600	-400
IA	Audubon	53	10,560	-1,510	–	-2,510	-850
IA	Black Hawk	128	52,230	-7,440	-25,070	-47,710	-9,840
IA	Cerro Gordo	484	413,000	-60,350	-260	-9,500	-26,900
IA	Clay	56	23,300	-1,660	-13,330	-7,390	-1,460
IA	Clinton	200	890,070	-34,220	-258,580	-36,830	-37,950
IA	Des Moines	193	1,157,200	-30,720	-223,460	-35,030	-38,500
IA	Dubuque	57	109,800	-11,110	-117,260	-109,760	-17,230
IA	Louisa	713	4,178,900	-13,870	-68,670	-88,050	-14,690
IA	Marshall	46	14,570	-1,590	-1,370	-10,390	-1,600
IA	Muscatine	252	1,082,980	-69,580	-844,970	-248,620	-91,790
IA	Polk	487	194,130	-27,290	-2,820	-42,330	-16,650
IA	Pottawattamie	1,567	11,559,290	-198,780	-421,570	-345,050	-202,000
IA	Scott	105	770,450	-17,570	-131,640	-30,370	-18,010
IA	Story	88	326,080	-5,440	-23,470	-24,430	-7,110
IA	Union	29	11,980	-1,810	–	-10,700	-1,720
IA	Wapello	637	3,229,680	-144,690	-1,095,560	-216,570	-197,500
IA	Woodbury	1,468	9,421,680	-310,380	-1,790,420	-1,025,230	-329,520

Displacement data for top 10 load days

Figure 19 shows a summary of the 10 days in the region featuring the highest level of fossil fuel load. Separate columns show the total fossil generation in each day, the expected displaced generation, the simulated displaced generation, and displaced emissions. All results are shown rounded to the nearest 10. Dashes ("—") indicate results greater than zero, but lower than the level of reportable significance.

Figure 19. Displacement data for top 10 load days for an example wind program in the Upper Midwest.

Upper Midwest, 2011 AVERT

Output: Displacement Data for Top Ten Peak Days

Click here to return to Step 4: Display Outputs

Day Rank	Date	Total Fossil Generation (MWh)	Expected Displaced Generation (MWh)	Displaced Generation (MWh)	Displaced NO_x (lbs)	Displaced SO_2 (lbs)	Displaced CO_2 (Tons)	Displaced $PM_{2.5}$ (lbs)
1	Jul 18	1,048,930	-13,490	-13,860	-39,530	-17,890	-8,730	-1,770
2	Jul 19	1,039,940	-17,190	-17,270	-61,370	-25,000	-13,150	-2,440
3	Jul 21	1,024,750	-15,770	-15,820	-58,630	-23,210	-13,000	-2,350
4	Jul 20	1,018,680	-16,810	-16,810	-57,920	-22,360	-13,410	-2,590
5	Jul 22	1,003,160	-12,930	-13,030	-44,900	-17,970	-10,620	-1,960
6	Aug 02	993,440	-12,690	-12,700	-46,380	-18,640	-10,370	-1,860
7	Aug 01	988,190	-12,610	-12,650	-46,790	-19,670	-10,530	-1,880
8	Aug 03	983,760	-12,070	-12,110	-34,960	-14,660	-9,550	-1,830
9	Jul 28	979,210	-10,310	-10,290	-36,970	-15,170	-8,330	-1,440
10	Jul 29	975,520	-8,010	-8,130	-25,300	-10,340	-6,580	-1,210

Negative numbers indicate displaced generation and emissions.
All results are rounded to the nearest ten. A dash ("—") indicates a result greater than zero, but lower than the level of reportable significance.

Monthly displacement data by county

Figure 20 shows a summary of the displaced generation and emissions for each of the counties from each of the states contained within the region, broken out by month and with an annual total. All results (except for peak generation) are shown rounded to the nearest 10. Dashes ("–") indicate results greater than zero, but lower than the level of reportable significance.

Figure 20. Monthly displacement data by county for an example wind program in the Upper Midwest region.

Upper Midwest, 2011 AVERT

Output: Monthly Displacement Data by County

Click here to return to Step 4: Display Outputs

Negative numbers indicate displaced generation and emissions. All results are rounded to the nearest ten. A dash ("—") indicates a result greater than zero, but lower than the level of reportable significance.

State	County	Month	Displaced Generation (MWh)	Displaced SO_2 (lbs)	Displaced NO_x (lbs)	Displaced CO_2 (Tons)	Displaced $PM_{2.5}$ (lbs)
IA	Allamakee	3	-6,990	-53,440	4,080	-8,120	-2,350
IA	Allamakee	4	-7,640	-57,470	6,140	-8,660	-2,490
IA	Allamakee	5	-6,030	-44,440	-1,270	-6,840	-1,970
IA	Allamakee	6	-3,290	-24,500	-80	-3,780	-1,090
IA	Allamakee	7	-1,830	-13,710	-530	-2,130	-610
IA	Allamakee	8	-2,050	-15,390	-430	-2,380	-690
IA	Allamakee	9	-4,970	-37,160	-2,130	-5,740	-1,650
IA	Allamakee	10	-6,880	-52,320	3,830	-7,890	-2,280
IA	Allamakee	11	-6,400	-48,680	3,010	-7,410	-2,130
IA	Allamakee	12	-5,230	-39,850	2,760	-6,070	-1,750
IA	Allamakee	Annual	-60,810	-461,920	20,200	-70,380	-20,280
IA	Appanoose	1	-20	-10	-80	-10	–
IA	Appanoose	2	-20	-10	-40	-10	–
IA	Appanoose	3	-40	-30	-310	-30	-10
IA	Appanoose	4	-10	-10	-110	-10	–
IA	Appanoose	5	-10	-20	-170	-20	–
IA	Appanoose	6	-10	-30	-230	-30	-10
IA	Appanoose	7	-70	-130	-1,230	-130	-30
IA	Appanoose	8	-20	-50	-430	-50	-10
IA	Appanoose	9	-30	-40	-380	-40	-10
IA	Appanoose	10	-30	-40	-340	-40	-10
IA	Appanoose	11	-20	-20	-180	-20	–
IA	Appanoose	12	-10	-10	-100	-10	–
IA	Appanoose	Annual	-310	-390	-3,600	-400	-80
IA	Audubon	1	-80	–	-50	-30	–
IA	Audubon	2	-10	–	10	–	–

Daily NO_x displacement data by county

Figure 21 shows a summary of displaced NO_x emissions in the counties of each state contained within the region, broken out by day and with a daily average. Users enter up to 10 days for the analysis year in (MM/DD) format. All results are shown rounded to the nearest 10. Dashes ("–") indicate results greater than zero, but lower than the level of reportable significance.

Figure 21. Daily NO_x displacement data by county in Upper Midwest region.

Upper Midwest, 2011 AVERT

Output: Daily NOx Displacements (lbs)

Click here to return to Step 4: Display Outputs

Negative numbers indicate displaced generation and emissions. All results are rounded to the nearest ten. A dash ("—") indicates a result greater than zero, but lower than the level of reportable significance.

Enter up to ten dates in the header column. This page will calculate the NOx displacement associated with each day in each county, as well as the average for each county. Use the filters to select individual states or counties.

		Enter dates of interest (MM/DD)										
State	County	8-Aug	7-Jul	6-Jun	5-May	8-Sep	8-Jul	6-Sep	5-Jun	19-Aug	20-Aug	Average
IA	Allamakee	46	-5	-4	-86	-77	-9	-58	50	-6	-123	-27
IA	Appanoose	-29	-5	-13	-7	-1	-16	12	-5	-4	8	-6
IA	Audubon	-31	-22	-25	-3	-2	-16	-3	-5	-23	-2	-13
IA	Black Hawk	-311	-227	-303	-52	-54	-214	-99	-81	-243	-81	-166
IA	Cerro Gordo	-7	-4	-7	-17	-11	1	-11	-22	-2	-20	-10
IA	Clay	-44	-57	-41	-81	-40	8	-11	25	-51	5	-29
IA	Clinton	13	-38	-68	-73	75	-100	-41	-95	-28	-158	-51
IA	Des Moines	6	80	23	115	1	30	-18	-35	-9	6	20
IA	Dubuque	-121	-90	-102	-249	-163	-106	-204	-367	-130	-115	-165
IA	Louisa	-111	-418	-640	160	-587	23	-249	-222	-560	-570	-317
IA	Marshall	-81	-63	-67	-50	5	-49	-23	21	-57	-20	-38
IA	Muscatine	-298	-162	-253	-487	-307	-259	-233	-441	-216	-423	-308
IA	Polk	-288	-213	-299	-141	8	-203	2	-26	-209	-54	-142
IA	Pottawattamie	-161	-51	-282	-861	-470	-339	-20	-800	-207	-591	-378
IA	Scott	-51	-60	-38	-288	52	-28	-65	-53	-70	-66	-67
IA	Story	-146	-121	-117	-140	-24	-93	-64	-6	-143	-40	-89
IA	Union	-91	-53	-84	2	-9	-57	-7	-5	-50	1	-35
IA	Wapello	-197	-289	-431	-441	-512	-315	-389	-741	-307	-124	-374
IA	Woodbury	-564	-752	-1,115	-2,248	-2,683	-548	-2,359	-1,775	-720	-639	-1,340
IL	Clay	-22	-14	-16	0	-3	-11	-1	-4	-17	-2	-10
IL	Crawford	-198	-151	-174	-509	-131	-113	-181	-276	-189	-211	-213
IL	Fayette	-9	-5	-6	0	0	-4	0	0	-6	0	-3
IL	Ford	-9	-4	-6	4	-6	-6	-1	4	-4	-3	-3

Charts and Figures

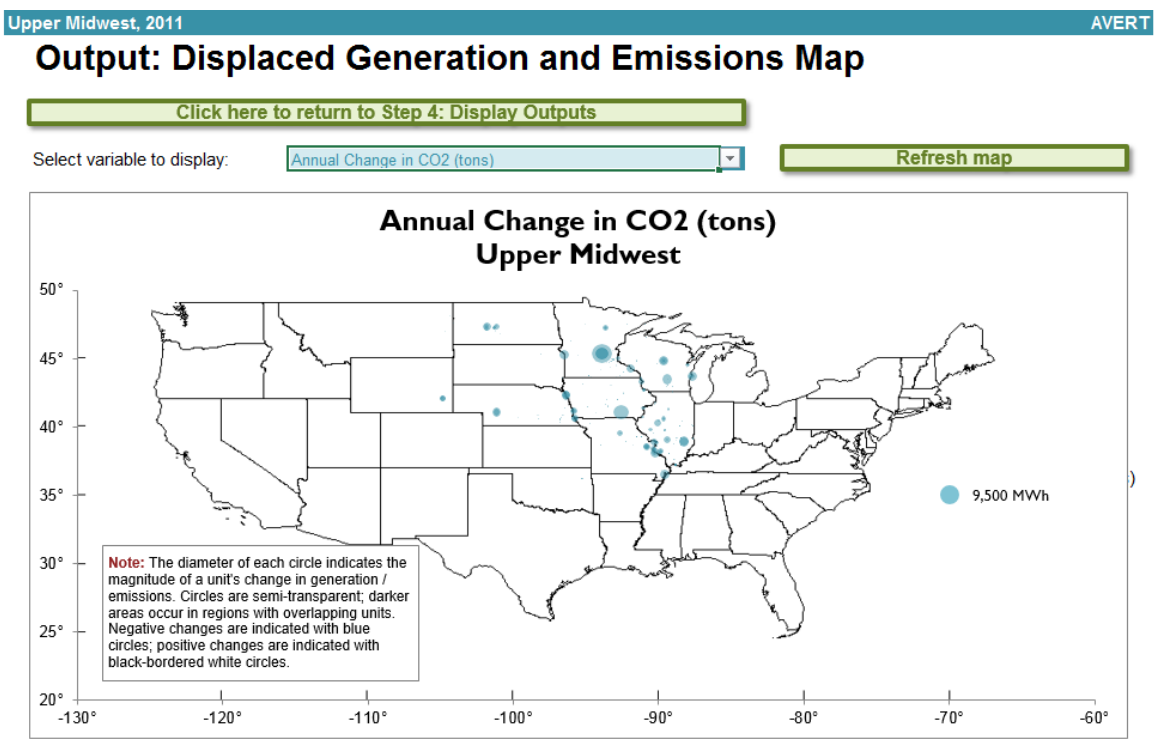
Displaced generation and emissions map

This dynamic map (shown in Figure 22) shows where emissions have been displaced within the selected region. You can choose from the following options in a dropdown menu:

- Annual Change in Generation (MWh)
- Annual Change in Heat Input (MMBtu)
- Annual Change in SO_2 (lbs)
- Annual Change in NO_x (lbs)
- Annual Change in $PM_{2.5}$ (lbs)
- Annual Change in CO_2 (tons)
- Ozone Season Change in SO_2 (lbs)
- Ozone Season Change in NO_x (lbs)
- Ozone Season Change in $PM_{2.5}$ (lbs)
- Ozone Season, 10 Peak Days Change in SO_2 (lbs)
- Ozone Season, 10 Peak Days Change in NO_x (lbs)
- Ozone Season, 10 Peak Days Change in $PM_{2.5}$ (lbs)

Click on "Refresh map with selected variable" after making a selection. The map displays the annual, seasonal, or peak displaced emissions at specific sources in the region. The size of the circles indicates the relative displacement of each resource. Circles are semi-transparent. If multiple sources are near the same location, the circle is darker. Occasional negative values (i.e., an emissions increase) are shown with black outlines and white interiors; these are often the result of the timing of maintenance outages in the base-year data (see Appendix G for details).

Figure 22. Displacement generation and emissions map for an example wind program in the Upper Midwest region.



The diameter of each circle indicates the magnitude of an EGU's change in emissions. Circles are semi-transparent; darker areas occur in regions with overlapping EGUs. Emissions reductions are indicated with blue circles; increases in emissions are indicated with black-bordered white circles.

Displacement data by month

Monthly output can be viewed over the entire region, or a specific state or county within the region (see examples in Figure 23 and Figure 24). First select "Region," "State," or "County" in the top dropdown menu. If selecting a state, choose the state in the next dropdown menu. If selecting a county, choose both the state and the county in the next two dropdown menus.

Figure 23. Displacement data by month chart for an example wind program in the Upper Midwest region.

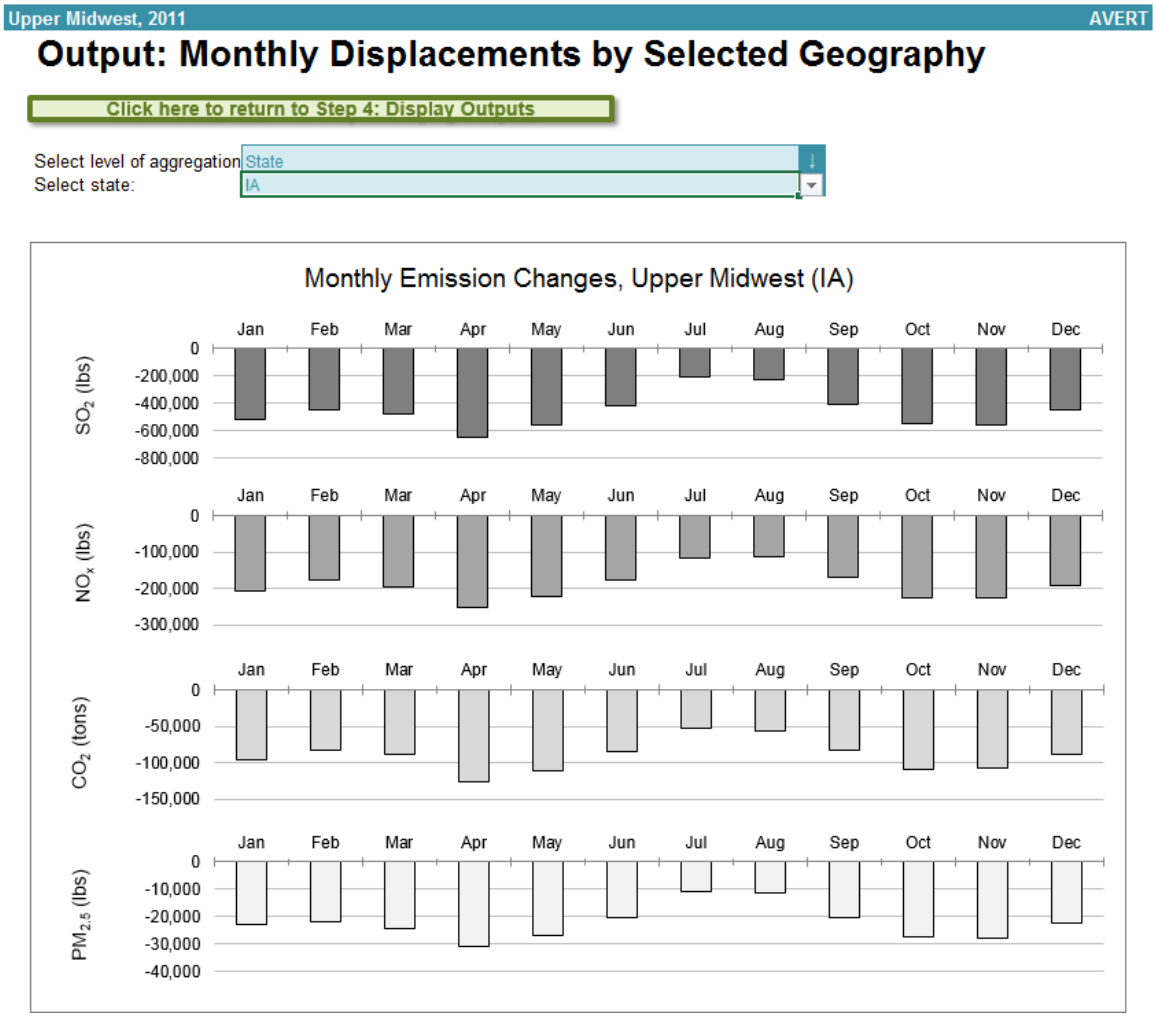


Figure 24. Displacement data by month table for an example wind program in the Upper Midwest region.

Monthly Emission Changes, Upper Midwest (IA)

	Gen (MWh)	SO_2 (lbs)	NO_x (lbs)	CO_2 (tons)	$PM_{2.5}$ (lbs)
Jan	-90,940	-514,390	-208,440	-96,620	-23,080
Feb	-73,610	-450,810	-176,470	-82,480	-21,930
Mar	-79,370	-477,900	-195,080	-88,990	-24,280
Apr	-114,200	-650,670	-252,620	-126,120	-31,000
May	-100,980	-560,910	-221,810	-110,090	-26,860
Jun	-77,470	-420,200	-175,320	-84,010	-20,460
Jul	-53,240	-208,720	-116,120	-51,790	-10,910
Aug	-57,860	-227,730	-114,160	-56,390	-11,250
Sep	-76,440	-411,480	-170,550	-82,770	-20,420
Oct	-98,070	-547,520	-227,010	-108,790	-27,470
Nov	-97,290	-557,430	-226,030	-108,030	-27,790
Dec	-79,650	-453,030	-190,250	-88,030	-22,600
Total	*-999,000*	*-5,481,000*	*-2,274,000*	*-1,084,000*	*-268,000*

Negative numbers indicate displaced generation and emissions. All results are rounded to the nearest ten. A dash ("—") indicates a result greater than zero, but lower than the level of reportable significance.

