AVoided Emissions and geneRation Tool (AVERT)

User Manual
Version 3.0

September 2020

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 and Colby Tucker 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., Caitlin Odom, Avi Allison, Jamie Hall, Erin Camp, Elizabeth A. Stanton, Ph.D., and Bruce Biewald. Eastern Research Group, Inc. (ERG) provided production and logistical support and developed the web-based version of AVERT, with thanks to Chris Lamie, Courtney Myers, Bryan Neva, Emma Borjigin-Wang, and several ERG colleagues. ERG and Synapse provided these services under EPA contracts #EP-BPA-12-H-0025, #EP-BPA-12-H0036, and #68HERH19D0028. 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

What's New in AVERT 3.0?

AVERT 3.0 is the latest version of AVERT and has several new features. For a full version history, see Appendix J. Key updates include:

- Revised regions. The 14 revised AVERT regions reflect the modern electric grid and are based on aggregations of one or more balancing authorities. For more information on how these regions are defined, see Appendix B.
- Offshore wind. EPA added the ability to model offshore wind for the regions where the electrical grid would connect to offshore wind farms. For more information, see page 54.
- Capacity factor scaling (Excel-based AVERT only). Users can now adjust the hourly default capacity factors for renewable energy resources. For more information, see page 32.
- Statewide analysis (web-based AVERT only). The web version of AVERT can now perform analyses for a selected state, including states that span more than one AVERT region. For more information, see Appendix I.
- Improvements to the quality of underlying emissions data. AVERT uses historical hourly generation, heat input, and emissions data collected by EPA and reported by power plant operators. While the vast majority of these data are measured, in rare instances power plants report "substitute" data when measured data are not available. These substitutions constitute less than 2% of all data points. A subset of these substitute data is the "maximum potential concentration" (MPC)—that is, the maximum amount of emissions physically possible from the plant. These MPC values are generally a substantial overestimation of the actual emissions; therefore, to improve reliability of AVERT's results, these values have been excluded during the creation of Regional Data Files (RDFs). For more information on the creation of the RDFs, see Appendix B.

1. Introduction

The U.S. Environmental Protection Agency (EPA) recognizes that many states are adopting, implementing, and expanding cost-effective energy efficiency (EE), renewable energy (RE), electric vehicle (EV), and energy storage policies and programs. States are investing in policies and programs to achieve benefits including lowered customer costs, improved electric supply reliability, and diversified energy supply portfolios.[1] Certain energy policies 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 changes resulting from energy policies.[2] Basic methods entail a simple calculation: multiplying the amount of generation or electricity consumption changed by the 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, offer more temporal resolution and greater functionality than basic methods, while being transparent, credible, free, and accessible. Sophisticated methods offer the highest level of detail, but 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 energy policies and programs 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 estimates the change in generation from one or more energy policy scenarios. These scenarios could be EE savings or RE deployments that reduce the amount of generation needed, or policies and programs that increase the amount of generation needed (e.g., EVs). AVERT applies this change in generation and predicts changes in hour-by-hour generation and emissions for individual power plants, called electric generating units (EGUs). AVERT is therefore indirectly measuring the change in emissions from these interventions, which is in contrast to direct measurements, like emissions reductions resulting from stack controls in an EGU's smokestack.

Energy policies may be implemented though specific programs and technologies that have hourly load[3] profiles, which are hour-by-hour schedules of expected reductions or increases in electricity demand or electricity production for a year. Understanding the hour-by-hour relationship between specific energy programs and the dispatch of fossil fuel EGUs is essential to the estimation of the magnitude and location of changes in emissions resulting from energy policies.

EPA has developed a credible, free, user-friendly, and accessible tool to estimate emissions changes resulting from energy policies and programs so that air quality planners can incorporate

[1] A variety of technologies, policies, programs, and specific projects can be modeled in AVERT. These activities increase or decrease electricity generation, electricity demand, and/or electric sector emissions in at least one hour of the year. For simplicity, the term "energy policies" is used in this document to encompass all these types of activities.

[2] See Appendix I at https://www.epa.gov/energy-efficiency-and-renewable-energy-sips-and-tips/energy-efficiencyrenewable-energy-roadmap.

[3] "Load" is the term used throughout this manual to describe regional demand for electricity.

those impacts into their NAAQS State Implementation Plans (SIPs).[4] The AVoided Emissions and geneRation Tool (AVERT) quantifies the changes in 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 energy policies and programs within the contiguous 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 these energy changes in place.

AVERT users can analyze how different types of EE programs, as well as wind, solar, and other RE and electrification 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 Changes in Emissions

Estimating the location of changes in generation and associated changes in emissions 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 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 customer demand for electricity in each moment and the variable cost of production at each plant.[5] 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 and 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.[6] EE and RE resources displace higher-variable-cost, higher-emission-producing fossil-fuel generation. While electricity planners typically think about a single

[4] See Appendix I of the *Roadmap for Incorporating Energy Efficiency/Renewable Energy Policies and Programs* (https://www.epa.gov/energy-efficiency-and-renewable-energy-sips-and-tips/energy-efficiencyrenewable-energy-roadmap) for details on how this approach can be used in the different NAAQS SIP pathways.

[5] "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.

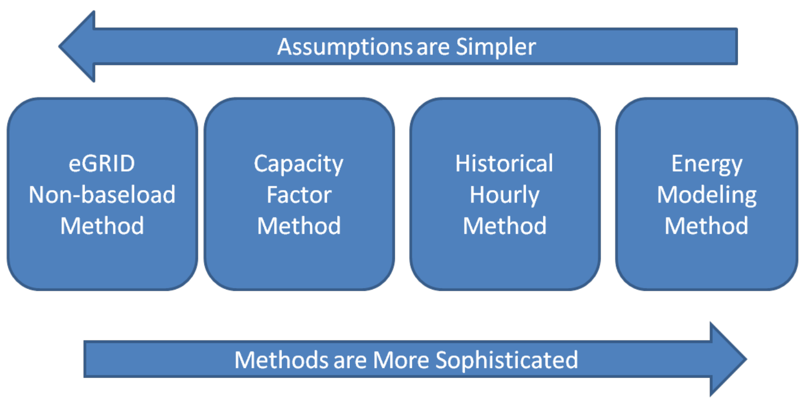
[6] "Must-take" resources are so named because they cannot generally be centrally dispatched (i.e., a controller cannot determine when they provide power), and as such they must be taken when they provide power. These resources can be curtailed under unusual circumstances, such as during periods of excess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

marginal resource,[7] 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 resources impact different generation in different hours or seasons. Hourly energy 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, hourly energy profiles can represent a portfolio of programs used to meet a policy target, such as the Energy Efficiency Resource Standards adopted by 27 states.[8] 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 impacted during particular hours or under certain conditions is a complex endeavor. It is not possible to definitively predict how resources from an energy policy will affect any given power plant. There are, however, several ways to estimate which EGUs would be impacted when and by how much based on new resources' hourly energy profiles, EGUs' historical operational behavior, projected information on cost, and other factors affecting dispatch in each regional electricity market.