Hourly displacements by week

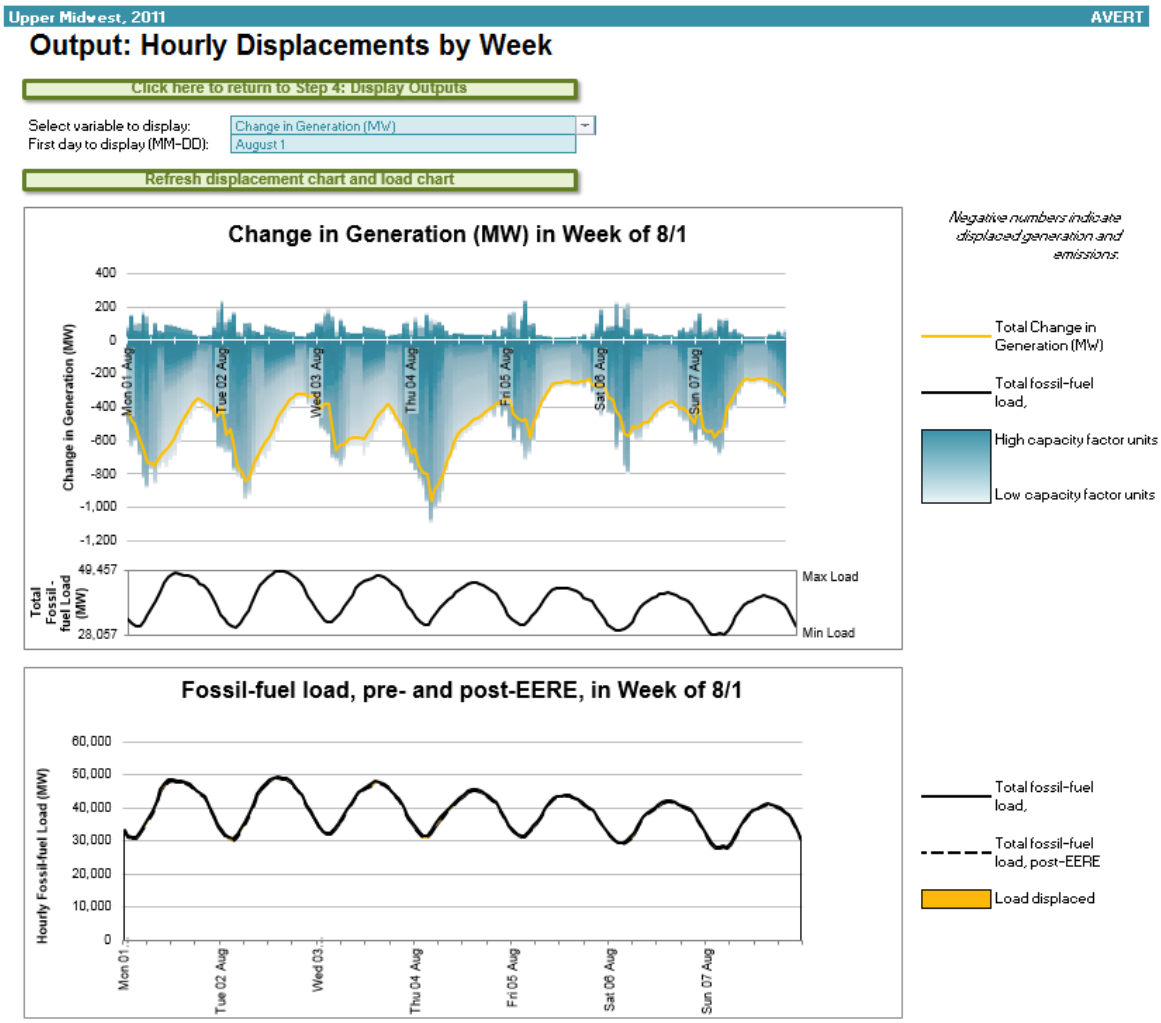
Figure 25 is a dynamic representation of hourly displacement from each EGU in a region. Individual plants are stacked as gradated bar plots, from high-capacity-factor "baseload" EGUs in dark blue to low capacity factor peaking EGUs in light blue.[46] The total contribution of all EGUs sums to the yellow line. As noted above, some EGUs can show a net increase in emissions as regional load is reduced, often due to the timing of maintenance outages in the base-year data.

The second chart in Figure 25 shows the same week-long load impact profile as above, but presents the displaced load in reference to the total fossil-fuel load. The purpose of this chart is to illustrate the degree of change represented by the EE/RE program relative to the baseline. The solid line represents the total fossil-fuel load by hour in the baseline; the dashed line represents the fossil-fuel load after the user-specified EE/RE reduction has been modeled. At the bottom of the graphic, the gray area graph represents the hourly EE/RE reduction as specified by the user.

Select which variable to review (changes in generation, heat input, or $PM_{2.5}$, SO_2, NO_x, or CO_2 emissions), and the first day of the analysis week. Once these variables are chosen, click on "Refresh displacement chart and load chart" to view the results.

[46] Gradations are on a relative scale. Within a region, the unit with the highest capacity factor sets the darkest gradation end (baseload), while the unit with the lowest capacity factor sets the lightest gradation end (peaking). Units are sequentially partitioned into color blocks. Given that most regions include several hundred units, this gradation will likely be similar in most regions with true baseload units at the darkest end, and true peaking units at the lightest end.

Figure 25. Hourly displacement data for an example wind program in the Upper Midwest region.

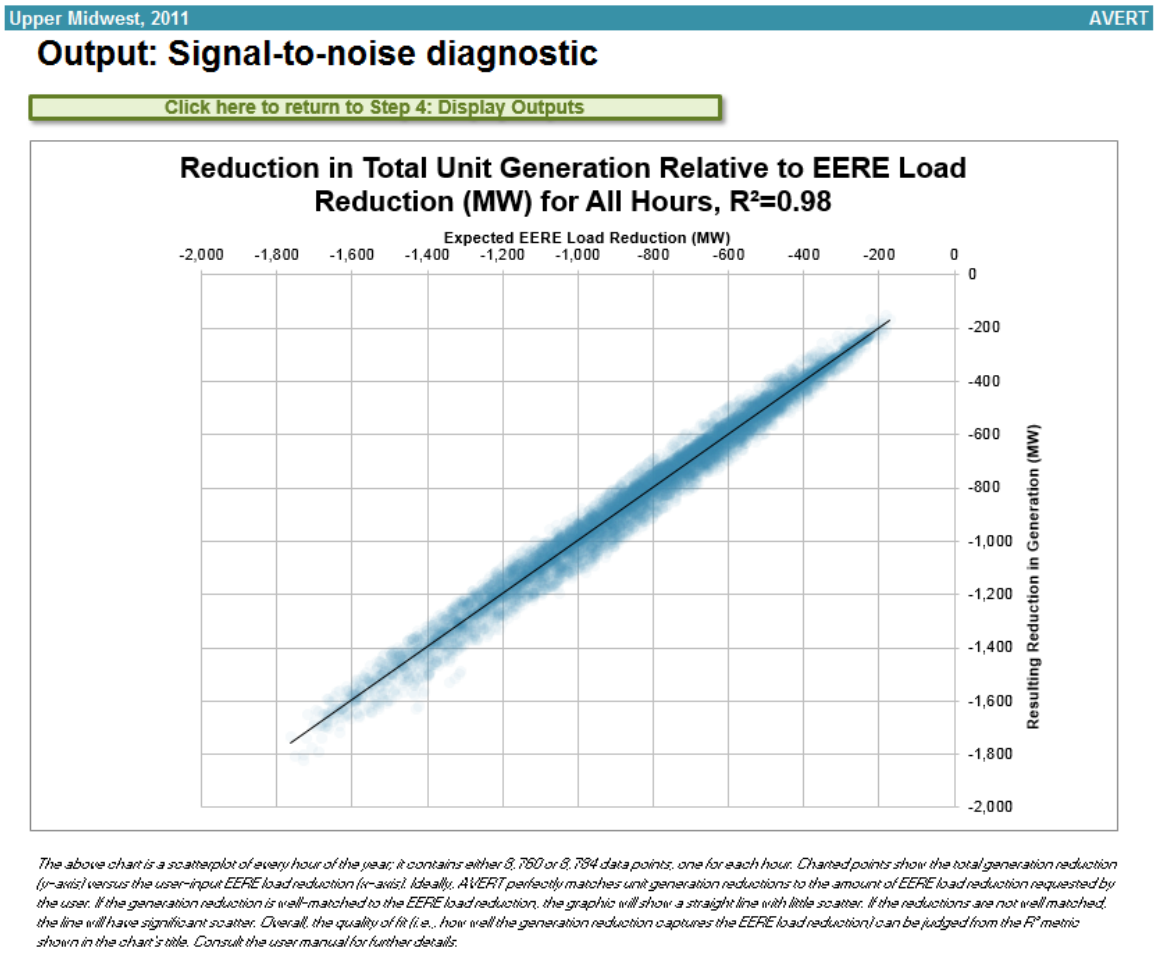


Signal-to-noise diagnostic

The signal-to-noise diagnostic shown in Figure 26 has a different structure from the time-series images shown previously. This chart is a scatterplot of every hour of the year (8,760 or, in a leap year, 8,784 points), showing calculated total generation reduction in each hour (y-axis) against user-input EE/RE load reduction in each hour (x-axis). Ideally, AVERT perfectly matches unit generation reductions to the amount of EE/RE load reduction requested by the user. This graphic shows where that assumption holds and where it does not hold, and to what extent. If the generation reduction is well-matched to the EE/RE load reduction, the graphic will show a straight line with little scatter. If the reductions are not well matched, the line will have significant scatter. Overall, the quality of fit (i.e., how well the generation reduction captures the EE/RE load reduction) can be judged from the R^2 metric shown in the chart title.[47] Highly scattered data points should be viewed with less weight than well-constrained data points.

[47] R^2 values indicate the quality of fit of a line, or how well dependent variables describe independent variables (i.e., how well the y-axis value describes the x-axis). Random points have an R^2 value of zero (0), while perfectly

Figure 26. Signal-to-noise diagnostic for an example wind program in the Upper Midwest region.



Note that flat load reductions (i.e., the same MW reduction in every hour of the year) will result in a very different pattern than shown here. In this unique circumstance, the expected EE/RE load reduction (the x-axis in this graphic) will be a single value, while there will be variance along the "resulting reduction in generation" (the y-axis in this graphic). In this case, the R^2 value will have limited value, but you can visually review the scatter in the plot to determine the reasonableness of the output.

SMOKE Text File

AVERT allows you to create files for use in SMOKE: enter a filepath in the bottom center of the "Step 4: Display Outputs" sheet, then press the "Generate SMOKE text files" button. Twenty-four text files are then generated in this filepath, two for each month. One of these files is for the selected region and year, pre-EE/RE displacement, while the second set of files details information post-displacement. For more detailed instructions on how to interpret and use SMOKE outputs

matched data have an R^2 value of 1. The R^2 value of 0.99 shown in this figure indicates that AVERT captures 99 percent of the EE/RE required by the user (i.e., noise accounts for 1 percent of the observed variability).

from AVERT, see the tutorial and step-by-step instruction slides available on EPA's website at https://www.epa.gov/statelocalenergy/avert-tutorial-using-avert-outputs-smoke-overview.

Advanced Outputs

AVERT does track the estimated output and emissions from specific EGUs, we recommend only using these outputs for SMOKE processing and/or quantitative validation purposes.

To access annual output on a unit-by-unit basis, restore default Excel functionality via the button on the Welcome page. Data are available for each EGU in the region of interest in the "Summary" worksheet. EGUs are identified by their ORISPL number,[48] unit number, and unit name, fuel type, state, county, and geographic location (latitude/longitude). Summary data are provided for each EGU in a similar format to the county data, as described previously.

In addition, detailed data are available in the worksheets labeled "Gen" (generation), "HeatInput," "SO_2," "NO_x," "CO_2," and "PM_{25}." These worksheets record displaced emissions and generation for each EGU in the region for each hour of the modeled year. Hours are arrayed vertically; EGUs are arrayed horizontally.

In contrast to the results shown in the summary tables, charts, and figures, which have been rounded to the nearest 10, results shown in the advanced outputs have not been rounded. Unrounded results should only be used after due consideration of their significance.

[48] The ORIS or ORISPL number is a code used by DOE and EPA to identify specific generating plants, where a "plant" is a site that may include multiple EGUs. Each ORIS number is unique and (usually) persistent. "Unit numbers" are assigned to generators and boilers by DOE and EPA, respectively, and are subject to change or modification by accounting agency or reporting entity.

Appendix A: Installation Instructions

AVERT is divided into three components: an Excel-based platform for user-specified analysis of displaced emissions (called the **Main Module**), a MATLAB®-based statistical analysis program (called the **Statistical Module**), and a second Excel-based spreadsheet for creating user-specified future year scenarios (called the **Future Year Scenario Template**). This section provides installation instructions for each AVERT module. More detailed information on AVERT components is provided in Section 2 of this manual, "Understanding AVERT."

Main Module

AVERT's Main Module estimates the displaced emissions likely to result from EE/RE programs in reference to a base-year or future year scenario.

System Requirements

The Main Module requires Excel 2007 or newer to run in Windows. The Main Module can also be used in Excel 2011 or newer for Mac; it has been verified to work up to Excel for Mac 2016 v15.31. Macros must be enabled. You do not need to install the Statistical Module and the Future Year Scenario Template to use the Main Module to estimate displaced emissions for EE/RE programs modeled in reference to a historical base year; however, you will need all three AVERT modules to model displaced emissions with reference to user-created future years.

The Main Module has no special requirements for hard drive space or RAM on the computer running it, but it will run faster on computers with more RAM and higher-speed processors. Excel files generated in the Main Module can exceed 100 MB in size, depending on the number of EGUs in the region of analysis. Analyzing data for large regions may take over 10 minutes on some computers.

Installation

To use the Main Module, download two files and save both to the same folder on a local computer or drive:

- The Main Module workbook: "AVERT Main Module.xlsx". Download the workbook at https://www.epa.gov/statelocalenergy/download-avert.
- The Regional Data File for the region under analysis.
    - Default Regional Data Files developed for use by EPA are labeled "AVERT RDF [DataYear] EPA_NetGen_PM25 ([Region]).xlsx"; they can be obtained at https://www.epa.gov/statelocalenergy/download-avert.
    - Regional analyses developed by advanced users using AVERT's Statistical Module will be saved, by default, in a folder of the Statistical Module titled "AVERT Output." These files use the following naming convention: "AVERT RDF [DataYear] [RunName] ([Region]) [RunDateTime].xlsx."

In the Regional Data File:

- "Region" refers to one of 10 regions defined for the purposes of this tool. AVERT's regions are described in Section 3 of this manual, under "AVERT Regions" (page 15). The

"BaselineYear" tag indicates the base year (the year upon which the analysis is based). Generally, for contemporary or forward-looking analyses, this should be the most recent full year of data available from CAMD's Air Markets Program, although data years 2007 through 2016 are currently available for input.

- "RunDateTime" indicates when the data file was generated by the Statistical Module.

Launching AVERT's Main Module

To launch the model, open the Main Module workbook in Excel and follow the step-by-step instructions in Section 4 of this manual.

Technical Assistance

For more information, please contact EPA's State and Local Energy and Environment Program at avert@epa.gov.

Statistical Module

AVERT's MATLAB®-based Statistical Module performs statistical analysis on AMPD to generate output files used to model displaced emissions in the Main Module. Running the Statistical Module is *not* required to operate the Main Module; it is anticipated that most AVERT users will not run it. Users creating specific future year scenarios, however, will need to run the Statistical Module.

For more information on AVERT's Statistical Module, see Appendix D.

System Requirements

The Statistical Module requires a machine capable of running Windows XP or higher.

It is recommended that computers operating the Statistical Module have at least 2 GB of memory available. Processing time for individual regions depends on the number of EGUs in the analysis and the number of processors available for use by the MATLAB® platform. In development of AVERT, it was found that for full-scale runs, larger regions could take over two hours to analyze with four processers dedicated to the operation.

The Statistical Module can perform analysis either with a pre-loaded base-year dataset from 2007 through 2016, or with a revised electricity generation fleet created in the Future Year Scenario Template, used in conjunction with a pre-loaded base-year dataset.

Installation and Launching

To use the Statistical Module, follow the instructions in Appendix E.

This output file can be used directly in the Main Module to analyze displaced emissions from EE/RE programs.

Technical Assistance

For more information, please contact EPA's State and Local Energy and Environment Program at avert@epa.gov.

Future Year Scenario Template

AVERT's Future Year Scenario Template allows the user to modify the list of EGUs analyzed by the Statistical Module. EGUs can be added or retired, or have their emissions rates modified. Newly added EGUs are copied from existing EGUs (proxy units), but can be scaled to a desired capacity, and given a location (county or latitude/longitude) in a different location.

System Requirements

The Future Year Scenario Template requires Excel 2007 or newer to run. It has been designed for Windows and has not been tested on a Mac, as the companion Statistical Module requires Windows. You do not need to install the Statistical Module to design scenarios within the Future Year Scenario Template, but you will need it to analyze those scenarios and estimate their future emissions in the Main Module.

The Future Year Scenario Template has no special requirements for hard drive space or RAM, but it will run faster on computers with more RAM and higher-speed processors. Scenarios saved by the Future Year Scenario Template are likely to be between 14 and 25 MB in size, depending on the number of EGUs being added in a new scenario.

Installation

The Future Year Scenario Template is packaged with the Statistical Module executable package. Instructions on obtaining this package can be found in Appendix E.

On downloading and unpacking the package, you will be presented with a folder entitled "AVERT Future Year Scenarios." This folder contains a number of example templates illustrating retirements, additions, and retrofits.

Launching and Working with the Future Year Scenario Template

To launch the Future Year Scenario Template, open the workbook in Excel and follow the step-by-step instructions in Appendix F.

Technical Assistance

For more information, please contact EPA's State and Local Energy and Environment Program at avert@epa.gov.

Appendix B: Data

AVERT uses Air Market Program Data (AMPD) from the EPA Clean Air Markets Division (CAMD).[49] This version of AVERT includes the data necessary to use 2007 through 2016 as the base year of analysis.[50]

For the purposes of tracking and verifying emissions, and monitoring emissions trading programs, AMPD collects extensive operational data from nearly all operating fossil-fuel EGUs with generating capacities greater than 25 MW in the lower 48 states (i.e., excluding Alaska and Hawaii).[51] Data collected in AMPD include reported gross generation (in megawatt hours per hour, or MWh/h),[52] steam output (in tons, from combined heat and power facilities), heat input (in million metric British thermal units, or MMBtu), and emissions of sulfur dioxide (SO_2), oxides of nitrogen (NO_X), and carbon dioxide (CO_2). Each quarter, CAMD consolidates information from the previous quarter (i.e., there is typically a three-month delay in releasing data) and produces text-based datasets for each of these factors for each fossil-fuel EGU in each state.[53]

A MATLAB®-based preprocessing engine converts these hourly text files into compact data arrays and a reference EGU records file.[54] The preprocessing engine calls an Excel-based spreadsheet populated with ancillary information about each EGU, with most information gathered from AMPD "facility information" records. The spreadsheet is populated with ancillary lookup information about each EGU that has reported to CAMD from 2005 to 2011, which allows the model to be backward-compatible with prior year data.