Figure 1. Emissions quantification methods.



As noted above, methods for estimating projected changes to 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 changes to emissions. The more sophisticated fourth approach predicts future electricity market conditions and emissions changes. Each method attempts to identify the group of EGUs whose generation activity would change as a result of new programs or measures that vary in terms of their sizes, geographic areas, and timing during the day and the year.

Basic Method: eGRID Non-baseload Method

This basic method calculates the average non-baseload changes in emissions resulting from energy policies and programs in one of EPA's "eGRID" subregions.[9] Annual electricity generation or sales increased or displaced by a program or measure are multiplied by the "non-baseload"

[7] The highest-cost unit that is required to meet customer demand at any particular time.
[8] U.S. EPA. 2015. *Energy and Environment Guide to Action.* Chapter 4.1. https://www.epa.gov/statelocalenergy/energy-and-environment-guide-action.
[9] eGRID data can be found at https://www.epa.gov/energy/egrid.

emissions rate for each pollutant in each eGRID subregion.[10] The non-baseload emissions rates for an eGRID subregion are appropriate to represent the average emissions rate for the EGUs most likely to be impacted by EE or RE.

Basic Method: Capacity Factor Approach

The capacity factor approach estimates emissions impacts 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).[11] The capacity factor is used as a proxy for the likelihood that any given EGU will be impacted by new resources resulting from energy policies. Infrequently dispatched EGUs with low capacity factors are more likely to be impacted 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.[12] This method couples historical hourly generation and emissions with the hourly load profiles of energy resources to determine hourly marginal emissions rates and hourly changes in emissions. AVERT can be used to predict emissions changes 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.[13] 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 scenarios.[14]

---

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

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

[12] See EPA's Power Sector Emissions Data at https://ampd.epa.gov/ampd/.

[13] 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.* https://www.synapse-energy.com/sites/default/files/Emissions%20Reductions%20from%20Renewable%20Energy%20and%20Energy%20Efficiency%20in%20California%20Air%20Quality%20Management%20Districts%2008-016.pdf.

[14] A variety of utility-standard models are available to estimate the impact of new energy changes on existing plant 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, 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 impacts of specific new resources. These "capacity expansion" models include such platforms as EGEAS (https://www.epri.com) and System Optimizer and Strategist (https://new.abb.com/enterprise-software/energy-portfolio-management/commercial-energy-operations/capacity-expansion). 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, or IPM

Using AVERT

AVERT is a free tool that allows users with minimal electricity-system expertise to easily evaluate county-level changes in emissions resulting from energy policies. AVERT is primarily designed to estimate the impact of new energy policies and 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.[15]

To estimate changes in emissions using AVERT, users will need to know the type of program or measure to be analyzed or the program's energy profile. An annual energy 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 will experience a change in output as a result of specific programs or measures.[16] In the absence of specific data on energy changes, planners need to use their judgement to approximate the timing of these changes.

Using these inputs, AVERT automatically estimates emission changes 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 changes in emissions, with the option of highlighting high-electric-demand days. Expert air quality modelers assessing changes in $PM_{2.5}$, NO_x, and SO_2 emissions can use the SMOKE (Sparse Matrix Operator Kernel Emissions) output function to produce hourly, EGU-specific air-dispersion-model-ready data. AVERT users assessing the public health impacts of the criteria pollutant reductions can use the COBRA (CO-Benefits Risk Assessment) output function to produce model-ready county-level emissions impact data.

AVERT is best suited to analyze the emissions changes resulting from state-wide or multi-state energy policies and programs. Since AVERT modeling is conducted in one of 14 large regions that represent electricity markets and does not account for transmission constraints within each region, this tool is not recommended for estimating the change in emissions under small local programs. Smaller programs can use AVERT-generated emission factors to estimate emission changes 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 load changes to be modeled in AVERT.) In addition, the tool is equipped to predict changes 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.

(https://www.epa.gov/airmarkets/clean-air-markets-power-sector-modeling); the National Renewable Energy Laboratory's Regional Energy Deployment System, or ReEDS (https://www.nrel.gov/analysis/reeds/); and DOE's National Energy Modeling System, or NEMS (https://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.

[15] See EPA's *Roadmap for Incorporating Energy Efficiency/Renewable Energy Policies and Programs in SIPs* (https://www.epa.gov/energy-efficiency-and-renewable-energy-sips-and-tips/energy-efficiencyrenewable-energy-roadmap) for details on other regulatory requirements.

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

AVERT provides useful information to expert energy or air quality planners, and also to interested stakeholders. In 2018, EPA released a web-based version of the AVERT Main Module on EPA's website (www.epa.gov/avert). It provides a streamlined interface with much of the same functionality as the downloadable Excel-based Main Module, without the need to use Excel software or upload separate Regional Data Files (RDFs). The web edition relies on the most recent year of input data. Refer to Appendix I for a comparison between the Excel- and web-based Main Modules' functionality and available display outputs.

Example Use A: Air Quality Planner Quantification of Changes in Emissions Resulting from an EE Program for SIP Compliance

Air quality planners can use AVERT to quantify the expected emissions of a new wind farm, solar initiative, or EE program for the purposes of Regional Haze Rule or NAAQS SIP/Tribal Implementation Plan 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 SO_2 and $PM_{2.5}$ 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 can incorporate expected retirements and changes in emissions rates expected in future years, and establish new baseline conditions. Because AVERT can 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.[17]

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

Stakeholders can use AVERT to develop and test multiple types of EE 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. Using AVERT, they can quickly test different types of EE load profiles and estimate the resulting displaced emissions. Users would modify input parameters to simulate baseload, peak load, 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, which can help them consider adopting and/or implementing programs with the greatest improvements to air quality.

Cautionary Note

AVERT should only be used to assess changes to emissions resulting from energy programs—not to assess changes to an EGU fleet. For example, AVERT is not equipped to examine the changes

---

[17] 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.

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 changes in emissions resulting from changes to the overall pattern of dispatch.

Benefits of Using AVERT

AVERT combines historical hourly generation data with energy profiles, making it possible for users to:

- Compare the emissions benefits of different types of energy polices, programs, or technologies.
- Incorporate energy policies and programs into air quality models; public health impact tools, such as EPA's COBRA Screening Model; and SIPs to demonstrate Clean Air Act compliance.
- Estimate emission changes 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 change in emissions 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 changes 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 load changes 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.. Current and historical emission factors are available at https://www.epa.gov/avert and can be used for quick estimates of avoided emissions, especially for very small energy policies. They were calculated by assuming a 0.5% reduction in the regional fossil generation and are divided into six categories: onshore wind, offshore wind, utility PV, distributed PV, portfolio EE, and uniform EE.