Gross generation is converted to net generation within the preprocessing engine using unit-specific parasitic loss factors. These factors were calculated based on a comparison of by-plant gross generation[55] and by-plant net generation[56] using 2015 data.[57] Different loss factors are used for coal-fired steam units with and without sulfur controls (8.3% and 6.9%, respectively); natural gas-fired combined cycle units (3.3%) and combustion turbines (2.2%); and natural gas- or oil-fired steam units (7.7%). For example, a sulfur-controlled coal steam unit with an annual gross generation of 100 GWh is assumed to export a total of 91.7 GWh to the grid, while a natural gas-fired conbined cycle unit with the same gross generation is assumed to export 96.7 GWh.

---

[49] https://ampd.epa.gov/ampd/.

[50] Future years will be released as data is made available from CAMD.

[51] For the purposes of AMPD collections, "units" are typically individual boilers, but sometimes represent either a single emissions source (i.e., smokestack) from several attached boilers or the consolidated output of a single generator with multiple boilers. AMPD unit designations are often, but not always, the same as U.S. Department of Energy unit designations.

[52] Gross generation is measured at the level of the boiler, prior to parasitic use by the plant or generator. Parasitic use may include use for fans, pumps, heating and cooling, and emissions control equipment. Therefore, generation seen by the grid may differ from the values in this database by 0 to 10 percent, depending on the unit. Emissions, however, are "at stack" and represent total emissions released to the atmosphere.

[53] AMPD collects data from most fossil-fired electrical generating stations over 25 MW in the lower 48 contiguous states (i.e., excludes Alaska, Hawaii, and territories). This data set generally does not include data from biomass generation or most small diesel backup generators.

[54] http://www.mathworks.com/products/matlab/.

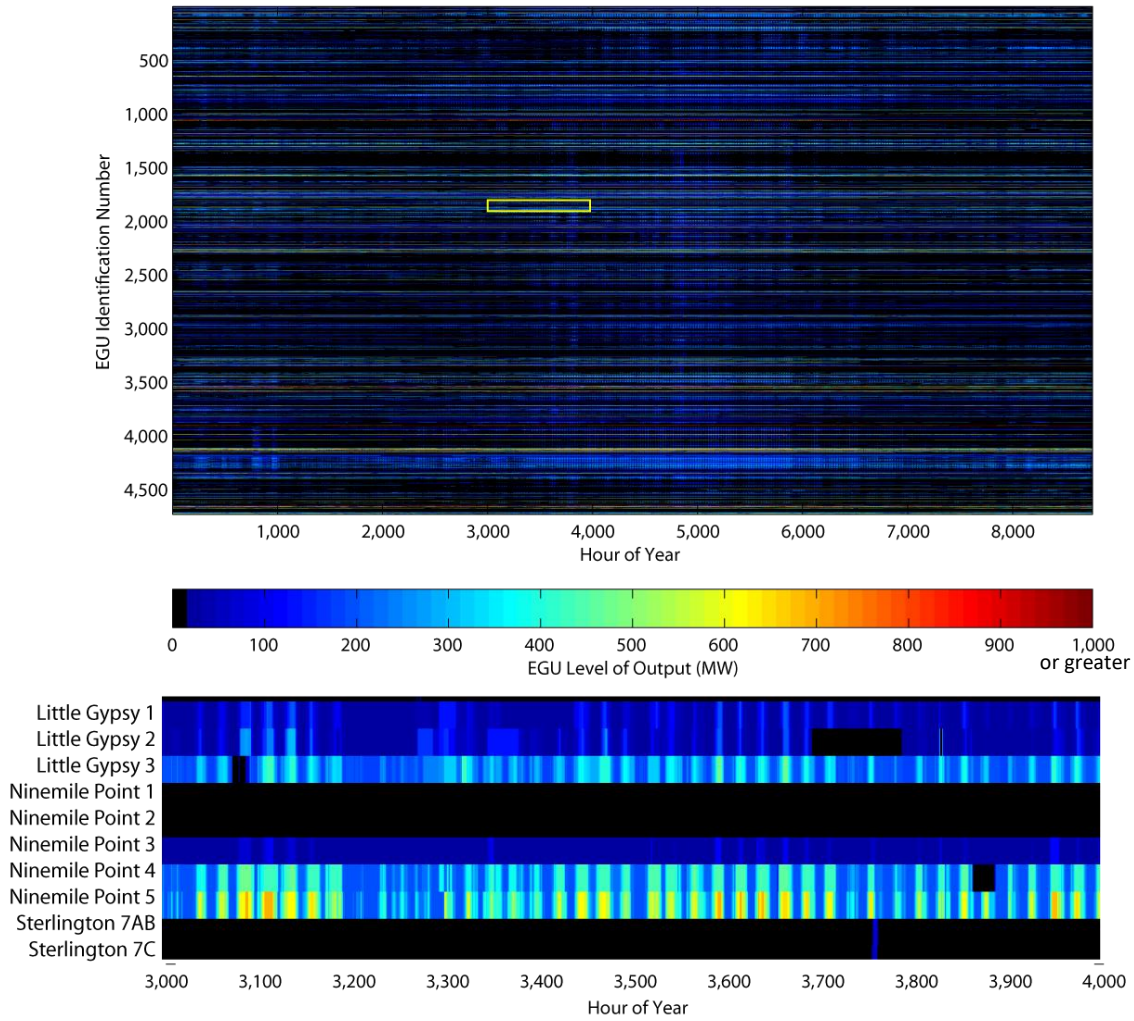
[55] As reported to AMPD.

[56] As reported to the U.S. Department of Energy's Energy Information Administration on Form 923 (https://www.eia.gov/electricity/data/eia923/).

[57] Empirical parasitic loss factors were found to be comparable to those published in the literature.

The six data arrays store two-dimensional matrices of net generation, steam output,[58] heat input, $PM_{2.5}$, SO_2, NO_x, and CO_2 organized by EGU and by hour of the year. Figure 27 shows an example two-dimensional data array for base-year hourly generation (8,760 or 8,784 hours across the horizontal axis) for each of the 4,734 fossil-fuel EGUs (down the vertical axis) for which AMPD collected emissions data in 2011. Black areas represent hours during which particular EGUs are not in operation (or are operating at very low levels, i.e., less than 10 MW). Figure 27 also includes detail from the data array that focuses in on 10 EGUs and hours 3,000 through 4,000 in the base year.

Figure 27. 2011 gross generation output (in MW) for each EGU in each hour of the year.



Colors represent the level of EGU generation.

The reference EGU records file (a structural array in MATLAB®) holds the name, ORISPL number (a value assigned to each plant site by the Department of Energy [DOE]), EPA unit ID, a lookup table (LUT) pointer to the two-dimensional matrices, locational information, and fuel information for each EGU. Table 2 shows an example record for the Handley Generation Station, Unit 5. The

[58] AVERT does not use steam output.

"Unique ID" shown in Table 2 is a unique identifier created within AVERT, consisting of the ORISPL number concatenated with the EPA unit identification number as a string.[59] In addition, each record stores a lookup value (not shown in Table 2), which codes for the location of the plant in the two-dimensional data files.

Table 2. Example record in the reference EGU records file.

Name	Handley Generating Station
UnitID	5
NERCSub	ERCT
NERCSub_Ix	26
State	TX
State_Ix	44
LUTValue	4022
ORISPL	3491
Lat	32.7278
Lon	-97.2186
County	Tarrant
FuelPrimary	Pipeline Natural Gas
FuelSecondary	Diesel Oil
PrimeFuelType	Gas
UniqueID	3491|5
CSIRegion	TX
CSIRegionIX	9

As of summer 2017, EGU records also include a plant-specific emission rate for $PM_{2.5}$, in pounds of particulate matter per MMBTU of heat input, as well as including expected CO_2 emissions data for units that do not report CO_2 to AMPD on an hourly basis.

$PM_{2.5}$ emissions rates were calculated using plant-specific point source emissions data from the 2014 National Emissions Inventory,[60] combined with heat input data as reported in AMPD. For prior data years, plants without $PM_{2.5}$ are assigned the average rate of similar plants (i.e., the same prime mover and fuel type) within the same AVERT region. $PM_{2.5}$ emission rates are used within the AVERT statistical module to calculate unit-specific $PM_{2.5}$ emissions for each unit within each load bin.

Expected hourly CO_2 emissions data were calculated within the AVERT statistical module only for units that do not report CO_2. Expected CO_2 emissions for these units were calculated as the product of an assumed fuel-specific CO_2 content factor and the unit's heat input for each hour. CO_2 factors in tons of CO_2 emitted per MMBTU of fuel consumed were calculated using the "unspecified coal", "natural gas", and "distillate fuel oil" carbon content values codified for EPA's Greenhouse Gas Reporting Program (GHGRP) in 40 CFR Part 98, Subpart C. Units with a fuel type other than coal, oil, or gas were assumed to have the same carbon emissions factor as oil-fired units.

[59] The pipe character ("|") is used to separate the ORISPL and Unit ID for legibility.

[60] https://www.epa.gov/air-emissions-inventories/national-emissions-inventory-nei

AVERT analysis is conducted by region, with the continental United States divided into 10 reasonably autonomous electricity-market trading and dispatch areas. These AVERT regions are generally aggregations of the eGRID subregions used by EPA, and are similar, but not identical, to North American Electric Reliability Corporation regions.[61] For a map of AVERT regions, see Figure 3 (page 16).

Several of the AVERT regions represent electricity market areas or balancing authorities. The Northeast region represents a combination of the New England and New York Independent System Operators (ISOs), the Great Lakes/Mid-Atlantic region represents the PJM Regional Transmission Organization (RTO), the Upper Midwest region encompasses most of the Midwest ISO; the Texas region represents ERCOT, and California represents the California ISO region. The Southeast region includes the SERC and Florida reliability regions. Both the Northwest and Southwest regions encompass several large interconnected utilities and major transmission systems that have numerous interdependencies. The Rocky Mountain and Lower Midwest regions operate largely autonomously relative to the other AVERT regions shown here.

Analysis based on smaller regions, such as eGRID regions, risks missing important interdependencies between the EGUs in a larger region (e.g., the impact of New Jersey load reductions on Ohio EGUs). Using still larger regions, such as the Eastern Interconnect, spreads the influence of load reductions too widely, making it difficult to ascribe load reductions at a particular location to a reasonable cohort of EGUs.

[61] AVERT regions separate most of the major ISO and RTOs, such as Texas (ERCOT), the California ISO, and the Southwest Power Pool (SPP, or Lower Midwest here). The Midwest ISO is generally aggregated into the Upper Midwest region, with the exception of Michigan, which is interconnected with the PJM RTO (called here the Great Lakes/Mid-Atlantic region). The Southwest region is primary composed of several large multi-state utilities (Duke/Progress, Southern Company, TVA, Entergy, and Florida Power and Light). While the western region of the United States is highly interconnected as well, most of California is independently dispatched, and few resources in the Rocky Mountain region are used for export purposes to either the Northwest or Southwest. In addition, there are few connections between the Northwest and Southwest.

Appendix C: Proxy Renewable Energy Hourly Profiles

AVERT's Main Module provides example proxy hourly capacity factors for generic solar and wind projects. These capacity factors are meant to provide quickly accessible options to review example renewable project portfolios in each of the regions discussed here. The user is encouraged to develop site-, state-, or region-specific renewable energy load profiles. Where such information is not available or for the purposes of exploration, the proxy capacity factors in the Main Module provide a reasonable basis for expected wind and solar hourly profiles.

Annual hourly capacity factors for rooftop photovoltaic (PV) and utility PV were obtained from the National Renewable Energy Laboratory's PVWatts v.1 tool.[62] Each hourly capacity factor assembled for each AVERT region is based on the average PV capacity factor for four to 10 cities in the region. The number and location of the sampled cities were chosen to provide a representative distribution of the AVERT region's insolation (energy from sunlight) at the largest load centers.

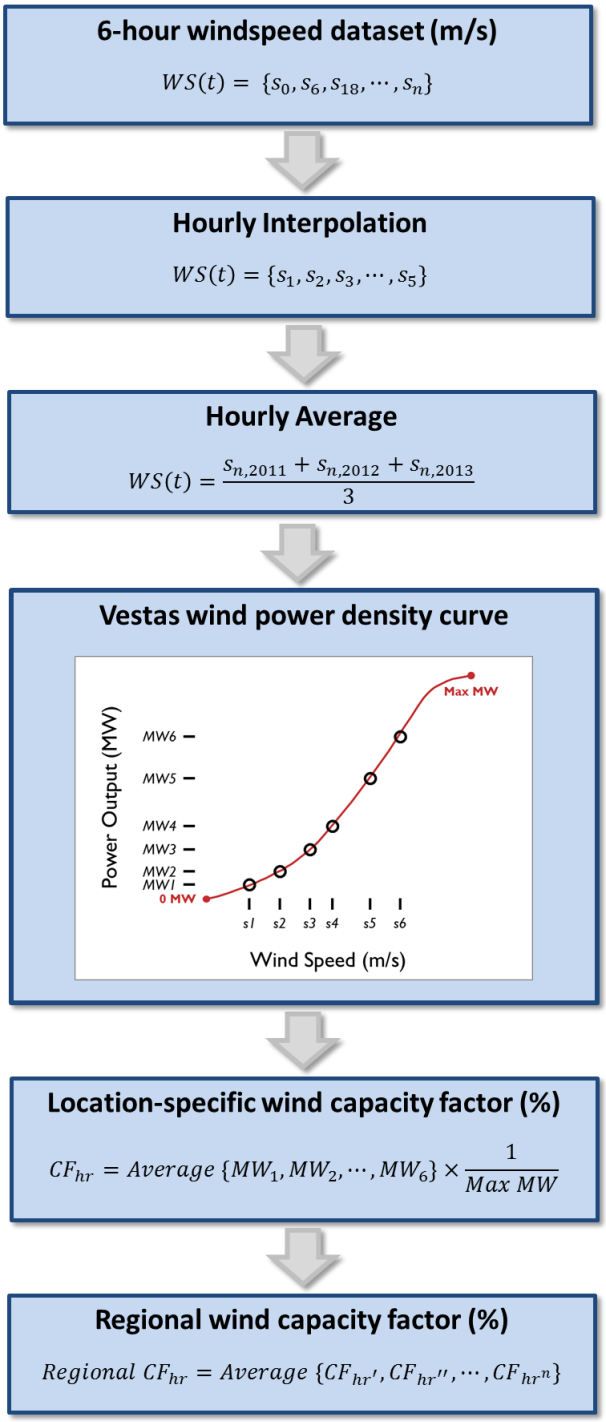
Wind capacity factors were developed from annual 6-hour datasets of modeled wind speeds at 80-meter turbine (hub) heights obtained from the Global Model Database developed by AWS Truepower for 2011 through 2013. Depending on the size of the region, between five and 15 locations were used to provide a representative distribution of hypothetical wind turbine installations. Once hourly wind speed data for each site were created by interpolating each of the 6-hour intervals, 2011-2013 hourly wind speed datasets were averaged and were then applied to a power density curve for a Vestas V112 3 MW Wind Turbine.[63] These hourly data were divided by total regional wind nameplate capacity to produce hourly capacity factors. Hourly capacity factor datasets from all the sites within a region were then averaged to produce a regional hourly dataset for capacity factors. The flow of data is shown in Figure 28.

Users are encouraged to develop site-specific capacity factor profiles for renewable energy options whenever the data are available.

[62] National Renewable Energy Laboratory. n.d. PVWatts: A performance calculator for grid-connected PV systems. Accessed December 14, 2012. Available at http://rredc.nrel.gov/solar/calculators/PVWATTS/version1/version1_index.html.

[63] Vestas Wind Systems. 2013. *3 MW Platform*. Available at https://www.nhsec.nh.gov/projects/2013-02/documents/131212appendix_15.pdf.

Figure 28. Flowchart for converting wind speed data into hourly regional capacity factors.



Appendix D: Overview of AVERT's Statistical Module

For each region, the MATLAB®-based Statistical Module provides the model's core statistical analysis. (For installation instructions, see Appendix A.)

Data analysis within the Statistical Module is conducted in five steps, described briefly in the sub-sections below:

1. Parsing the base year into "bins" of hours with similar levels of total regional fossil-fuel load.
2. Collecting statistical information (probability distributions for generation, heat input, and emissions) on how each fossil-fuel EGU has responded to regional load requirements in each hour of the base year.
3. Extrapolating this statistical information to extend to potential lower and higher fossil-fuel loads not experienced in the base year.
4. Estimating the ranges of generation, heat input, and emissions likely to be experienced by each EGU for each fossil-fuel load bin (or approximate regional load).
5. Preparing outputs for export to AVERT's Main Module.

Appendix E provides step-by-step instructions to using the Statistical Module.

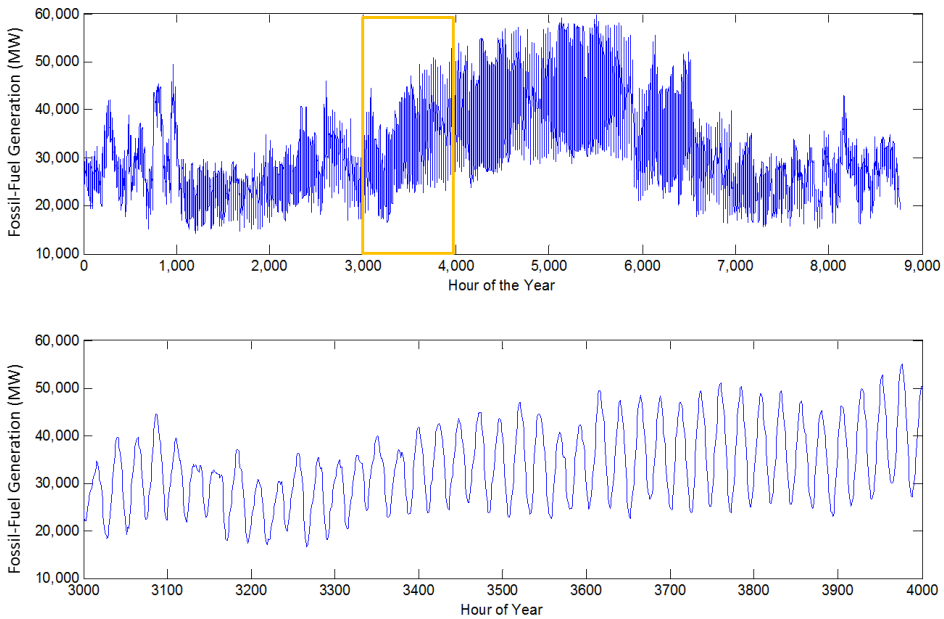
The Statistical Module is also equipped to estimate how fossil-fuel EGUs respond to regional load requirements given changes in the fleet of EGUs available in future years. The module inputs information from AVERT's Future Year Scenario Template to identify existing EGUs to be retired, the expected impact of pollution-control retrofits on existing EGUs' emissions rates, and new EGUs coming on line. AVERT then re-estimates all statistical information based on each region's projected fleet of fossil-fuel EGUs for a particular future year scenario. (See Appendix F for a more detailed description of the Future Year Scenario Template.)

Parsing Generation Demand into Fossil-Fuel Load Bins

In its first step, the Statistical Module sums up all fossil-fuel generation in each hour under analysis to arrive at a total regional fossil-fuel load by hour (see Figure 29, which includes a detail of hours 3,000 to 4,000).[64]

[64] Hour 3000 = May 5th. Hour 4000 = June 15th.

Figure 29. 2011 hourly sum of fossil-fuel generation in the Texas region.



These hourly sums of fossil-fuel generation are sorted from lowest to highest generation level and grouped into 41 "fossil-fuel load bins" for the purpose of collecting statistics for each EGU at each approximate load level (see Figure 30).[65] Thirty-seven of the bins contain 224 or 225 hours; the second lowest and second highest bins contain 204 or 205 hours; and the bins for the lowest and highest fossil-fuel loads contain just 20 hours each to best represent these extreme load levels.[66] Bin thresholds (the fossil-fuel load levels dividing the bins) and bin medians vary by region.[67]

Figure 30 illustrates how the bins are formed relative to total system fossil-fuel load. The figure shows a typical "load duration curve" in dark red for fossil generation in Texas in 2011. This curve represents all fossil-fuel load levels of the year (8,760 data points) in declining order. The horizontal axis represents the fraction of time that fossil generation is at or above a certain level (e.g., fossil generation only exceeds the 20 percent marker in 20 percent, or 1,752, hours). The vertical axis shows the fossil-fuel load for each point on the curve.

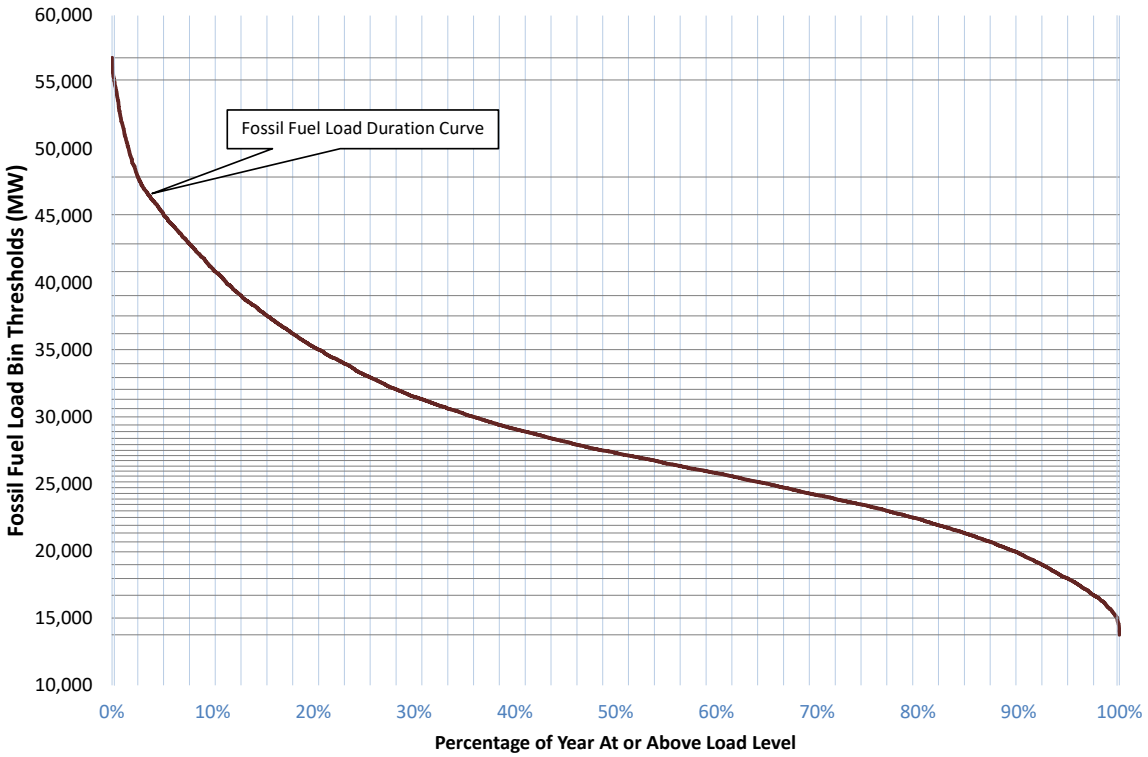
---

[65] "Load" always refers to regional, system-wide demand, and never to individual unit generation. The fossil-fuel load bins group together hours that have similar generation levels ignoring their chronological order.

[66] The ranges of the historical fossil-fuel load bins are determined is as follows: A region's 8,760 one-hour loads are sorted from low to high, and then divided into 39 bins each containing 224 or 225 hours, depending on rounding. For each bin (excluding the highest and lowest of the 39 bins, described below), the maximum threshold is the MW load of the highest-load hour in the bin, and the minimum threshold is the MW load of the highest-load hour the next lower bin. Bin "widths" are the high bin threshold in MW minus the low bin threshold. Bin medians are the load (in MW) of the median hour of the bin. The highest and lowest of the 39 bins are each divided into two parts, such that there are 41 fossil-fuel load bins from historical data in every region. The lowest of the 39 original bins is split into the 20 hours with the lowest loads and the remaining 204 or 205 hours; the highest bin is split into the 20 hours with the highest loads and the remainder.

[67] AVERT output includes additional fossil-fuel load bins designed to capture regional load levels that did not occur in the base year (see the "Extrapolation to Higher and Lower Fossil-Fuel Loads" subsection below).

Figure 30. 2011 fossil fuel load duration curve for Texas region indicating load bins.



The horizontal axis has 42 light blue lines on it, representing the outside thresholds of the 41 fossil-fuel load bins. Thirty-eight of these lines are evenly spaced from zero percent to 100 percent,[68] capturing 224 or 225 hours each. In other words, each of these bins represents slightly over 2.5 percent of the hours in the year (again, grouped according to total fossil load in that hour rather than by chronology). At the extreme ends, there are two additional light blue lines very near to the zero and 100 percent markers. These additional lines fall 20 hours from the extremes; therefore there are two bins at the extremes with 20 hours each, and two bins just prior to the extremes with 204 or 205 hours each.[69]

Wherever a percentage threshold crosses the fossil-fuel load duration curve, it creates a horizontal line, representing a fossil-fuel load bin threshold. These are the horizontal grey lines shown on the chart above, closely spaced in the lower middle of the graph and spreading out toward the highest and lowest loads. This is because the majority of hours experience total fossil load that is neither extremely high nor extremely low. In other words, there are more hours represented in the middle of the fossil load range (for example, the regime from ~20,000 to ~32,000 MW in Figure 30) than at very high or very low fossil loads. In order to capture an approximately equal number of hours in each bin, each bin in the middle of the fossil load range captures a narrower range of MW. This is shown in Figure 30 based on the spacing between the grey horizontal lines, where the points along the load duration curve that fall between two horizontal threshold lines are the points in the

[68] Each line represents a demarcation of 2.56 percent.

[69] 20 hours is represented by 0.23 and 99.77 percent on this axis.

corresponding fossil-fuel load bin, and the points in each bin (apart from the end binds, as discussed above) represent roughly 2.5 percent of hours in the year.

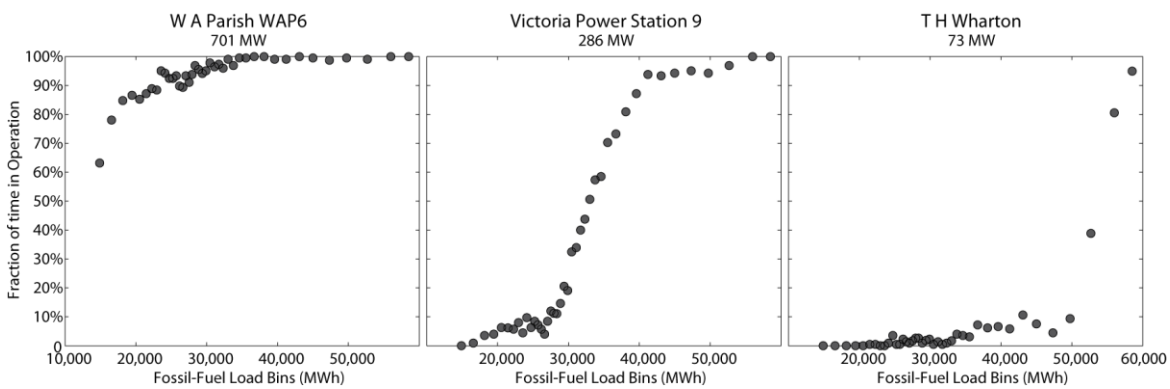
Collecting Statistical Information

Next AVERT gathers statistics about how each EGU responds to the generation requirements of each fossil-fuel load bin. Three types of probability distributions are constructed: frequency of operation by fossil-fuel load bin, generation level by fossil-fuel load bin, and heat input and emissions by generation level.

Frequency of Operation by Fossil-Fuel Load Bin

In this first set of probability distributions, AVERT calculates the share of hours within each fossil-fuel load bin for which a particular unit is turned on (i.e., has generation greater than zero). Figure 31 shows the frequency of operation for three EGUs in the Texas region in 2011.

Figure 31. 2011 frequency of operation by fossil-fuel load bin for three indicative EGUs in the Texas region.



In the figure above, the 701-MW coal-fired EGU shown on the left operates in nearly every hour of the year, with its probability of operation dropping below 90 percent only at the lowest fossil-fuel load requirements. This pattern is typical of a baseload EGU that operates continually with the exception of maintenance outages scheduled to occur at low load requirement levels. The middle EGU, a 286-MW gas-fired station, operates only rarely at low load requirements, but its frequency of operation increases steadily with regional demand. At fossil-fuel load levels above 40,000 MW, this EGU operates in nearly every hour. This pattern is typical of an intermediate-load EGU such as a combined-cycle EGU. The 73-MW gas turbine on the right is a peak-load EGU, operating only at the highest load requirements.

Generation Level by Fossil-Fuel Load Bin

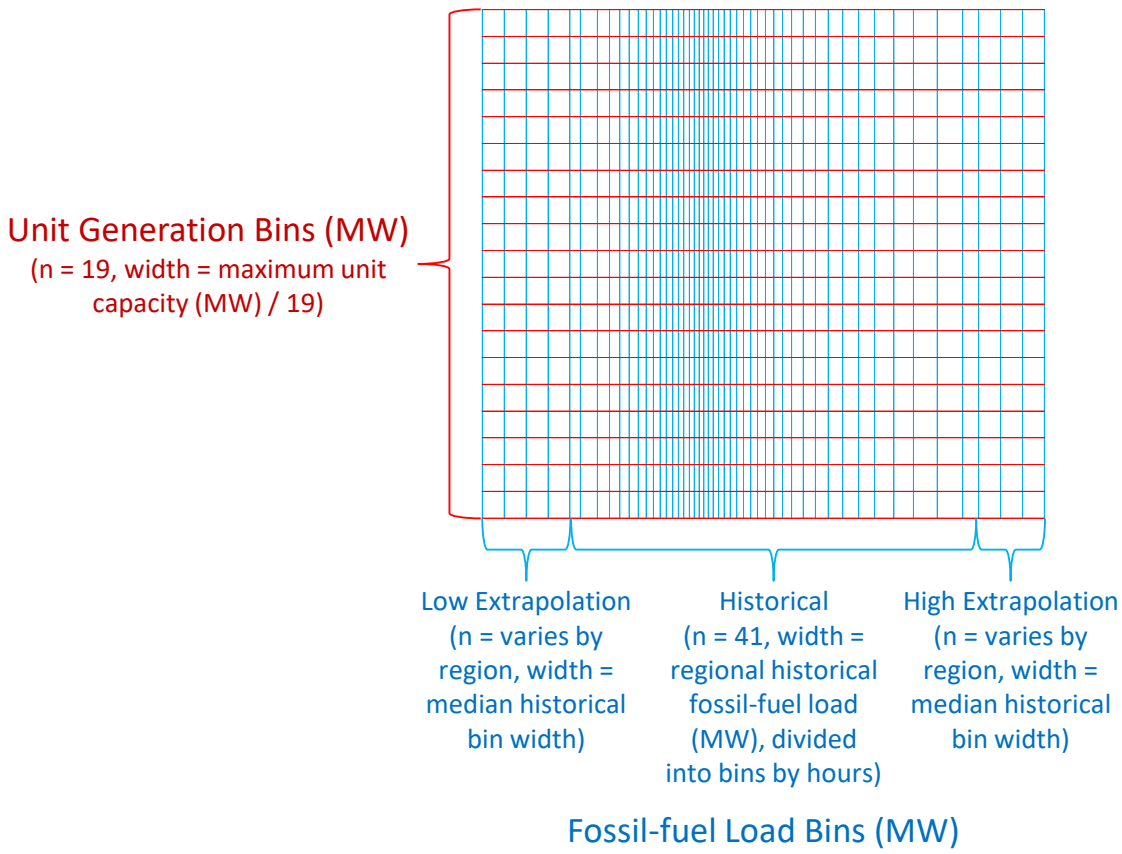
The second set of probability distributions calculated by AVERT describes generation output for each EGU in operation in each fossil-fuel load bin.[70] AVERT divides each EGU's generation into 19 evenly-spaced "unit generation bins."[71] Figure 32 depicts the intersection of these two types of

[70] For each fossil-fuel load bin, AVERT filters out the units which did not generate, and reviews only the operational units.

[71] The thresholds between unit generation bins are unit-specific.

bins. Smaller fossil-fuel load bins (where the vertical lines are closer together) indicate a higher concentration of hours at those load levels.

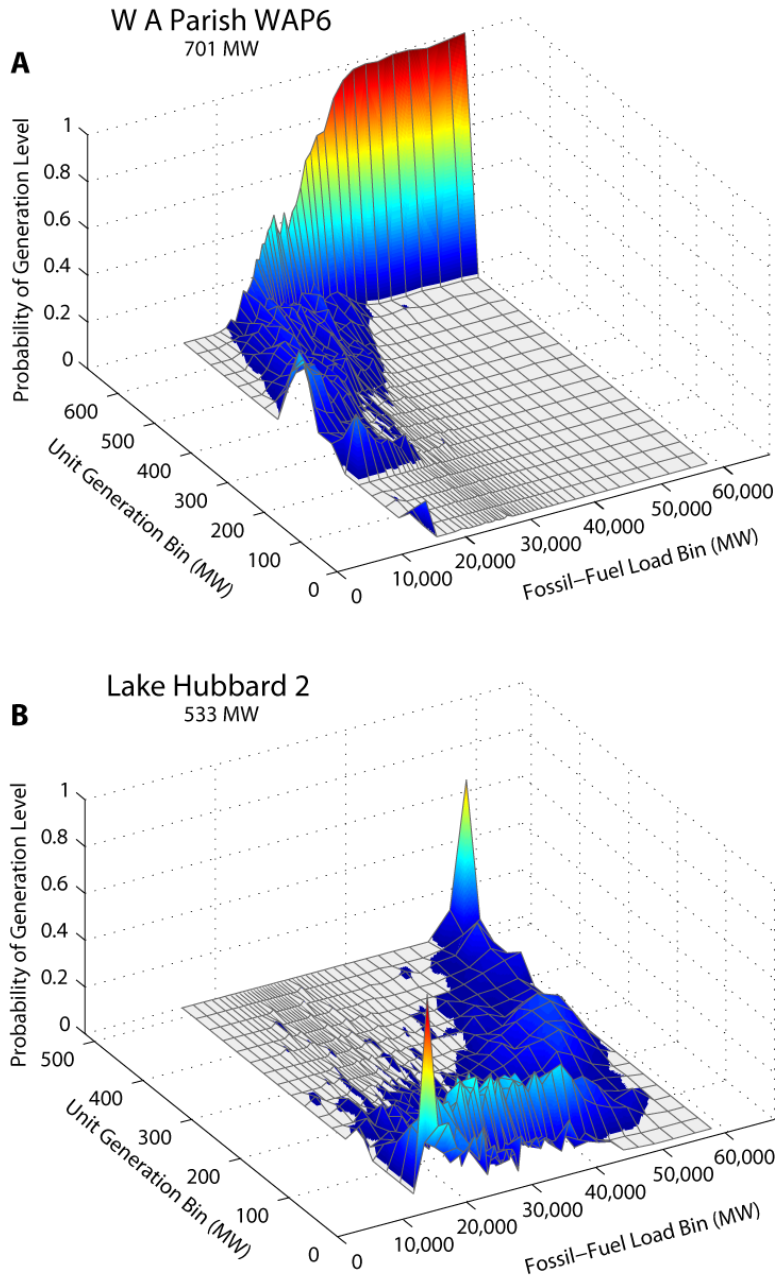
Figure 32. Schematic of unit generation bins and fossil-fuel load bins.



For each of the 41 fossil-fuel load bins, AVERT determines the number of hours in which the unit generated at an amount within each of the 19 unit generation bins. In this way, the model creates a discrete probability distribution of generation for each fossil-fuel load bin during all hours in which the EGU is in operation.

Figure 33 shows the probability distributions of generation at two EGUs in the Texas region. The axis to the bottom right of each plot represents the region's fossil-fuel load bins. The axis to the bottom left represents unit generation bins, from zero to the EGU's maximum generation in the base year. The vertical axis is the probability that the EGU is operating at the given unit generation level in each fossil-fuel load bin.

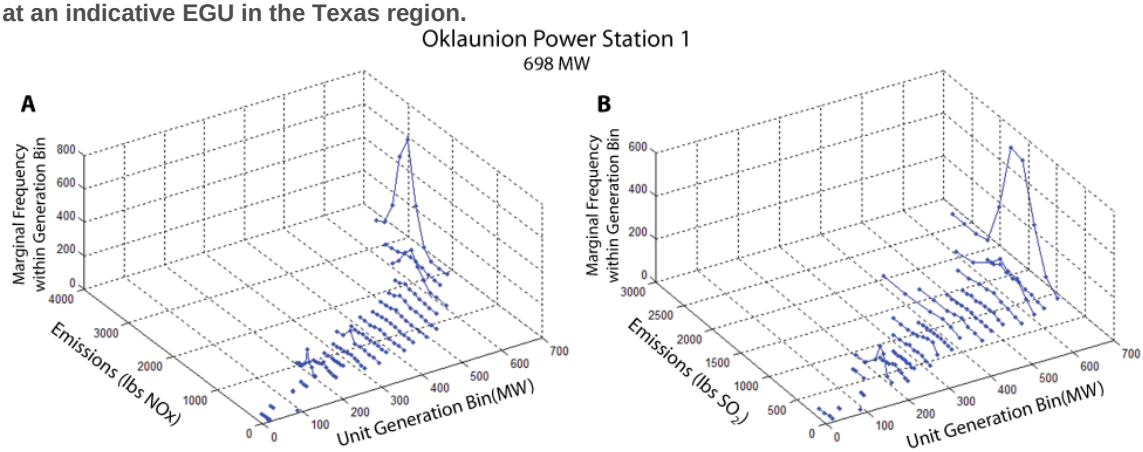
Figure 33. 2011 generation level by fossil-fuel load bin and unit generation bin for two indicative EGUs in the Texas region.