AVERT is driven entirely by historical, publicly available data reported to EPA and the U.S. Department of Energy's (DOE's) Energy Information Administration (EIA). It uses statistically driven "behavior simulation" to estimate near-term future emissions changes 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,[18] 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,

[18] A must-run designation indicates that a unit is required to operate for reliability reasons; such units often operate at minimum levels to maintain the ability to meet higher load in subsequent hours.

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 manual.

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 13 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 manual or EPA's AVERT online tutorial.[19] In 2018, EPA launched a simplified web-based version of the Main Module. Refer to Appendix I for a comparison between the web and Excel versions.

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

Key Abbreviations

AVERT	AVoided Emissions and geneRation Tool
BOEM	Bureau of Ocean Energy Management
CAMD	EPA Clean Air Markets Division
CHP	combined heat and power
CO_2	carbon dioxide
COBRA	CO-Benefits Risk Assessment Health Impacts Screening and Mapping Tool
DOE	U.S. Department of Energy
EE	energy efficiency
EGU	electric generating unit
EIA	Energy Information Administration
EPA	U.S. Environmental Protection Agency
EV	electric vehicle
GW	gigawatt
GWh	gigawatt-hour
ISO	Independent System Operator
lb	pound
MMBtu	million metric British thermal units
MW	megawatt
MWh	megawatt-hour
NAAQS	National Ambient Air Quality Standards
NO_x	nitrogen oxides
$PM_{2.5}$	particulate matter with a diameter of 2.5 microns or less
PV	photovoltaic
RDF	Regional Data File
RE	renewable energy
SMOKE	Sparse Matrix Operator Kernel Emissions Model
SO_2	sulfur dioxide
TWh	terawatt-hour

2. The AVERT Analysis Structure

AVERT has three components:

- An Excel- and web-based **Main Module** allows users to estimate the changes in emissions likely to result from new energy programs, policies, or projects. The Excel-based version requires users to select RDFs generated by the Statistical Module to analyze scenarios in reference to either a historical base year or a future year. (See Sections 3 and 4 for a detailed description of the Main Module.) The web-based version of the Main Module provides a streamlined interface with much of the same functionality as the downloadable Excel tool, without the need for Excel software or separate RDFs. The web version relies on the most recent year of input data and generates a subset of display outputs of state and county level emission changes. Refer to Appendix I for a full comparison of the Excel- and web-based Main Modules. Except for this appendix and where noted otherwise, this user manual describes features available in the Excel version.
- The MATLAB®-based **Statistical Module** performs statistical analysis on historical generation, heat input, and emissions data collected by the EPA Clean Air Markets Division (CAMD)[20] 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 CAMD data 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.[21] Using detailed hourly data from CAMD, 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 energy changes from modeled resources. Figure 2, below, shows the flow of data from its source, through various processing tools, to its end-use in the Main Module.

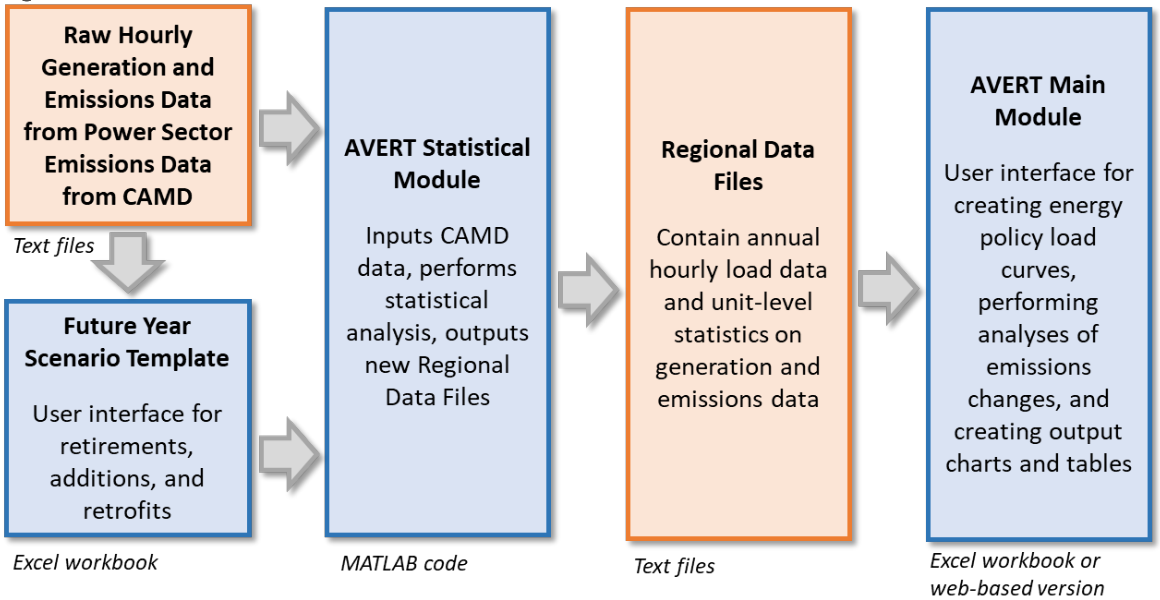
In general, hourly "prepackaged" CAMD data are input into AVERT's Statistical Module. Hourly generation, heat input, and emissions of $PM_{2.5}$, SO_2, NO_x, and CO_2 from each EGU reporting to CAMD (a requirement for fossil-fuel EGUs 25 MW and greater) are read from monthly or quarterly files.

---

20 Power Sector Emissions Data are available from EPA's Air Markets Programs Data website: https://ampd.epa.gov. For more information, see "CAMD's Power Sector Emissions Data Guide": https://www.epa.gov/sites/production/files/2020-02/documents/camds_power_sector_emissions_data_user_guide.pdf.

21 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 are 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.[22] AVERT's Future Year Scenario Template allows users to create a scenario for a year in the near future[23] 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.[24] These EGU and load-level-specific averages are stored in the AVERT RDFs, 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 is accessible as an online tool or a downloadable Excel workbook. It allows users, regardless of their level of electricity modeling expertise, to quickly estimate the changes in emissions likely to result from energy policies in a chosen year.[25] AVERT's Main Module provides a simple interface that guides users through inputting an hourly energy profile depicting electricity demand in every hour of a year. The user is then prompted to launch automatic calculations that

---

[22] Versions of the Future Year Scenario Template are available for 2017 through the present. It is expected that data for future years will continue to be provided as additional data from CAMD are released.

[23] 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.

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

[25] The web-based version of AVERT's Main Module only has the most recent data year available and limited result formats. Refer to Appendix I for a complete comparison.

result in final results tables and charts for one of the 14 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 modeling applications. Both the Excel and web versions output COBRA-formatted data for public health 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:

- **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.[26] 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 energy policies, retirements, environmental controls, or new EGUs.[27] 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 RDFs 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 changes in 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.