Heat Input and Emissions by Generation Level

The final set of probability distributions relate EGU heat input and $PM_{2.5}$, SO_2, NO_x, and CO_2 emissions to unit generation. For heat input and emissions of $PM_{2.5}$, SO_2, NO_x, and CO_2, statistics for the ozone season and non-ozone seasons are gathered and stored.[72] AVERT creates eight discrete probability distributions—ozone season SO_2, NO_x, and CO_2 emissions and heat input, and non-ozone-season SO_2, NO_x, and CO_2 emissions and heat input—for each EGU at each of the 19 unit generation bins. In addition, $PM_{2.5}$ data is calculated by multiplying the heat input data by unit-specific $PM_{2.5}$ emission factors, as explained above. Probability distributions are not a function of regional fossil-fuel load. Figure 34 displays a single EGU's emissions of SO_2 and NO_x relative to its generation level.

Figure 34. 2011 ozone-season emissions of SO_2 (right graph) and NO_x (left graph) by generation level at an indicative EGU in the Texas region.



Extrapolation to Higher and Lower Fossil-Fuel Loads

The end purpose of AVERT is to allow users to estimate the emissions displaced by reducing regional load due either to recent historical or expected/proposed near-future EE/RE programs. In either case, the range of fossil-fuel load requirements in the base year may be insufficient to represent EE/RE scenarios. For example, a scenario with load reductions from EE/RE measures might require the user to examine regional load requirements that are lower than the range represented by the base year. In contrast, a user can choose to estimate the emissions benefits of EE/RE programs already in place today, which could entail examining a scenario with fossil loads higher than the range represented by the base year.

In the third step of AVERT, load requirements outside of the base-year range are estimated by extrapolating each EGU's statistics below and above base-year regional load requirements. Two sets of probability distributions are subject to extrapolation: probability of operation and generation

[72] Where "ozone season" is considered May through September, inclusive, for most states (states with different ozone season designations are not recognized in this model). Ozone season distinctions are used to capture differences in emissions output where generators are required to reduce emissions output during selected times of the year to reduce ozone formation. Heat rate (heat input divided by generation) and CO_2 rates are not considered to change considerably from season to season, but are recorded in these categories for computational convenience.

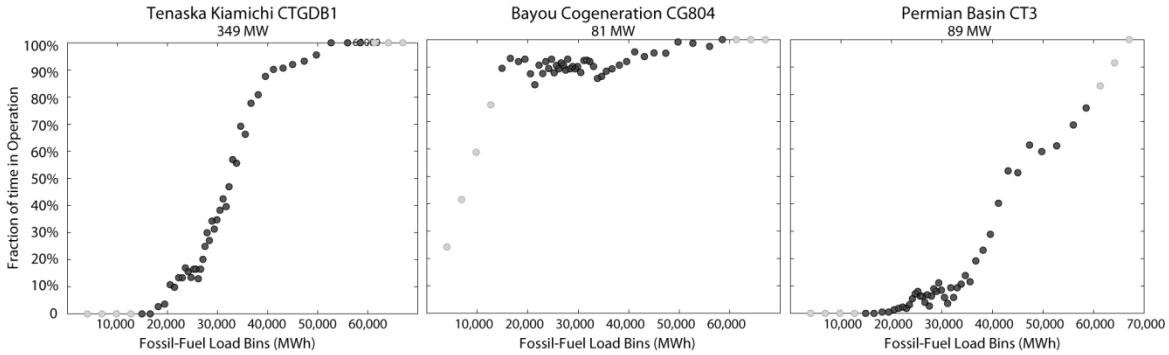
level for each fossil-fuel load bin. A flexible number of fossil-fuel load bins are constructed below the regional minimum load (with a lowest bound of zero), and above the regional maximum, such that the new maximum bin threshold is the coincident maximum generation of all of the fossil-fuel EGU on the system—that is, the level of load that could be reached if every fossil-fuel EGU were operating at its maximum output.[73] Bin thresholds and medians vary by region. Theoretically, the regional extrapolated maximum can be reached by the simultaneous use of every EGU in the system, but in practice load curves that reach this maximum are unlikely.

Extrapolating the Probability of Operation

The minimum amount of potential generation is zero, a level that would require zero generation from all EGUs in the region. If an EGU is already at a zero probability of operation at a low load requirement, the zero value is maintained into the lower potential fossil-fuel load bins. Any probability of operation above zero is extrapolated linearly down to zero from the probability at the lowest recorded load level.

The potential maximum generation is the combined simultaneous maximum output of all EGUs in a region; to reach that maximum point, therefore, all EGUs in the region need to be operating at their full capacity. EGUs that have a 100 percent probability of operation at the base-year's highest fossil-fuel load bin maintain that probability of output. Any probability of operation lower than 100 percent is extrapolated linearly up to the potential maximum from the probability at the highest recorded load level.

Figure 35. 2011 base year and extrapolated probabilities of operation for three indicative EGUs in the Texas region.



Black points represent the probability of operation during base-year load periods. Gray points are the probability of operation at potential low and high loads beyond the base-year range.

Figure 35 displays extrapolated values for the probability of operation for three EGUs in the Texas region. In this figure, black points represent the probability of operation at the base-year fossil-fuel load, and gray points represent the probability of operation at potential high and low fossil-fuel loads beyond the base-year range. Extrapolation is simple in the figure to the left (Tenaska), as the EGU does not operate at all during the lowest loads and operates continually during the highest

[73] The number of fossil-fuel load bins outside of the base-year range is determined as follows: For each region, the median of the fossil-fuel load threshold times four sets the MW size of the extrapolated bins. Bins of this size are extended below the base-year minimum until zero is exceeded and above the base-year maximum until the coincident maximum peak load is exceeded. The lowest and highest bins are truncated to begin at zero and end at the coincident maximum, respectively.

load periods. The middle figure (Bayou) requires downward extrapolation to a zero probability of generation at a zero load, and the figure to the right (Permian Basin) requires upward extrapolation to meet the highest load requirements.

Extrapolating the Generation Level

EGUs not only run more often at higher load requirements, but also need to generate higher levels of output to meet the requirements of the higher fossil-fuel load bins. Within the base-year range, EGU generation is described as a series of discrete probability distributions for each fossil-fuel load bin.

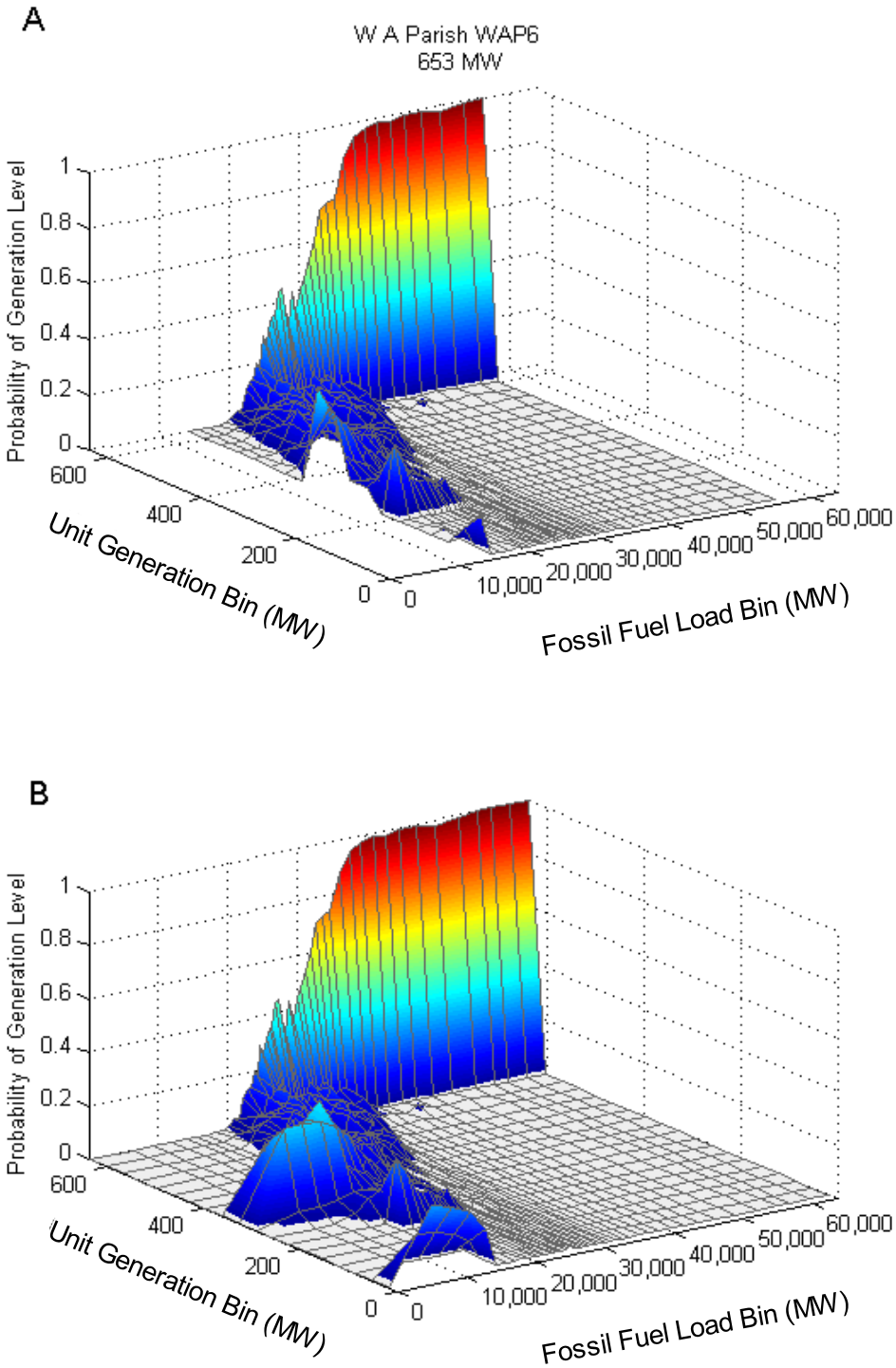
The extrapolated space encompasses fossil-fuel load bins that extend to the highest possible coincident peak generation (i.e., all EGUs in a region operating at maximum capacity simultaneously) and down to zero. New fossil-fired load bins are created at intervals equal to four times the size of the median load bin.

To extrapolate to potential higher fossil-fuel load bins, AVERT assumes that each unit will have 100% probability of generating at its highest output if fossil load is at its theoretical maximum, and 0% of generating at any other level of output given maximum fossil load. For each level of generation (i.e., within each unit generation bin), AVERT determines the slope of the line connecting the unit's probability of generating at that level at the highest historical fossil load bin to either 100% probability (for the highest unit generation bin) or 0% probability (for all other generation bins). The unit's probability of generating at that level is then extrapolated accordingly. Once all levels of generation have been extrapolated, AVERT normalizes the height of the extrapolated load bins such that the total value of all points in each load bin sums to one. A similar process is repeated for lower extrapolated fossil-fuel load bins, except that AVERT assumes that the unit's output will be zero if total fossil load is zero.

The example in Figure 36 (below) shows an extrapolation of EGU generation to potential lower and higher fossil-fuel load bins. The graphs show base-year unit generation bins (on the left-hand horizontal axis) for any fossil-fuel load bin (on the right-hand horizontal axis). The height of the surface represents the probability of operating at a given generation level in a particular fossil-fuel load bin. Below about 15,000 MW (the lowest fossil-fuel load bin median in 2011) and above about 56,000 MW (the highest fossil-fuel load bin median in 2011), the surface is the figure showing data for the historical year (A) is blank, indicating that no hours fell into those bin combinations in the base year.

To extrapolate to higher and lower fossil-fuel load levels, a line is extended linearly towards the corner constraints described above—100% probability of generating at full output given maximum fossil load, and no unit output at a zero fossil load. The bottom graph (B) shows the results of this extrapolation. From 60,000 MW to the peak load, this method returns generation exclusively at this EGU's maximum, 701 MW. When the probability of operation is zero, the generation output is automatically set to zero as well.

Figure 36. 2011 base year (A) and extrapolated (B) probabilities of generation levels for an indicative EGU in the Texas region.



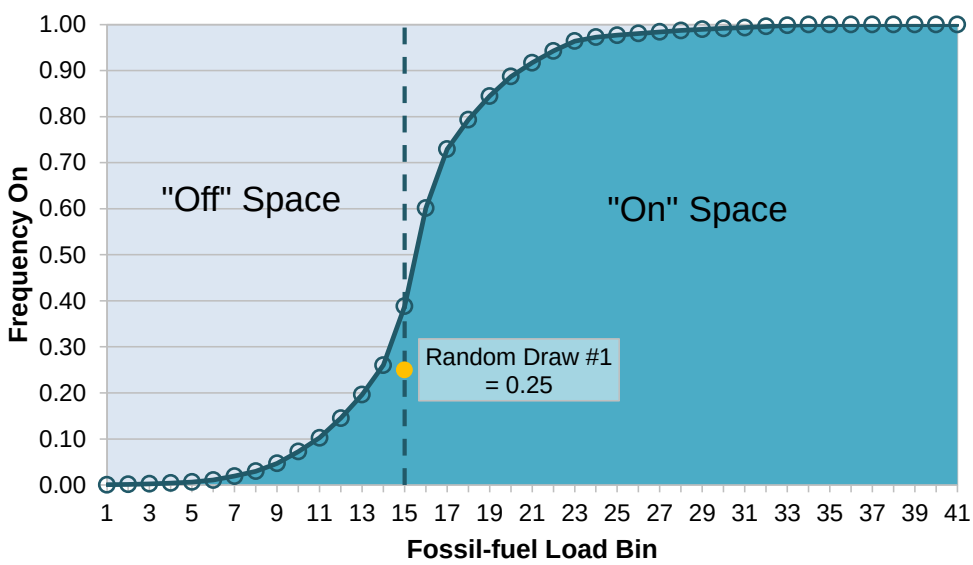
Statistical Analysis

The fourth step in the Statistical Module is to estimate the predicted range and expected (average) generation, heat input, and $PM_{2.5}$, SO_2, NO_x, and CO_2 emissions for each EGU at each of the fossil-fuel load requirement bins, from zero MW up to the coincident maximum generation of all of fossil-fuel EGUs in a region.

AVERT's Monte Carlo analysis (contained within the Statistical Module) uses discrete probability distributions to estimate key variables' range and expected value for each EGU in each fossil-fuel load bin. For each EGU and fossil-fuel load bin, AVERT draws three random numbers between zero and one:

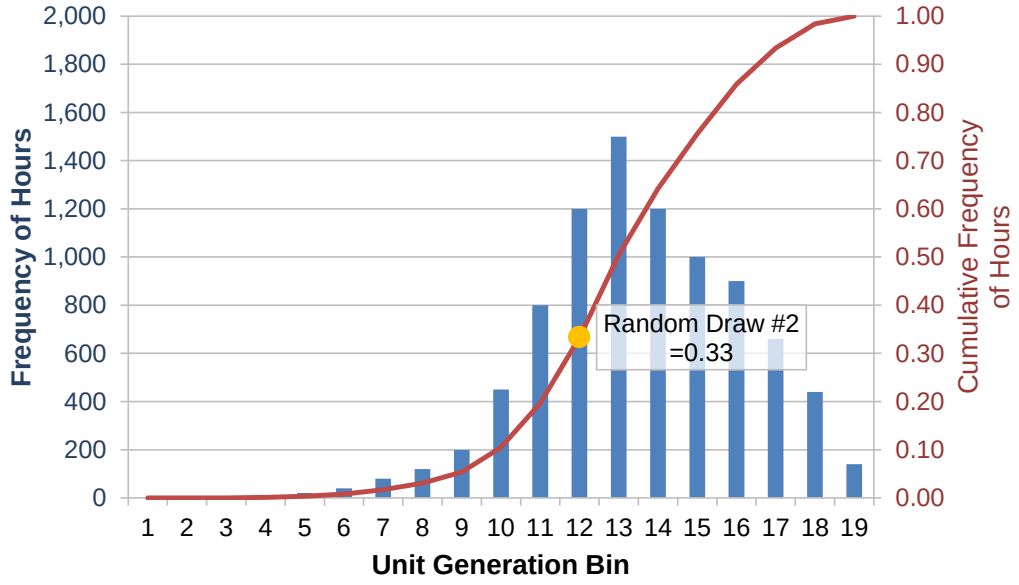
- The first number drawn is compared to the EGU's probability of operation at the selected fossil-fuel load bin. If the number drawn is greater than the probability of operation, the EGU is turned off and draws two and three are not conducted. If the number drawn is less than the probability of operation, the EGU is turned on. Figure 37 illustrates this first draw. Starting in fossil-fuel load bin number 15 (representing a particular system-wide fossil load level), the simulator randomly draws a value of 0.25. This value is slightly lower than the probability of operation in bin 15 (approximately 0.40), and this EGU is "turned on."

Figure 37. EGU frequency of operation and example of random draw selection.



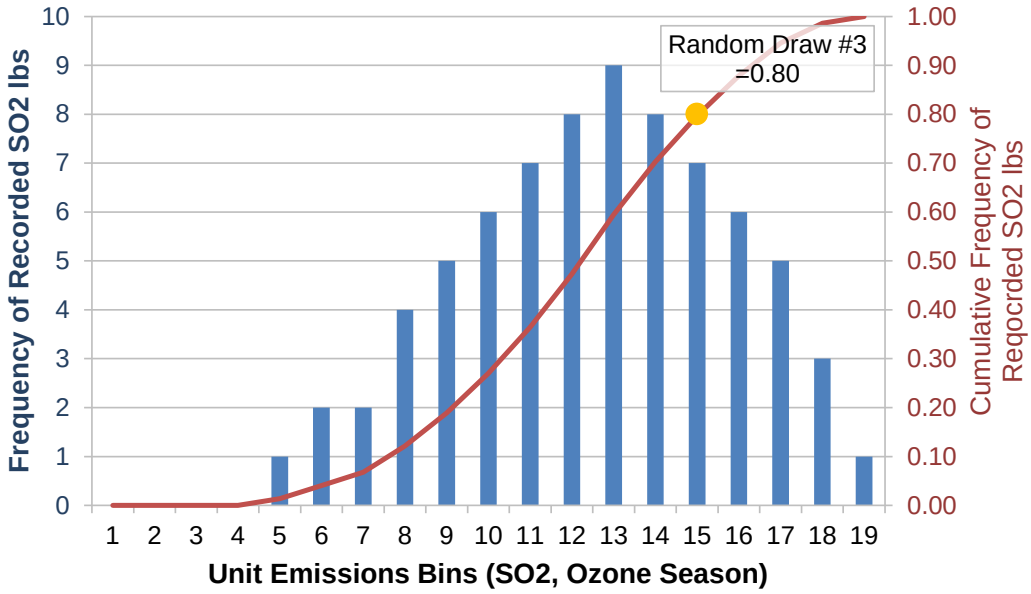
- The second number drawn is compared to the discrete *cumulative* distribution function of EGU generation for each fossil-fuel load bin. The model selects the EGU's unit generation bin as the next highest EGU output greater than the cumulative probability value indicated by the number drawn. Figure 38 illustrates this step: the random draw is 0.33, which results in the selection of unit generation bin 12.