[26] 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.

[27] 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.

- **Limited resolution for energy policies with small impacts:** Due to the limited resolution of generation, when focusing on smaller-scale energy programs, AVERT may return a higher level of "noise" in the changes in emissions—that is, a greater divergence between desired reductions or increases in generation and modeled reductions or increases in generation. Small changes 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.[28] There is no hard limit on the smallest project that can or should be reviewed in AVERT, but results for changes of less than several hundred MW should be reviewed carefully.[29] Appendix H discusses reasonable minimum levels of load change for the purposes of obtaining useful results from AVERT.
- **Limited ability to capture dispatch implications of very large energy policies:** AVERT is designed to model marginal changes in system demand. Very large-scale energy projects or 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.[30] Appendix H discusses reasonable maximum levels of load change 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[31] of CO_2). In general terms, users should consider the number of significant figures in their specified MW load change, 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, changes to 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,

---

28 Pre-generated emission factors for recent and historical years are available at https://www.epa.gov/avert.

29 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 noise in expected results via a post-run diagnostic (discussed under "Signal-to-noise diagnostic" on page 43). In addition, AVERT rounds changes from energy policies to the closest 10 units (MWh, lbs of $PM_{2.5}/SO_2/NO_x$, or tons of CO_2); very small energy policies will effectively report little or no specific changes. Ultimately, the user must judge if the results return adequate information or appear reliable. For more information, see Appendix H.

30 See Brown, P. 2012. *U.S. Renewable Electricity: How Does Wind Generation Impact Competitive Power Markets?* Congressional Research Service. R42818. https://www.fas.org/sgp/crs/misc/R42818.pdf. See also National Renewable Energy Laboratory. 2016. *Eastern Renewable Generation Integration Study.* https://www.nrel.gov/grid/ergis.html.

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

would spread the influence of load changes too widely, making it difficult to ascribe load changes to particular EGUs.

- **Unconstrained transmission:** AVERT looks at the dynamics of each region as a whole regardless of transmission constraints.[32] 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 resources or demand change resulting from energy policies, 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.
- **Infrequent emission events for SO_2:** In some limited circumstances, infrequent extreme emission events may be over-represented in the AVERT dataset. For example, instances during which an EGU switches from one fuel to another (e.g., from natural gas to oil), or EGU equipment experiences malfunctions, may cause SO_2 emission rates for one or more hours to be hundreds or thousands of times higher than emission rates in other hours with similar levels of generation.[33] Under these conditions, SO_2 emission factors produced by AVERT may skew higher than they might otherwise be expected to, given the low prevalence of these high-emission hours. These unusually high emission factors appear only in certain years, at certain EGUs within a limited number of AVERT regions, and only for SO_2 (one of the four pollutants reported in AVERT). Depending on the region and year, these high emission factors produce annual total SO_2 emissions 12% to 90% higher than actual observed emissions. Known instances of this issue include:
    - 1 EGU (of 132) in the 2018 New England RDF
    - 6 EGUs (out of 205) in the 2017 New York RDF
    - 1 EGU (out of 222) in the 2018 New York RDF
    - 9 EGUs (out of 203) in the 2019 New York RDF
    - 4 EGUs (out of 207) in the 2017 Southeast RDF
    - 5 EGUs (out of 227) in the 2018 Southeast RDF
    - 1 EGUs (out of 213) in the 2019 Southeast RDF

[32] 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.

[33] The data for these circumstances are reported as *measured*, which contrasts with the maximum potential concentration *substitute* data discussed in Appendix B.

To account for these infrequent emission events, AVERT outputs are modified to not report the marginal SO_2 emissions for those EGUs affected by infrequent emission events. This conservative modification ensures that AVERT does not overstate SO_2 emissions benefits from EE/RE. Additionally, for the regions and years above, regional SO_2 total emissions are based on actual reported emissions (CAMD data) rather than AVERT's modeled data. EPA is currently evaluating approaches to improve the modeling of units with infrequent events for future versions of AVERT.

3. AVERT Main Module: An Overview

This section provides a simplified overview of user inputs and model results. 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. Appendix I provides a comparison between the web- and Excel-based versions of AVERT's Main Module.

AVERT's Excel-based Main Module estimates the emission changes resulting from user-entered energy policy scenarios. AVERT predicts emissions changes for every individual fossil-fuel EGU in a region and aggregates these changes to the county level.[34] 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 EGUs 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 energy profile depicting user-created 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 energy policy 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 energy profile of an energy policy is the change in 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 energy profile; calculating the changes resulting from this profile; and accessing tables, graphs, and maps summarizing the results. Once an energy 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 changes from energy policies occur region-wide. All AVERT analysis, therefore, is conducted at a regional level. For users, designating one of the 14 AVERT regions for analysis is "Step 1" in using AVERT's Main Module. A map of these regions is shown in Figure 3.

Twenty-four of the contiguous U.S. states are split between two or more regions each; the other 24, and the District of Columbia, are not split. Table 1 describes each region in detail.

Generally, air quality managers for states that are split between more than one AVERT region should evaluate the emission changes for all regions that state is a part of. Appendix G includes further discussion of the regions and more complete instructions for users analyzing expected changes from energy policies in split states.

[34] Excludes EGUs smaller than 25 MW that do not report to CAMD.

Figure 3. Map of AVERT's regions.

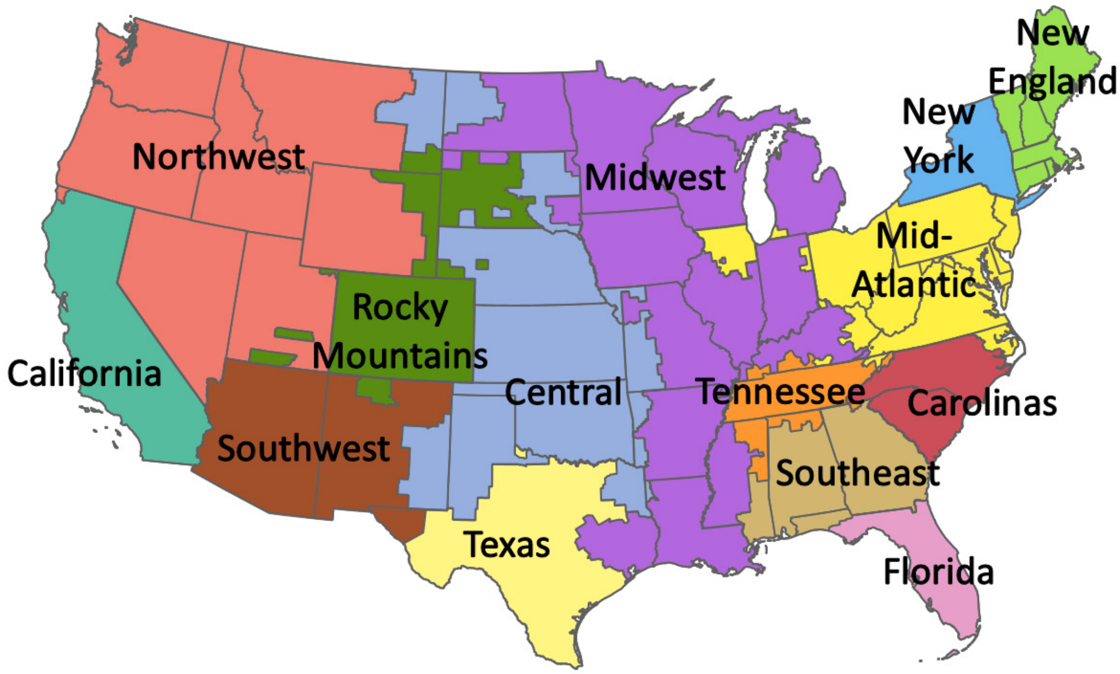


Table 1. AVERT regions, abbreviations, and states.

AVERT Region	Full States	Partial States
California	California	—
Carolinas	South Carolina	North Carolina
Central	Kansas	Arkansas, Iowa, Louisiana, Minnesota, Missouri, Montana, North Dakota, Nebraska, New Mexico, Oklahoma, South Dakota, Texas
Florida	—	Florida
Mid-Atlantic	District of Columbia, Delaware, Maryland, New Jersey, Ohio, Pennsylvania, Virginia, West Virginia	Illinois, Indiana, Kentucky, Michigan, North Carolina, Tennessee
Midwest	Wisconsin	Arkansas, Iowa, Illinois, Indiana, Kentucky, Louisiana, Michigan, Minnesota, Missouri, Mississippi, North Dakota, Oklahoma, South Dakota, Texas
New England	Connecticut, Massachusetts, Maine, New Hampshire, Rhode Island, Vermont	—
New York	New York	—
Northwest	Idaho, Nevada, Oregon, Washington	Montana, Utah, Wyoming
Rocky Mountains	Colorado	Montana, Nebraska, New Mexico, South Dakota, Utah, Wyoming
Southeast	—	Alabama, Florida, Georgia, Mississippi
Southwest	Arizona	New Mexico, Texas
Tennessee	—	Alabama, Georgia, Kentucky, Mississippi, Tennessee
Texas	—	Texas

Energy Policy Characteristics

AVERT users should understand the characteristics of the energy scenario 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 some intervention scenario created by the energy policy, resulting in an energy profile consisting of hourly changes to fossil-fuel EGU generation. This in turn leads to a change in emissions. Starting with a baseline schedule of load for every hour of a reference year (the "load profile"),[35] the Main Module guides the user to create or input an energy profile to represent their energy policy—i.e., the amount that load that will be reduced or increased by the energy policy on an hourly basis. For details and instructions, refer to Step 2 in Section 4.

Users are encouraged to create and adopt their own energy profiles, representing energy policies specific to their interest or area of concern. The following energy 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 EE programs that target some or all hours of the year, but preferentially target higher hours with greater demand. Users can also use this option to increase fossil-fuel generation by entering a negative number for the percent generation reduction.
- **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. Users can also use this option to increase fossil-fuel generation by entering a negative number for the amount of generation reduction.
- **RE proxy.** With this option, users can model onshore wind, offshore wind, utility solar, and rooftop solar resources that are broadly representative of the selected region.
- **Combination of energy policies.** Users can also mix and match from the above options, as well as combine the pre-set options with manually entered energy changes.

AVERT combines all of the user's inputs to generate a single energy profile with 8,760 hourly values.[36] 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 energy profile to account for avoided transmission and distribution line losses associated with certain resources that avoid the need for long-distance transmission: specifically, EE and distributed PV systems.[37] The magnitudes of hourly load changes associated with each of these resources are adjusted upward by the following formula:

adjusted load change = user's input / (1 – x),

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

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

[37] 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 losses.

where *x* is the regional average line loss percentage. Starting with Main Module version 2.3 (released in spring 2019), AVERT uses line loss factors from the Annual Energy Outlook, published by EIA.[38] AVERT uses the historical line loss factors that correspond to the year and region of the user's analysis, as shown in Table 2.

Table 2. Transmission and distribution line loss factors used in AVERT.

Data Year	Texas	Eastern Interconnect	Western Interconnect
2017	5.60%	7.00%	8.13%
2018	4.83%	6.74%	8.54%
2019	5.38%	7.20%	8.60%

The Eastern Interconnect corresponds to the following AVERT regions: Carolinas, Central, Florida, Mid-Atlantic, Midwest, New England, New York, Southeast, and Tennessee. The Western Interconnect corresponds to the following AVERT regions: California, Northwest, Rocky Mountains, and Southwest. The Texas region in Table 2 corresponds to the AVERT Texas region.

This adjustment has the effect of increasing the magnitude of fossil load change and emissions change associated with distributed RE generation and energy policies and programs that change electricity consumer demand (e.g., EE). The adjustment provides more accurate results. Without it, AVERT would underestimate changes to emissions. For example, AVERT without adjustments would assume that 100 MWh of EE or 100 MWh of onsite (distributed) PV generation in the Eastern Interconnect in 2018 avoids 100 MWh of fossil generation, whereas it actually avoids approximately 107 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 an energy profile has been designed, the user is prompted to launch the automatic emissions calculations in Step 3 of the AVERT Main Module.

Scenario Results

Step 4 of AVERT's Main Module reports the difference between the baseline and modeled energy policy scenario through the following outputs:

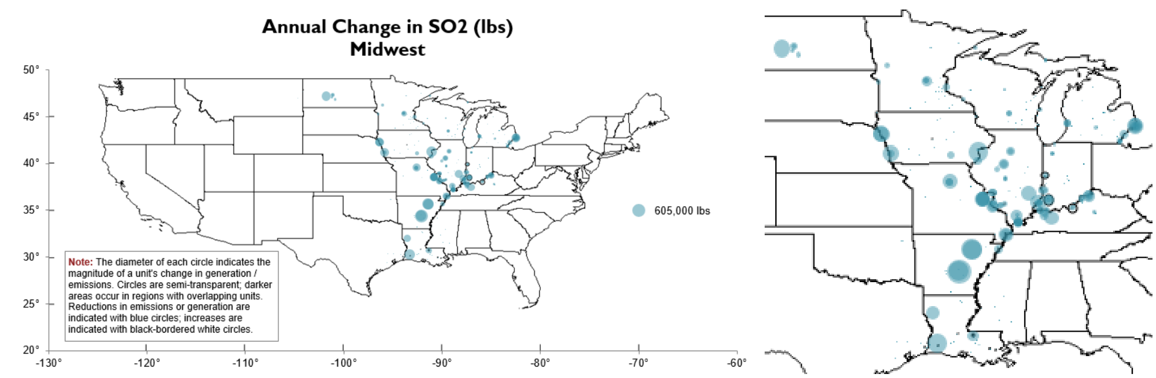
- Summary tables:
  - Annual changes to generation and emissions
  - Emissions changes for top 10 fossil-fuel generation days
  - Annual emissions changes by county
  - Monthly emissions changes by county
  - Daily NO_x emissions changes by county
- Charts and figures:
  - Map of generation and emissions changes

[38] Annual Energy Outlook data can be downloaded from https://www.eia.gov/outlooks/aeo/. Each Outlook provides historical data for the preceding year. The transmission and distribution line loss factors are calculated as ((Net Generation to the Grid + Net Imports – Total Electricity Sales)/Total Electricity Sales).