Figure 38. EGU generation histogram, cumulative probability distribution, and example of random draw selection.



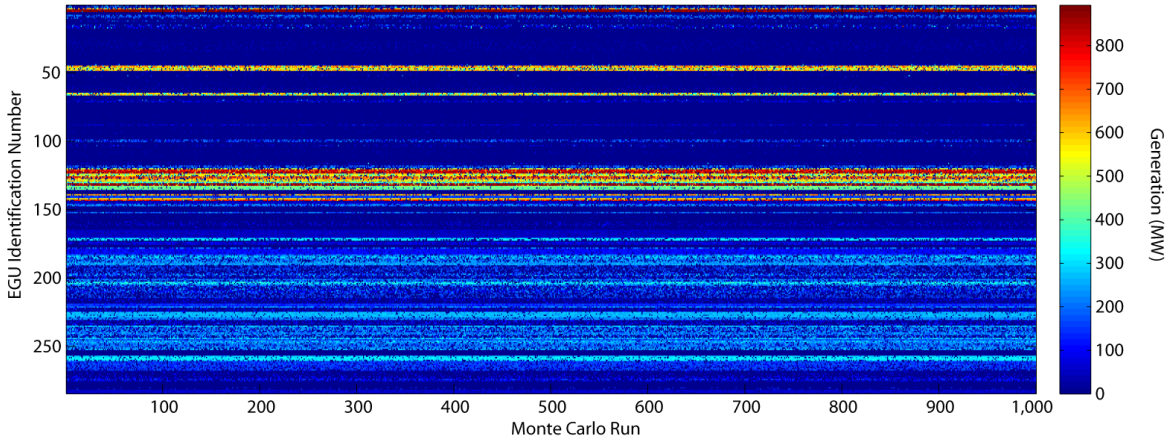
- The final number drawn is compared to the seven discrete cumulative distributions for heat input and emissions in the unit generation bin identified in the previous draw. In Figure 39, the third random draw is 0.80 and unit emissions bin 15 is selected.

Figure 39. EGU SO_2 emissions histogram, cumulative probability distribution, and example of random draw selection.



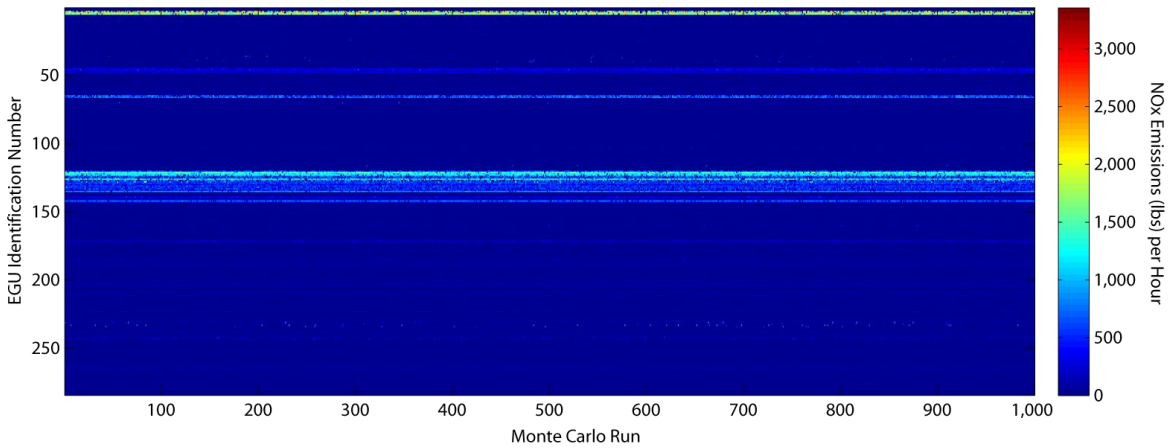
Generation, heat input, and emissions output from each EGU at each fossil-fuel load bin is recorded for 5,000 Monte Carlo runs.[74] Each of these runs repeats the process described above of drawing and applying three random numbers in sequence. Examples of the projected generation and NO_x emissions at a hypothetical fossil-fuel load of 30,000 MW for the 270 fossil-fuel EGUs in the Texas region are shown in Figure 40 and Figure 41.

Figure 40. Generation (MW) for 1,000 Monte Carlo runs at 270 EGUs in the Texas region at a fossil-fuel load of 30,000 MW (2011).



[74] The base dataset provided by EPA uses 5,000 Monte Carlo runs. The default for users of the Statistical Module is 1,000 runs.

Figure 41. NO_x ozone season emissions (lbs) for 1,000 Monte Carlo runs at 270 EGUs in the Texas region at a fossil-fuel load of 30,000 MW (2011).



AVERT takes the average (expected value) generation, heat input, and $PM_{2.5}$, SO_2, NO_x, and CO_2 emissions for each EGU within a region across 5,000 Monte Carlo runs and records these values in a new structural array.

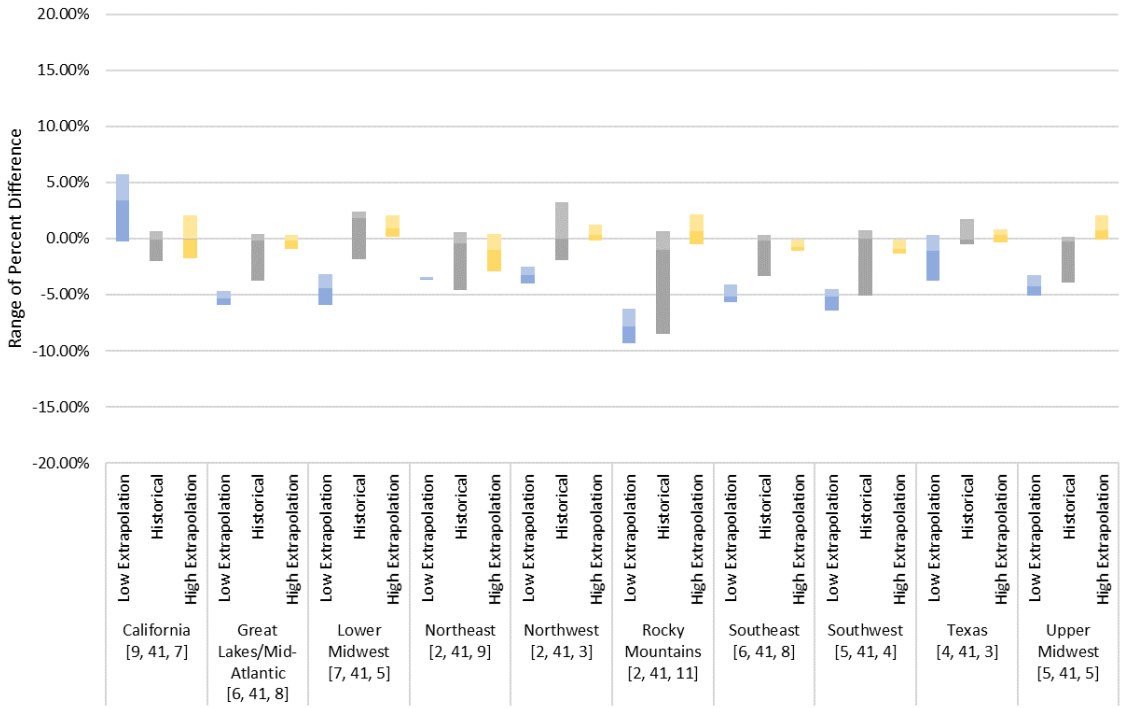
Figure 42 depicts ranges of percent differences between fossil-fuel load bin medians and the regional sum of generation in that same bin. For each of the 10 regions, three bar charts are shown. The middle bar represents the minimum, mean, and maximum percent differences between measured or expected fossil-fuel generation[75] (e.g., fossil-fuel load bin medians) and the sum of generation for the bin as predicted by AVERT. The left bar in each region represents the same set of statistics for the fossil-fuel load bins interpolated between 0 MW and the actual system generation minimum, while the right bar represents the statistics for the load bins interpolated between the actual system generation maximum and the potential system generation maximum.

Values close to zero indicate that AVERT has closely matched the amount of generation in one or more fossil-fuel load bins, while values greater than zero indicate that AVERT has under-predicted the amount of generation in one or more fossil-fuel load bins. Some bias for both high and low interpolation bins is expected as EGUs experience both forced outages and imperfect responses to regional demand; therefore, this statistical approach cannot capture a situation in which each EGU in the system could reasonably be expected to generate at full capacity simultaneously. At the lowest load levels, the generation output of many baseload EGUs becomes binary (i.e., the EGU cannot ramp down below a minimum threshold, and simply turns off). AVERT therefore predicts a large number of simultaneous curtailments, and may under-predict generation at low load levels. Emissions and generation at these extrapolated load bins should therefore be viewed cautiously.

Underneath the name of each region is a set of numbers indicating the number of bins associated with the low interpolation, the actual data, and the high interpolation, in that order.

[75] "Expected" values for interpolated space.

Figure 42. 2011 percent difference between measured or expected EGU generation (fossil-fuel load bin median values) and mean predicted AVERT generation by region. Mean across bins, and minimum and maximum percent difference in any bin.



Bracketed numbers are the number of high-interpolation, actual data, and low-interpolation fossil fuel bins. Values above zero indicate that AVERT model under-predicts total sum generation.

Statistical Output

The final step is to generate an Excel output file to store the expected values of generation and emissions of each EGU at every level of base-year and potential load for each region, and a time series of the total base-year fossil-fuel load in each hour of the year; this file becomes an input file to the Main Module. Eleven sections of the output file each are composed of a matrix of the names and identifiers of each EGU and the expected value at each fossil-fuel load bin, with one section devoted to each of the following:

- Generation (MW)
- Heat input (MMBtu, ozone season)
- Heat input (MMBtu, non-ozone season)
- SO_2 emissions (lbs, ozone season)
- SO_2 emissions (lbs, non-ozone season)
- NO_x emissions (lbs, ozone season)
- NO_x emissions (lbs, non-ozone season)
- $PM_{2.5}$ emissions (lbs, ozone season)
- $PM_{2.5}$ emissions (lbs, non-ozone season)

- CO_2 emissions (tons, ozone season)[76]
- CO_2 emissions (tons, non-ozone season)

[76] CO_2 emissions are divided into ozone and non-ozone seasons to maintain algorithmic consistency with $PM_{2.5}$, SO_2 and NO_x emissions. In AVERT results, displaced CO_2 emissions are presented in terms of annual totals.

Appendix E: AVERT's Statistical Module: Step-by-Step Instructions

This section provides step-by-step instructions for using AVERT's Statistical Module to prepare inputs for AVERT's Main Module.

Step 1: Determine Windows Operating Environment

First, determine if your Windows system operates in a 32-bit or 64-bit environment. Generally, this information is displayed among the "Properties" of "My Computer" in Windows XP, or "Computer" in Windows Vista, Windows 7, or Windows 8. Instructions for determining your Windows environment can be found at http://windows.microsoft.com/en-us/windows7/find-out-32-or-64-bit.

32- and 64-bit operating environments will require different operating code.

Step 2: Download the Statistical Module Executable

If your system operates in a 32-bit environment, download the following two files and save them to your computer:

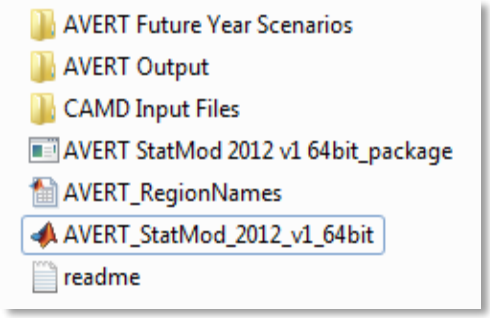
1) **AVERT's Statistical Module executable package:** "AVERT StatMod 2012 v1 32bit_package." Download this MATLAB executable at https://www.epa.gov/statelocalenergy/download-avert.
2) **The MATLAB Compiler Runtime (MCR).** Download the Windows 32-bit version of the MCR for R2012b from the Mathworks website at http://www.mathworks.com/products/compiler/mcr/index.html.

If your system operates in a 64-bit environment, download the following two files and save them to your computer:

1) **AVERT's Statistical Module executable package:** "AVERT StatMod 2012 v1 64bit_package." Download this MATLAB executable at https://www.epa.gov/statelocalenergy/download-avert.
2) **The MATLAB Compiler Runtime (MCR).** Download the Windows 64-bit version of the MCR for R2012b from the Mathworks website at http://www.mathworks.com/products/compiler/mcr/index.html.

Do not download a newer version of the MCR even if one is available from the Mathworks website. It is important to download the exact version listed here (R2012b, also known as version 8.0). This is necessary because the AVERT executable is packaged in a form that can only be compiled by an MCR of the same vintage.

Once the AVERT package is downloaded, we recommend creating a folder on your computer titled "AVERT Statistical Module." Place the AVERT executable package in the folder and run the file. The package will decompress to three files and three subfolders. These folders must stay in the same folder as the Statistical Module for the program to operate successfully.



The folders are:

- **AVERT Future Year Scenarios:** This folder contains the future year scenario template. Other versions of the future year scenario template must be saved in this folder in order for the AVERT Statistical Module to see them.
- **AVERT Output:** This folder will hold Regional Data Files generated by the Statistical Module.
- **CAMD Input Files:** This folder contains MATLAB-formatted flat data files with hourly generation and emissions from each fossil EGU in the United States. The most recent year of data is packaged by default with the Statistical Module. Other years of data can be obtained from EPA, and must be put in this folder to be accessed by the Statistical Module.

The three files are:

- **AVERT StatMod 2012 v1 32bit_package** or **AVERT StatMod 2012 v1 64bit_package:** the executable that will run the Statistical Module once the MATLAB compiler is installed.
- **AVERT_RegionNames:** A library file required to run the Statistical Module. Do not remove this file.
- **readme.txt:** basic instructions on the folders and instructions for obtaining the MATLAB compiler.

Step 3: Download CAMD Database

The Statistical Module package contains, by default, the most recent data year of data. If another year is desired, additional AMPD compatible with AVERT are available at https://www.epa.gov/statelocalenergy/download-avert. For most purposes, users will want to obtain the most recent data year. Download the file and save it in the subfolder "CAMD Input Files."

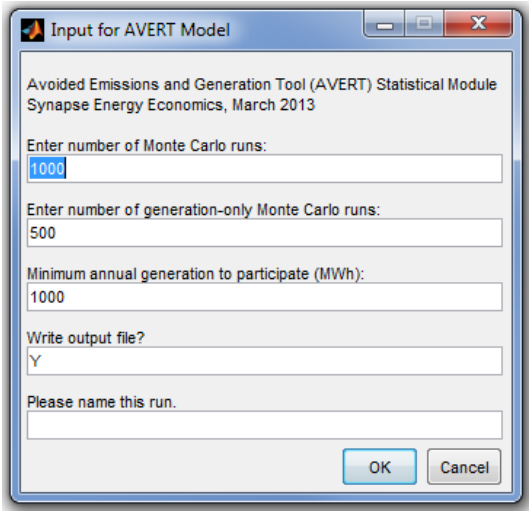
Step 4: Install MATLAB Compiler Runtime (MCR)

The Statistical Module executable requires additional, free MATLAB software in order to function. For additional instruction on how to verify that the MCR is installed properly on your computer, consult the readme.txt file. As noted on the previous page, it is critical to download and install the correct version of the MCR. Using a different version will give you an error message when you try to run the executable file.

Step 5: If Desired, Complete a Future Year Scenario Template

The Statistical Module can create either a base-year or a future year scenario (i.e., a scenario in which some EGUs are retired, new EGUs are brought online, and other EGUs change emissions rates). The process of creating a Future Year Scenario Template is described in Appendix F. A template for the Future Year Scenario Template is available in the folder "AVERT Future Year Scenarios."

Step 6: Launch the AVERT Executable



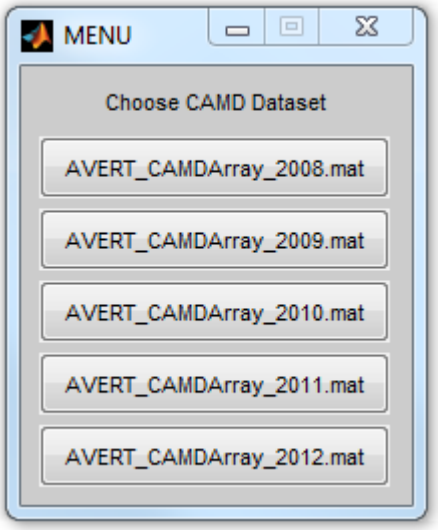
Click on the AVERT executable to launch the Statistical Module. A window labeled "Input for AVERT Model" will open. In this window, select:

- The number of Monte Carlo runs (default value is 1,000).
- The number of generation-only Monte Carlo runs (default value is 500).
- The minimum annual generation for an EGU to be considered in the model (default value is 1,000 MWh).
- Whether or not an output file should be written. Choose "Y" to create an input file for AVERT's Excel-based Main Module; choose "N" to skip writing an output file (typically used for test runs only).
- Designate a run name. This name will be part of the output file name.

Tip: *the number of Monte Carlo runs directly influences how long a run takes to execute. To ensure that inputs and outputs are correctly read, perform a test run with a small number of Monte Carlo runs and generation-only Monte Carlo runs (10 each). For final runs where the output will be used in the Main Module, use at least 1,000 Monte Carlo runs and 500 generation-only Monte Carlo runs.The base dataset supplied by EPA includes 5,000 Monte Carlo runs.*

Step 7: Choose a Base Year for Analysis

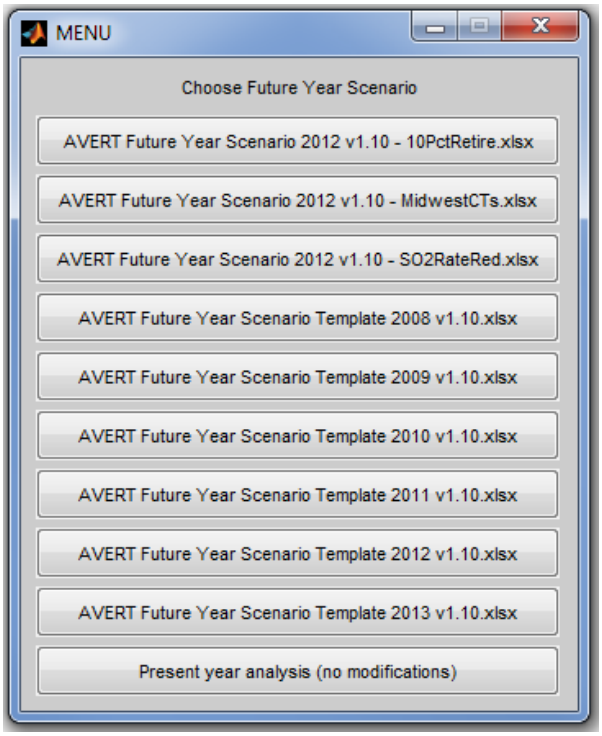
A window labeled “Choose CAMD Dataset” will open. In this window, choose the data file for your desired base year. A second window showing a progress bar will also be visible.