- Hourly emissions changes by week
- Monthly emissions changes by selected geography (region, state, or county)
- Signal-to-noise diagnostic
- COBRA text file generation (for public health impact modeling)
- SMOKE text file generation (for air quality modeling)

For assessing the air quality implications of energy policies, the location of air emissions changes resulting from either load increases or decreases can be critical. The example shown in Figure 4 represents a 2,000 MW onshore wind program in the Midwest AVERT region compared with 2019 base-year data. The map displays annual changes in SO_2 emissions from specific EGUs as blue circles; larger circles indicate greater changes to 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 Midwest region.



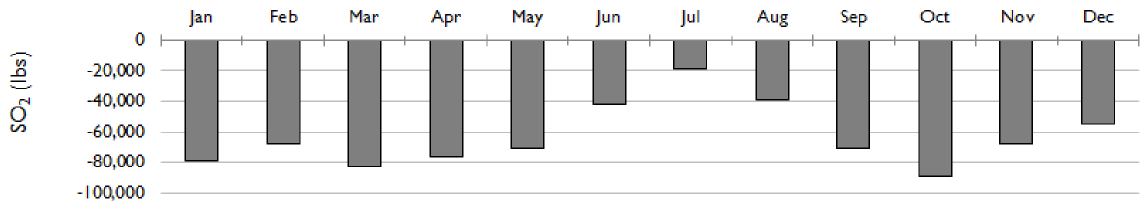
The diameter of each circle indicates the magnitude of an EGU's change in emissions. Circles are semi-transparent; darker areas occur in regions with overlapping EGUs. Emissions reductions are indicated with blue circles; increases in emissions are indicated with black-bordered white circles.

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, or if shifting load from peak to trough hours), or due to aberrations in the statistical dataset.[39]

[39] 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.

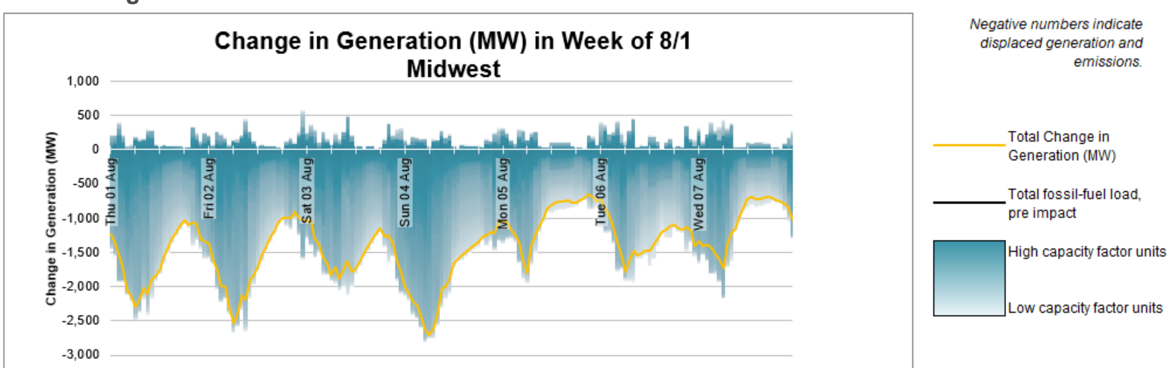
Many users will be interested in changes to emissions for smaller areas within a region. Monthly results can be displayed by region, state, or county. Figure 5 displays monthly SO_2 emissions changes within a single county in Illinois, continuing the same example shown in Figure 4.

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



Some users may wish to instead view hourly changes to 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 onshore wind program, Figure 6 displays the hour-by-hour fossil generation displaced in the week of August 1–7 in the 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).[40] 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.

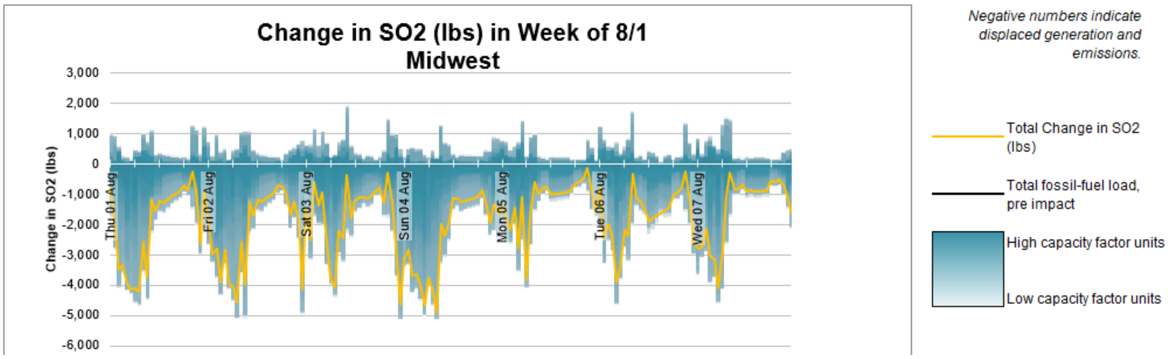
Figure 6. Hourly generation reductions in the week of August 1 from an example wind program in the Midwest region.



[40] 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 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.[41]

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



[41] 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 off-peak hours, and therefore are the units that will be displaced in off-peak hours when modeling a decrease to fossil generation. This analysis indicates that baseload units are displaced during off-peak 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 change in emissions resulting from energy policies.

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

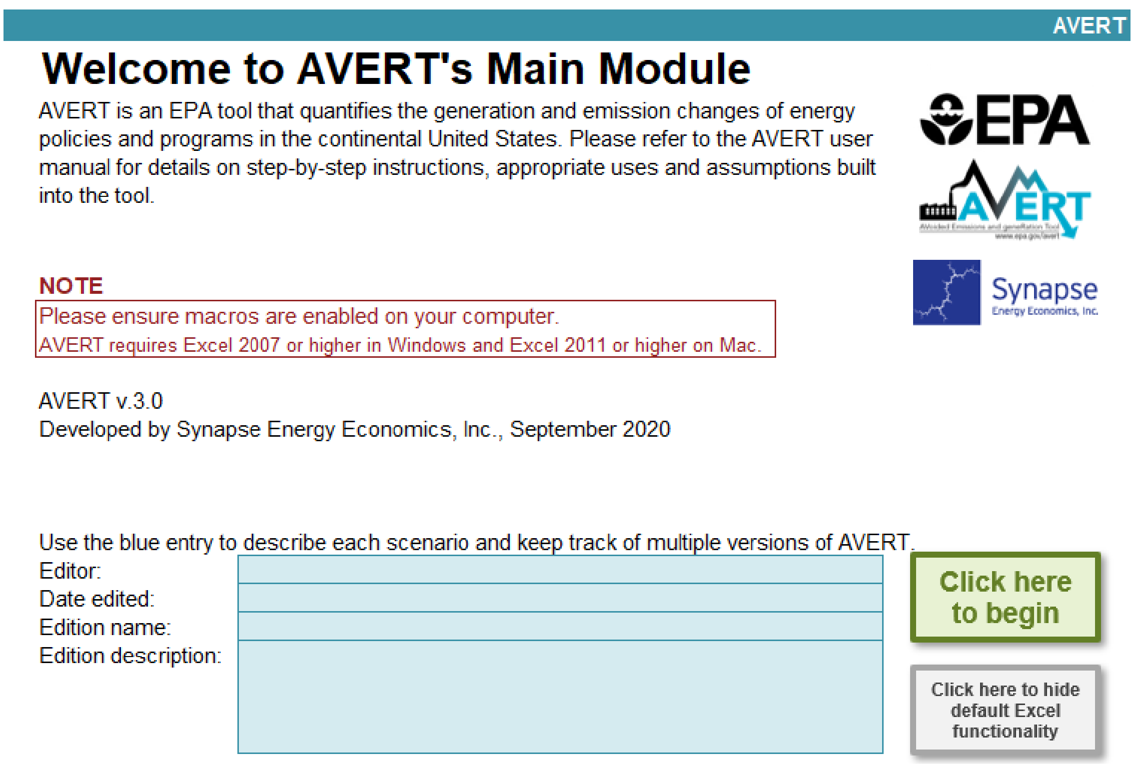
- The Main Module workbook: "AVERT Main Module.xlsm." Download the workbook at https://www.epa.gov/avert.
- The RDF for the region under analysis.
  - Default RDFs developed for use by EPA are labeled "AVERT RDF [DataYear] BaseEPA ([Region]).xlsx"; they can be obtained at https://www.epa.gov/avert.
  - 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.[42] Before you make any selections or begin 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 an RDF (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 energy policy for which emissions changes are to be estimated. This version specification is very useful for 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 an RDF, and is thus fairly small (<6 MB). When an RDF is loaded into AVERT and changes are calculated, the program grows substantially to 60 to 100 MB.

A final note on the Welcome page: The Main Module has been designed to provide 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 changes to 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.

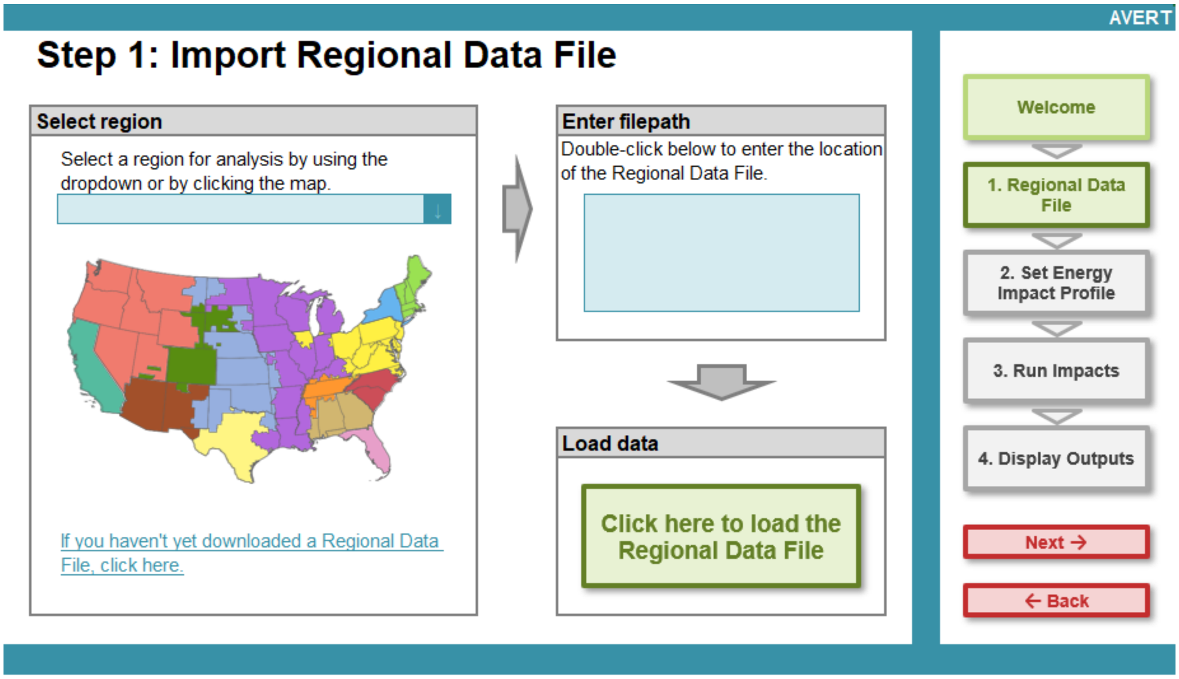
---

[42] 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 RDF. There are 14 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 the AVERT Main Module's "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 energy policies.

The 14 AVERT regions are:

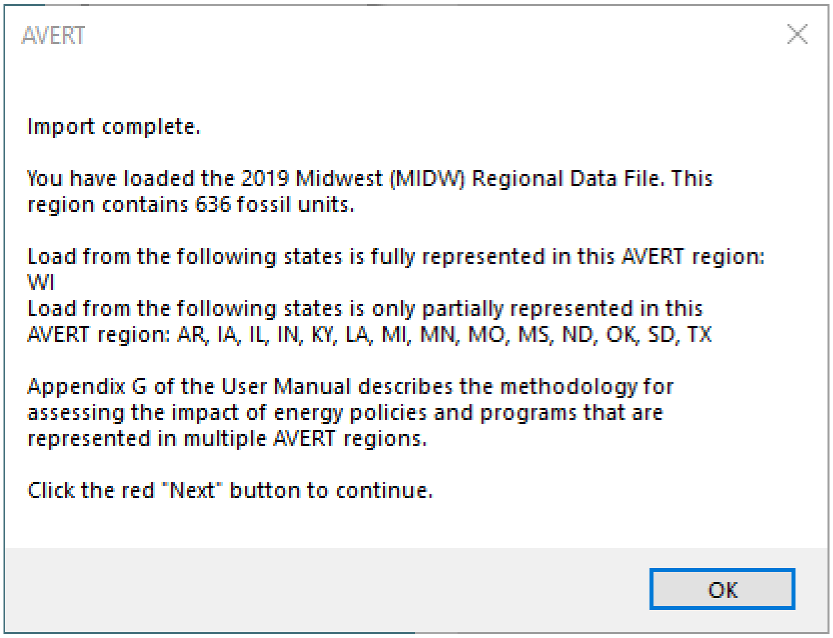
- California
- Carolinas
- Central
- Florida
- Mid-Atlantic
- Midwest
- New England
- New York
- Northwest
- Rocky Mountains
- Southeast
- Southwest
- Tennessee
- Texas

If you have not yet downloaded an RDF, 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 RDF 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 RDF 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. RDF import pop-up box example for the 2019 Midwest AVERT region.