Step 8: Choose a Base- or Future Year Scenario

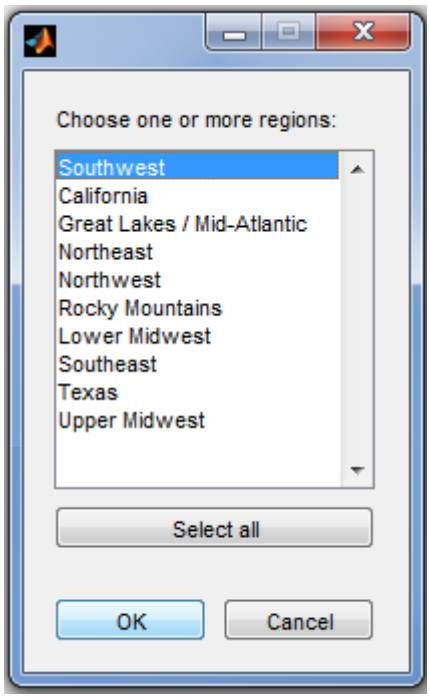
A window labeled “Choose Future Year Scenario” will open. In this window, choose a base- or future year scenario for this analysis. A second window showing a progress bar will also be visible.

Note that each historical baseline year has a unique Future Year Scenario Template. Use only the one associated with the historical baseline year of interest. In other words, having chosen a 2012 base year and using a future year scenario, ensure that the base year of the template is also 2012. In the example here, three scenarios have been created for the 20212 base year, titled “10PctRetire,” “MidwestCTs,” and “SO2RateRed.”



Step 9: Choose Region(s) of Interest

A window labeled “Choose one or more regions:” will open. Choose the region for analysis and click “OK,” or choose “Select All” to launch an analysis of each of the 10 AVERT regions in turn. Two additional windows showing progress bars will be visible.



The selection of a region launches the full Monte Carlo analysis, which can take up to several hours to complete depended on computer processing speed, region selected, and number of Monte Carlo runs selected.

A progress bar will inform the user of how far the program has progressed through various analysis stages, with the Monte Carlo runs usually taking the longest time. After all Monte Carlo runs are complete, an output file will be written if selected at the start of the program.

Each region is complete when the status bar reads “Finished with [Region].” If more than one region is chosen, the program automatically proceeds to the next region.

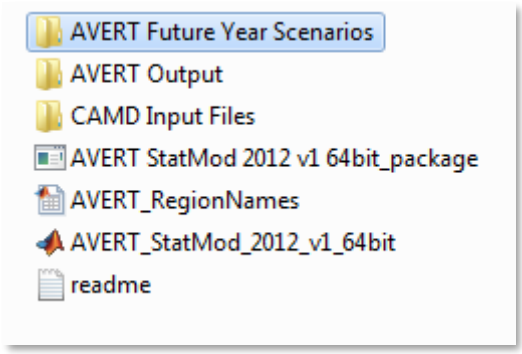
Appendix F: AVERT's Future Year Scenario Template

AVERT is equipped to estimate displaced emissions in scenarios projecting a future year by making adjustments to the regional fleet of fossil-fuel EGUs *before* calculating the probability distributions and expected values discussed in Appendix D.

The user implements these changes before running AVERT's Statistical Module using a spreadsheet called "AVERT Future Year Scenario Template [Year] v.3.0," where year is the data year associated with the file. The most recent historical baseline year template is stored in a subfolder of the Statistical Module called "AVERT Future Year Scenarios." To access and use the Future Year Scenario Template, download the Statistical Module, following instructions in Appendix E. To access other historical baseline year datasets and future year scenario templates, visit https://www.epa.gov/statelocalenergy/download-avert.

For each user-defined scenario, the user is strongly recommended to save this file (in the same subfolder) using the following naming convention:

"AVERT Future Year Scenario [Year] v.3.0 [Scenario X]" where "Scenario X" is a user-defined name and "Year" is the historical baseline year.



The Future Year Scenario Template workbook stores ancillary information about each EGU in the system, and also includes worksheets that the user modifies directly and then inputs into the Statistical Module. This section describes AVERT's process for projecting three types of user-specified adjustments to the fossil-fuel generation fleet:

- Retiring existing EGUs
- Adding additional "proxy" EGUs
- Changing emissions rates for existing EGUs to represent pollution-control retrofits

Users can make adjustments for multiple regions simultaneously; AVERT will correctly associate each EGU with its appropriate region.

Please note that each historical baseline year has a unique Future Year Scenario Template. Use the template associated with the historical baseline year of interest.

Retirement of Existing EGUs

EGUs can be retired from the analysis using the "Retires_Modifications" worksheet. The user finds the EGU of interest and selects "yes" in the dropdown menu under "Retire?"

Addition of Proxy EGUs

New EGUs can be added to the fossil-fuel fleet in the "Additions" worksheet. This process is more complex than that for retirements and retrofits, and requires some knowledge of the types of EGUs expected to be added into the system. To add a new EGU, the user finds a "proxy" EGU for which statistics are already recorded in AVERT and modifies this proxy to meet the requirements of the

user-defined scenario. In most cases and in most regions, the diversity of EGUs is sufficient to provide a proxy for most traditional fossil-fuel generating resources. If completely new types of resources are to be added (i.e., advanced combined cycle, integrated gasification combined cycle, or fossil-fuel backup for wind plants), the proxies available for selection may be insufficient.

In the "Additions" worksheet, the user copies existing rows to create one row for each new EGU required (see Figure 43).

Figure 43: 2011 Screenshot of example EGUs in the "Additions" worksheet.

#	Region	Fuel Type	Unit Type	Unit	ORSPL	UNIT ID	*Description* (Note that "0 MW" units did not run in 2011.)	Capacity (MW)	State	County	Lat - County	Lon - County
										Either select a county from the dropdown, or enter manually		
1	TX	Gas	CC	Bayou Cogeneration Plant CG802	10298	CG802	*This is a 84 MW unit. It is located in Harris County, TX. In 2011, it ran for 516 GWh at a capacity factor of 70%.*		TX	Bastrop	30.126	-97.296
2	TX	Gas	CC	Bayou Cogeneration Plant CG802	10298	CG802	*This is a 84 MW unit. It is located in Harris County, TX. In 2011, it ran for 516 GWh at a capacity factor of 70%.*		TX	Bastrop	30.126	-97.296
3	TX	Gas	CC	Bayou Cogeneration Plant CG802	10298	CG802	*This is a 84 MW unit. It is located in Harris County, TX. In 2011, it ran for 516 GWh at a capacity factor of 70%.*		TX	Bastrop	30.126	-97.296
⋮												
12	TX	Gas	CC	Bayou Cogeneration Plant CG802	10298	CG802	*This is a 84 MW unit. It is located in Harris County, TX. In 2011, it ran for 516 GWh at a capacity factor of 70%.*		TX	Bastrop	30.126	-97.296
13	TX	Gas	CC	Bayou Cogeneration Plant CG802	10298	CG802	*This is a 84 MW unit. It is located in Harris County, TX. In 2011, it ran for 516 GWh at a*		TX	Bastrop	30.126	-97.296

EPA_Facilities | Retires_Modifications | **Additions** | Dropdowns | EPA_AMP | RefTables | eGRID PLNT09 | CapacityGen

For each proxy EGU, the user selects from dropdown menus in the relevant cells:

- The region in which the EGU is to be placed
- The fuel type (gas, oil, coal, or other)
- The unit type (combined cycle, combustion turbine, steam, or other)

The user then chooses an appropriate proxy from a list of available EGUs that meet these selected criteria, and the worksheet automatically fills in the ORISPL code and Unit ID of the proxy and creates a brief description including the base-year capacity, output, and capacity factor of the EGU.

Next, the user adapts the proxy to more closely meet requirements by selecting:

- The desired capacity of the new EGU (i.e., it does not have to be the same size as the historical EGU)
- The state and county in which the EGU will be located

The worksheet automatically fills in the latitude and longitude center of that county as the new EGU's default location. If a more precise location is known, the user can override this latitude/longitude selection by manually entering the correct coordinates. The only purpose of this location selection is to map EGUs in AVERT's Main Module. The latitude and longitude serve no function in model calculations.

Pollution-Control Retrofits

Expected changes in emissions rates due to pollution-control retrofits are also made in the "Retires_Modifications" worksheet. The user finds the EGU of interest, selects "Yes" in the

dropdown menu under "Revise Emissions Rates?" and inputs new rates in lbs/MWh for SO_2 and NO_x, in tons/MWh for CO_2, and in tons/MMBTU for $PM_{2.5}$ in columns I, J, K, or L, respectively. To leave the rate for a particular pollutant unchanged, the user leaves the relevant cell blank. New rates entered by the user must be greater than zero. These adjusted emissions rates will be employed in AVERT as single point estimates of the mean rate; no probability distribution for adjusted emissions is developed for retrofit EGUs.

Running Future Year Scenarios in AVERT

When running AVERT's Statistical Module, the user is presented a menu of future year scenario files saved in the "FutureYearScenario" subfolder. The user can choose one of these files or select "Present Year Analysis (no modifications)." If the user selects a "Present Year Analysis," the model does not read or use any changes to the dataset, including retirements, additions, or changed emissions rates. If the user selects a particular future year scenario, the retirements, additions, and emissions modifications from that scenario's workbook are read into the Statistical Module. Once a region has been selected for analysis, the Statistical Module reports the individual EGUs that have been removed from or added to the region.

Note that each historical baseline year has a unique Future Year Scenario Template. Use the template associated with the historical baseline year of interest.

Future year scenarios require an additional level of calculations before the five steps described in Appendix D can be carried out. For each fossil-fuel load bin, the average generation level of each EGU (retired and active, and including new units) must be determined in a separate Monte Carlo analysis. The results of this analysis change the system fossil-fuel load *perceived* by all of the remaining EGUs to generate the correct output. Since the generation of each EGU is independently derived, each unit's generation is not affected by the generation levels of other EGUs.

If the net change to generating capacity of retiring old and adding new EGUs results in an increase in total generation, the region will incorrectly generate an amount greater than the required fossil load. AVERT determines how much to back down the "perceived" fossil-fuel load in each bin to output the appropriate amount of generation for that bin.[77] For net reductions in generation, the algorithm is simply reversed: perceived system fossil-fuel load is increased, allowing each EGU to generate more than it otherwise would and make up the gap left by retired EGUs.

[77] In this case, "perceived" load is the fossil-fuel load bin for which the model assigns generation and emissions.

Appendix G: AVERT Regions and Instructions for States that Cross Regional Boundaries

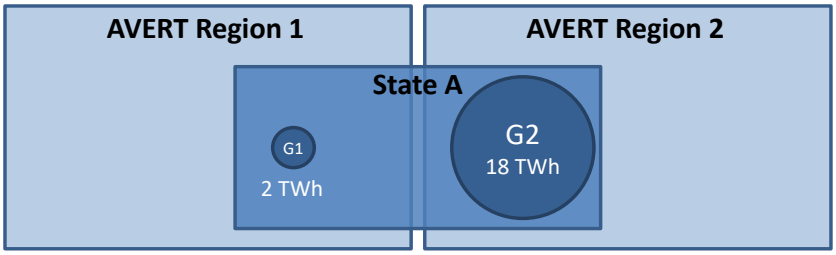
AVERT regions are aggregates of EPA's eGRID subregions and based on regional boundaries used by the North American Electric Reliability Corporation (NERC). Each region generally represents an electrically autonomous area. Each EGU is assigned to exactly one AVERT region. These assignments may change over time as a result of changes in the dynamics of supply and demand. The current version of AVERT assigns EGUs to regions based on the assignments in the 2010 edition of eGRID.

Electrical boundaries do not necessarily represent political boundaries, and as such only 26 states and the District of Columbia are encompassed entirely within one AVERT region. The remaining 22 states in AVERT (Hawaii and Alaska are excluded) are split across AVERT boundaries. With the exception of Missouri and Oklahoma, which are split across three AVERT regions, and Texas, which is split across four, the remaining states are split across two AVERT regions. Refer to Table 1 (on page 16) for the AVERT regions and the states they contain, either in whole or in part.

This section provides instructions for states that are split across more than one AVERT region. AVERT results represent the impacts of the programs only on generators that are contained within that AVERT region. AVERT regions are defined not by state geography but by the generators that fall within their borders. To capture the impacts of a state-wide EE/RE program across two or more AVERT regions, the EE/RE program must be parsed between the two (or more) AVERT regions straddled by the state. It is often not possible within a state to readily ascribe different load centers or EE/RE programs to one region or another. Instead, as a rule of thumb, the impacts of EE/RE programs are assigned, pro rata, to AVERT regions based on the proportional generation provided by EGUs in each AVERT region.

Figure 44 shows a schematic of such an example. In this case, State A crosses AVERT regions 1 and 2, and thus is only partially represented in each. However, the vast majority of State A's generation is located in and serves AVERT region 2. With some exceptions, as an approximation, the effects of the EE/RE program should be split into the two AVERT regions ratably, such that 90 percent of the program (represented by 90 percent of the generation) is run within AVERT region 2, and 10 percent of the program is run within AVERT region 1.

Figure 44. Schematic of recommendation to states that cross AVERT regions.



The exception to this rule is if the user has explicit knowledge of the location of new EE/RE programs and can readily identify the region into which they will fall using the map in Figure 3.

Table 3 indicates, by state, the approximate fraction of fossil generation found in each AVERT region. This table was constructed by reviewing how much fossil electricity was generated from 2010 to 2013 (inclusive) in each AVERT region.

EPA recommends that states that are split between more than one region execute the proportional split for any AVERT regions that contain more than 5 percent of the state's generation. By this logic, 16 states require multiple AVERT region runs. For example, New Mexico and Oklahoma have generation in multiple AVERT regions, but only one of the AVERT regions in which they are located has more than 5 percent of the state's generation; therefore, the other regions can be excluded under most circumstances.

For example, an air quality planner in Arkansas reviewing the displaced emissions benefit of 2,000 MW of wind would run AVERT twice—once with 1,780 MW in the Southeast region, and once with 220 MW in the Lower Midwest region—and then aggregate the results of these runs.

A New Mexico air quality planner, conversely, would run AVERT only once, with all of the EE/RE attributed to the Southwest region, which is in the Western Interconnect. While New Mexico does have territory in the Lower Midwest region, which is in the Eastern Interconnect (SPP RTO), it has relatively little generation in that region. However, wind developments in New Mexico are near the eastern boundary of the state, which is located in the Lower Midwest region. If a planner wanted to review the impact of wind in eastern New Mexico, it would be more appropriate to run AVERT for the Lower Midwest region than for the Southwest region, recognizing that little of the displacement will occur within New Mexico.

Texas covers four AVERT regions, but the fraction of Texas generation that occurs within the Southwest region is small (1 percent), and therefore EPA recommends that all EE/RE be parsed into the other three regions: Texas, Southeast, and Lower Midwest. To determine the fraction of EE/RE attributable to each region, users should normalize the remaining fractions such that they add to 100 percent; in Texas's case, this means dividing each region's fractional coverage by 99 percent. EE/RE in the Texas AVERT region should be apportioned as:

- Texas: 82 percent (or 81.6 percent divided by 0.99, rounded).
- Southeast: 6 percent (or 6.0 percent divided by 0.99, rounded).
- Lower Midwest: 12 percent (or 11.7 percent divided by 0.99, rounded).

Table 3. State apportionment in AVERT regions, based on fossil generation from 2010 to 2013.

State (# regions)	Northeast	Great Lakes / Mid-Atlantic	Southeast	Lower Midwest	Upper Midwest	Rocky Mountains	Texas	Southwest	Northwest	California
Alabama			100.0%							
Arkansas (2)			88.7%	11.3%						
Arizona								100.0%		
California								0.3%		99.7%
Colorado						100.0%				
Connecticut	100.0%									
District of Columbia		100.0%								
Delaware		100.0%								
Florida			100.0%							
Georgia			100.0%							
Iowa					100.0%					
Idaho									100.0%	
Illinois (2)		38.8%			61.2%					
Indiana		100.0%								
Kansas				100.0%						
Kentucky (2)		9.4%	90.6%							
Louisiana (2)			76.1%	23.9%						
Massachusetts	100.0%									
Maryland		100.0%								
Maine	100.0%									
Michigan		99.6%			0.4%					
Minnesota					100.0%					
Missouri (3)			21.0%	33.8%	45.2%					
Mississippi (1)			98.9%		1.1%					
Montana (1)					2.3%				97.7%	
North Carolina			100.0%							
North Dakota					100.0%					
Nebraska					100.0%					
New Hampshire	100.0%									
New Jersey (2)	23.4%	76.6%								
New Mexico (1)				2.9%				97.1%		
Nevada (2)								72.0%	28.0%	
New York	100.0%									
Ohio		99.7%			0.3%					
Oklahoma (1)			4.1%	92.8%			3.1%			
Oregon									100.0%	
Pennsylvania		100.0%								
Rhode Island	100.0%									
South Carolina			100.0%							
South Dakota					99.7%	0.3%				
Tennessee			100.0%							
Texas (3)			6.0%	11.7%			81.6%	0.7%		
Utah (2)									65.1%	34.9%
Virginia (2)		5.1%	94.9%							
Vermont	100.0%									
Washington									100.0%	
Wisconsin (2)		45.2%			54.8%					
West Virginia (2)		87.7%	12.3%							
Wyoming (2)						38.3%			61.7%	

Appendix H: Frequently Asked Questions

Renewable Energy and Energy Efficiency

Are users restricted to the EE/RE profiles created within AVERT's Main Module?

No. The Main Module maintains simple wind and solar profiles for various regions of the United States for the convenience of users, but does not restrict users to these profiles. Users are encouraged to create EE/RE profiles that reflect their regions and assumptions. Such profiles can be copied into the manual entry page of the Main Module.

Can I review renewable energy options other than wind and solar generation?

Yes. New non-intermittent, must-take renewable generation, such as hydroelectric generation or geothermal generation, can be approximated using either the manual hourly data entry or the preset EE impact sections. For example, if you want to model the impact of a new hydroelectric generator, you could click on "Enter hourly data manually" in AVERT's Step 2 and enter the expected hourly generation curve. If you assume the non-intermittent resource functions as a purely baseload resource, you could use the "annual GWh" setting as a proxy.

Is there a way for baseload renewables to be included?

You can model non-emitting, must-take baseload renewables like geothermal or hydroelectricity in AVERT using the "annual GWh" setting in Step 2.

How do you handle biomass, waste combustion generators, or combined heat and power (CHP) generators in AVERT?

If biomass, waste combustion, or CHP generators are emitting and have capacities greater than 25 MW, they are included in the EPA's Air Market Program Dataset (AMPD).

AVERT is not currently equipped to estimate the emissions of emitting generators that do not report to AMPD. However, if you know the expected generation and emissions from a new biomass, waste, or CHP generator, you could review the estimated displaced emissions and generation from the inclusion of that generator using AVERT (assuming an hourly load impact shape is known for the new EGU) and then add in that generator's emissions *post-hoc*. To do so, follow the steps below:

1. Determine estimated load impact profile for CHP generator and associated stack emissions.
2. Input load impact profile for CHP generator into AVERT under "manual EERE data entry" in Step 2.
3. Run Main Module to determine emissions offset due to new CHP generator.
4. Subtract CHP stack emisssions from emissions offsets to determine total emissions impact.

Net emissions reduction from CHP generator = AVERT displaced emissions + CHP stack emissions.

There is no current option to review emissionsdisplaced from new biomass, waste, or CHP generators if they do not already report to AMPD.

Are there any plans to incorporate electricity production from biogas facilities into the Tool?

If the facility is an emitting generator and has a capacity greater than 25 MW, it is currently included within the AMP EGU dataset. Otherwise, there are no current plans to incorporate electricity production from these types of facilities. Often, these facilities may generate electricity according to their on-site needs and fuel supply and may not be affected by regional changes in load or dispatch.

Can storage technology be modeled in AVERT?

Yes. Energy storage, such as batteries, pumped hydroelectric generation, and compressed air storage, is used to capture excess energy at low-cost (often low-demand) periods, and release that energy at high-cost (often high-demand) periods. AVERT draws statistics from, and dispatches against, a base year time-series of demand. You can create an energy storage assumption (how much energy is drawn off a renewable resource, when it is released, and what the associated losses are) and create a manual EE/RE profile that reflects this energy storage assumption. As with all other EE/RE assumptions in AVERT, users are encouraged to create a time-series of EE/RE generation that fits their region and assumptions.

How does AVERT account for the dispatch of new RE into the existing system?

RE generation sources typically have very low variable operating costs; in other words, they are very inexpensive to operate once they are constructed. Typically, low-operating-cost resources are dispatched first, and increasingly expensive resources are dispatched thereafter. RE sources are assumed to dispatch first (a common assumption across many economic dispatch models), and thus can be modeled as an equivalent reduction in demand. AVERT simply compares the generation and emissions of all fossil resources before the new RE resource (i.e., at the equivalent of full demand in each hour) and after the new RE resource (i.e., at the equivalent of a reduced demand in each hour). The difference in generation and emissions between the before and after scenarios represents the emissions displaced by RE.

How does AVERT account for the dispatch of new EE into the existing system?

EE usually results in a reduction in demand (in some cases and for some types of programs, it may result in a shifting of demand to off-peak hours). AVERT simply compares the generation and emissions of all fossil resources before the new EE resource (i.e., at the equivalent of full demand in each hour) and after the new EE resource (i.e., at the equivalent of a reduced demand in each hour). The difference in generation and emissions between the before and after scenarios are the emissions that are displaced by EE.

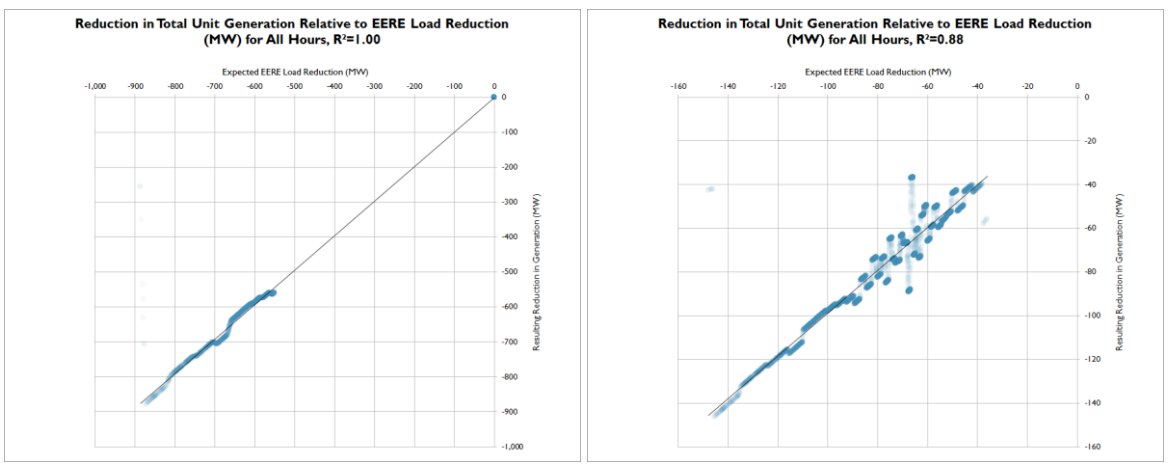
Is there a bound on the smallest EE/RE program that is appropriate to model?

No. In the current version of AVERT, users can review the output chart titled “Hourly Contribution to Reduction in Generation” for an indication of how closely their expected reduction is captured in hour-to-hour unit reductions. At very small scales of production, this graphical interface will indicate a rougher hour-to-hour displacement impact profile—i.e., the amount of generation displaced will look less like the amount of EE/RE implemented. For a more comprehensive check, the user should view the “Signal-to-noise diagnostic,” found on the “Display Outputs” page of AVERT’s Main Module. As described in this manual (p. 41), this scatter plot shows the generation reduction calculated by AVERT (on the y-axis) against the EE/RE load reduction implemented by the user.

More reasonable results (from a program size perspective) will appear closer to 1:1 lines. Smaller load reduction have more noise (i.e., scatter) in this plot, while larger load reductions have a straighter line relationship. The R^2 value in the title of the chart indicates how much of the generation reduction can be explained by the EE/RE load reduction. For examples, an R^2 value of 0.9 indicates that AVERT has captured 90 percent of the generation reduction required by the user, while a value of 0.7 indicates that AVERT has only correctly captured 70 percent of the EE/RE required by the user (i.e., noise accounts for 30 percent of the observed variability).

Figure 45 below shows two different load impact profile with very different R^2 values from the same region, and designed similarly. The graph on the left is a 1.5 percent load reduction during the peak 20 percent of hours. The reduction is sufficiently sized such that the generation reduction is able to match the requirement very closely—over 99 percent of the reduction in generation is a direct result of the input EE/RE program. The graph on the right is a 0.25 percent load reduction during all hours of the year. The reduction is insufficiently sized in this case and results in a wide range of uncertain results. Only 88 percent of the generation reduction can be attributed to the EE/RE program—the rest is noise.

Figure 45. Examples of two different load reductions with different R^2 values in the signal-to-noise diagnostic. Left: 1.5 percent load reduction in peak 20 percent of hours. Right: 0.25 percent load reduction in all hours.



Note that all numerical results are shown rounded to the nearest 10 unit.[78] Dashes ("–") indicate that AVERT reported a value greater than zero, but lower than the level of reportable significance. In some cases, no reasonable sized EE/RE program will result in reportable reductions. For example, the review of monthly displacement output for a single small county in a low load month may often result in low significance results. However, the user can use discretion to determine if an EE/RE program has resulted in an acceptable level of significance based on the signal-to-noise diagnostic and the degree to which critical results are below the level of acceptable significance (i.e. are obscured by dashes in numerical results).

[78] Data are reported by AMPD in integer units of MWh (generation), lbs (NO_x and SO_2), tons (CO_2) and MMBtu (heat input). Output data in AVERT are rounded to the closest 10 MWh, lbs NO_x and SO_2, tons CO_2, and MMBtu fuel input.

Is there a bound on the largest size EE/RE program that is appropriate to model?

There is not a formal bound on the largest size EE/RE program that should be modeled in AVERT. Realistically, at very low loads (i.e. below those historically experienced in the base data year), AVERT will generally under-predict the expected generation reductions achieved by EE/RE programs, and thus under-predict emissions changes. See Figure 42 for details on biases at low extrapolated load bins. It is recommended that programs generally not exceed 15 percent of fossil generation in any given hour. Users should note that AVERT is designed to review marginal operational changes in load, rather than large-scale changes that may change fundamental dynamics.

Are EE/RE reductions applied over the whole region? Is there a way to apply them at the state, county, or municipal level only?

Because AVERT does not model transmission constraints within a region, EE/RE reductions are assumed to have region-wide impacts. A limitation of AVERT is that it is insensitive to the physical location within a region of new EE/RE programs, despite the fact that real-world dispatch decisions may be quite sensitive to specific locations of new EE/RE resources as well as EGUs. AVERT assumes that EE/RE programs are spread across the modeled region and cannot currently identify the differential impacts of local versus regional EE/RE programs. Such differentiation requires the use of a production cost model.

Please see the user manual, Chapter 2, Section “Limitations and Caveats,” for more information. Detail on displacements at the state and county level are available on the output sheet “Annual Displacement Data by County.”

AVERT Outputs

Does AVERT account for losses?

Yes, AVERT accounts for two types of losses as of summer 2017 in Version 1.6 of the Main Module. First, gross generation as collected in the AMPD database is corrected to account for parasitic consumption of energy onsite at fossil-fired EGUs. AVERT applies a parasitic loss factor to each EGU based on unit and fuel characteristics and subsequently calculates emissions based on each unit’s “net” output of energy exported to the grid. Second, reductions in fossil load due to energy efficiency and distributed photovoltaic are corrected to account for avoided grid (transmission and distribution) losses, using region-specific grid loss factors. Wind and utility-scale PV profiles are not corrected for these losses, as it is assumed they are located at a similar distance from load centers as fossil-fired EGUs.

How can users assess the accuracy of the results returned by AVERT’s Main Module?

The current version of the Main Module is not equipped to return information on the accuracy or uncertainty of the model results.

While the Monte Carlo analysis run by AVERT creates information useful for some forms of uncertainty analysis, using this information to assess the accuracy of the results returned by the Main Module would require simultaneously performing a Monte Carlo analysis on the baseline scenario and on the EE/RE modified scenario, and returning uncertainty metrics associated with the difference between these two scenarios. The current version of AVERT does not contain this

information. EPA is exploring a future version of AVERT that could perform explicit uncertainty analyses and allow users to assess the accuracy of results returned by the model.

What is the accuracy of the map chart in AVERT's Excel-based Main Module?

The map is a visual cue only, and should not be used as a precise rendering of the location or influence of displaced generation or emissions from any EGU or cohort of EGUs. Maps could be used for visual presentations to show the general location of emissions.

Why do some EGUs show positive increases in generation with decreases in system load?

Some EGUs show positive increases in generation with decreases in load because the EGU statistics indicate either a slight increase in the probability of operation at very low loads, or an increase in generation at very low loads. Spot checks indicate that most of the EGUs that show generation increases with decreases in system load are due to baseload EGUs that show a lower probability of generation at mid-range loads then at either very high or very low loads. In other words, these EGUs counterintuitively *increase* the probability of operation as system load levels become very low. Further inquiry into these EGUs suggests that they have prolonged maintenance outages during spring or autumn—i.e., during periods of generally low load, but possibly not the lowest in the year. Therefore, the EGU will register as non-operational through a wide swath of medium-low loads, but may operate during the very lowest loads of the year. Therefore, the statistics capture this behavior and increase expected generation by a small margin when system load is reduced from very low load periods. This pattern is almost always observed in trough periods.

AVERT Statistical Module

Why is the model driven by system fossil generation instead of by demand or total load?

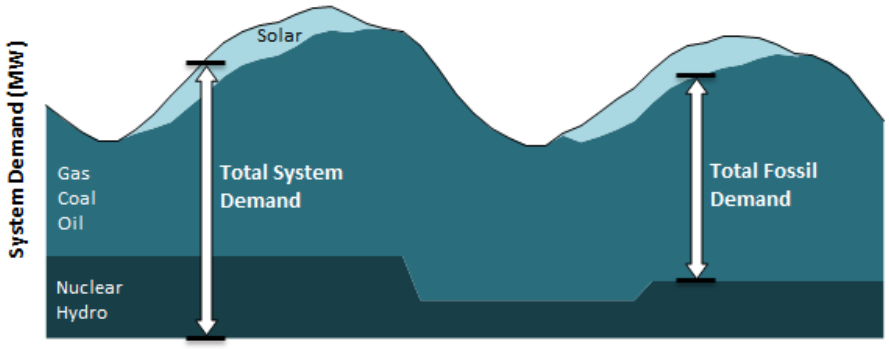
AVERT is a statistically based model that tracks and reproduces EGU behaviors. EGUs are forecast to operate in the near future much as they operate today. In electrical system dispatch, determing how an EGU operates is largely driven by two factors—total demand on the system and the cost of operation for any given EGU. In economic dispatch, more expensive EGUs are dispatched at higher levels of demand.

In AVERT, the degree to which an EGU will be dispatched in the future is assumed to be the same as the degree to which it has been dispatched at a historical level of demand .This assumption incorporates the relative operational cost of different EGUs. In other words, EGUs that dispatched at high demand were likely more expensive to operate and thus are likely to be on the margin at the same level of demand.

However, if AVERT were to observe the behavior of EGUs against total system demand, it would miss an important factor: the large number of non-fossil EGUs that are dispatched at very low operating costs—such as solar, wind, hydroelectric, and nuclear operations.These non-fossil EGU have the same effect as lowering system demand, or specifically, system demand that needs to be met by fossil generation. Therefore, AVERT dispatches against demand for fossil resources, rather than total system demand. New EE/RE programs are assumed to reduce the demand for fossil

resources. Figure 46 below illustrates the difference between total system demand and demand for fossil resources.

Figure 46. Diagram schematic of system demand over two days, divided into fossil and non-fossil components illustrating system and fossil demand.



Does the sum of all unit generation in any given Monte Carlo run add up to the size of the load bin (i.e., the expected fossil generation)?

Not necessarily. The generation from each EGU is calculated independently in each Monte Carlo run, meaning that there is no constraint that forces the output of all EGUs to equal the exact size of the load bin. The total sum of all unit generation from any given Monte Carlo run may be slightly larger or smaller than the load bin. However, over large numbers of Monte Carlo runs, the average output of each EGU will sum quite closely to the expected fossil generation, or the size of the load bin.

Is it possible to displace baseload EGUs in AVERT?

Yes. AVERT treats baseload EGUs, or units that run during most hours, including during baseload hours of the year, the same as all other EGUs. There is no distinguishing characteristic that either promotes or prevents an EGU from running during any given hour, except for how it has operated in the past. If an EGU has experienced little downtime in the past and operates continuously even a low levels of load, the model will replicate this behavior going forward. This type of EGU is unlikely to be displaced by EE/RE in AVERT. However, an EGU that ramps from high output in the daytime to low output on offpeak hours may show a displacement if system demand declines due to RE or EE.

Can AVERT capture or replicate ramping behavior?

No. AVERT performs a separate calculation for each hour of the year and does not evaluate the rate at which an EGU increases or decreases generation. Capturing this behavior requires a chronological dispatch model.

Can AVERT capture or replicate spinning reserves behavior?

Yes. AVERT captures historical generation patterns. EGUs that maintain a spinning reserve (i.e., maintain a minimum level of generation in most operating hours) will reflect this pattern in the statistics gathered by AVERT. The Lake Hubbard EGU shown in Figure 33 is a classic example of an EGU that appears to maintain a spinning reserve. It maintains an output of about 150 MW per

hour for most hours of the year. However, when system demand climbs above 45,000 MW, it quickly climbs towards an output of 500 MW.

Can AVERT capture transmission constraints or changes in transmission?

Generally, no. AVERT operates on the simplifying assumptions that there are no transmission constraints between load centers and EGUs within a region and that regions are independent of each other. Therefore, AVERT is insensitive to the location where new EE/RE resources are placed within a region, and thus does not capture transmission constraints. However, the behavior of some EGUs may be influenced by historical transmission constraints, and this behavior is captured by AVERT. For example, in “load pockets,” or areas of constrained inbound transmission, reliability EGUs may run at lower regional load levels than would otherwise be dictated by economic dispatch. Because AVERT is not an economic model, it simply replicates the behavior of these EGUs, which may capture some elements of current transmission constraints.

Due to the same simplifying assumptions that prevent AVERT from operating as a transmission-constrained dispatch model, AVERT cannot capture future changes in transmission, which typically change which future EGUs can compete to provide the lowest-cost energy in a particular area.

Are recent fuel prices reflected in AVERT?

Yes. To the extent that fuel prices have influenced dispatch during the base data year you choose, AVERT will reflect those dispatch decisions. AVERT cannot, however, change dispatch based on future economic or regulatory conditions, such as expected fuel prices, emissions prices, or specific emissions limits. AVERT should not be used for this type of analysis, as such changes require an economic dispatch model.

Are emissions control technologies reflected in AVERT?

Yes. To the extent that emissions controls were in operation at the time that data was collected in the base data year, emissions will reflect operational (and operating) control technologies. To the extent that a user requires a review of dispatch with different emissions rates, they can override observed emissions rates using the “Future Year Scenario Template” as described in Appendix F. Modeling emissions prices, specific emissions limits, or fuel switching requires an economic dispatch model.

Are predicted changes in fuel or emissions prices reflected in AVERT?

No. AVERT should not be used for this type of analysis; capturing this behavior requires an economic dispatch model.

What other tools are available to me to estimate displaced emissions aside from AVERT?

You can model generation and emissions displaced by new EE/RE programs in a production-cost dispatch model. These programs simulate real dispatch decisions based on explicit costs and operational constraints, optimizing generator use to minimize costs. Some of these models are sensitive to EGU ramp-rates, transmission constraints, and outage schedules.

For the most part, these models are highly detailed, proprietary, and require specialized labor and licensure to operate and use, as well as some degree of proprietary knowledge for fuel costs and operational constraints.

AVERT provides an alterantive, publicly available tool to estimate displaced emissions in near-term years (no more than 5 years from the baseline year).

Future Year Scenarios

Why is there a different future year template for each historical baseline year?

AVERT is sensitive to the composition of the electric fossil fuel fleet. Every year, the composition of the fleet changes slightly as new EGUs are added or retired. To accommodate this changing fleet, AVERT creates a new future year scenario template for each historical baseline year. Using a mismatched pair in AVERT's Statistical Module (e.g., a historical baseline year of 2009 but a future year template of 2012) risks accidentally using proxy "new" EGUs that did not exist in 2009, and thus will not be incorporated into a 2009 analysis.

Why are some generators excluded from AVERT's Future Year Scenario Template?

AVERT considers EGUs that report to EPA's Air Program Markets Dataset (AMPD) only. This may exclude generators with less than 25 MW of capacity or generators that did not operate in a particular year.

Why are some generators included in the Future Year Scenario Template but do not show up in the Regional Data File?

AVERT's Statistical Module allows users to exclude small, low-generation units from consideration in the displaced emissions analysis. Small peakers have statistics that may be non-representative of expected generation patterns (i.e., they cannot be readily extrapolated or interpreted outside of specific events). By default, AVERT excludes units that have generated less than 1,000 MWh per year. For a 25-MW unit (the smallest reporting unit), this would be the equivalent of 40 hours of generation over the year, or less than one-half of one percent of all possible operational hours.

In the future scenario demo, does the total for avoided emissions include the impact of the retirements, or just the EE/RE program impacts adjusted based on retirements?

Results from AVERT runs using the Future Year Scenario Template do not include displaced emissions from user-specified retired units. These units are assumed to be retired in both the "before" and "after" cases.

The purpose of the retirements category is to exclude from consideration any units that are likely to be non-operational in the future year, regardless of the EE/RE program selected.

Does EPA provide projections for use in AVERT's Future Year Scenarios?

At this time, EPA is not providing projections for use in AVERT. Future scenarios are meant to be developed by users. You can use AVERT's future scenario template to make known changes in the regional data set. However, AVERT is not meant to be used for more than 5 years in the future from the baseline. EPA will issue periodic updates to the historical data files available for download, but will not release stand-alone future scenarios. At this time, EPA anticipates releasing new Regional Data Files in the first quarter of each year.