Some states are divided by AVERT regions. For example, parts of Illinois are in the Midwest Region, while other parts are in the Mid-Atlantic Region.[43] Appendix G of this document describes the process that one should use to determine the emission changes resulting from energy policies in states that are partially represented in any one AVERT region. Users analyzing these states should assign the energy policies proportionally based on the fraction of the state's electricity sales within each relevant AVERT region. These fractions are shown in Table 4 in Appendix G and, as a reminder and for clarity, in the pop-up box.

After you load an RDF, the blue AVERT header bar will indicate the region and data year in the top left corner (e.g., "Midwest, 2019"). The blue footer bar will also indicate the name of the AVERT run that has been loaded in the RDF (e.g., "EPA_NetGen_PM25").[44] 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."

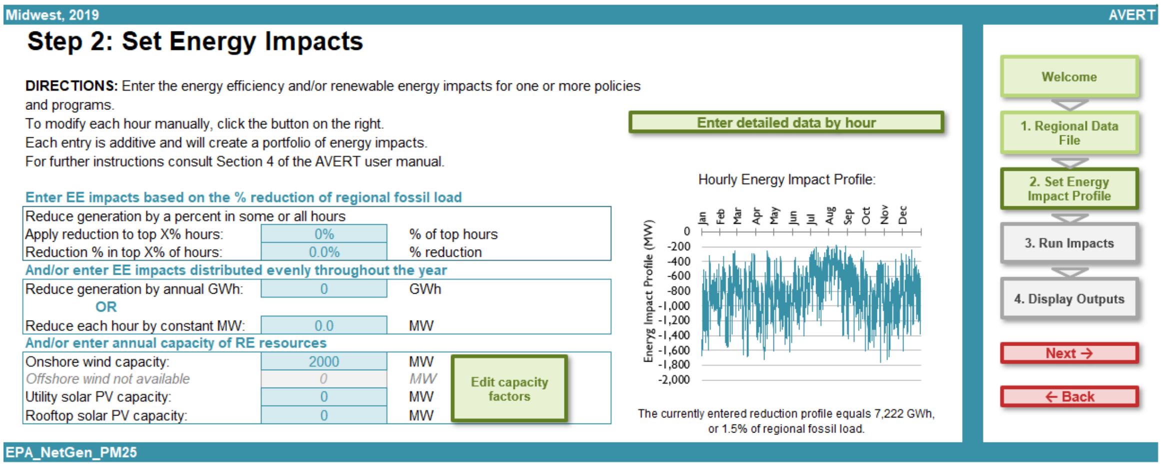
43 This division in Illinois is primarily a function of the eastern part of the state falling under the PJM Regional Transmission Organization, while the rest of the state falls into MISO.

44 Before the 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."

Step 2: Set Energy Scenario

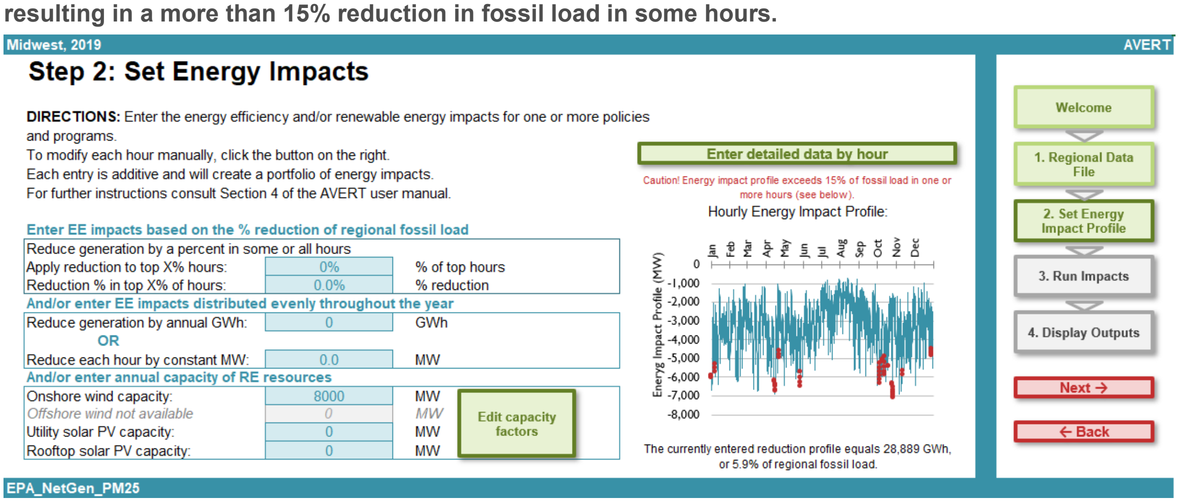
In this step, you will create an energy profile (schedule of changes to electricity demand for every hour of a year) depicting the change in load expected from an energy policy as shown in Figure 11. In this example, the user has input a 2,000 MW onshore wind program, the energy profile of which is being displayed in the chart in the bottom right hand corner.

Figure 11. Image of the AVERT Main Module's "Step 2: Set Energy Impacts" page.



If you enter an energy change (increase or decrease) that exceeds 15% of regional fossil load in any given hour, you will be shown an alert highlighting the hours of exceedance (Figure 12), but you can still proceed with the calculations.

Figure 12. Image of the AVERT Main Module's "Step 2: Set Energy Impacts" page with program size resulting in a more than 15% reduction in fossil load in some hours.



AVERT adjusts the scenario's energy profile to account for avoided transmission and distribution line losses associated with certain energy resources: specifically, EE programs and distributed PV systems.[45] This adjustment has the effect of increasing the magnitude of fossil load change and

[45] 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 losses.

emissions change, which provides more accurate results. Without this adjustment, AVERT would underestimate changes to emissions.

The Step 2 page allows you to estimate a change in load 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
- RE proxy
- Combination of energy policies including combining pre-set options with manual entry

Choose the option(s) that works best for your modeled energy policy 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 change (in GWh) achieved by the modeled energy policy. Total hourly changes can be found in the manual input page.

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

Manual User Input

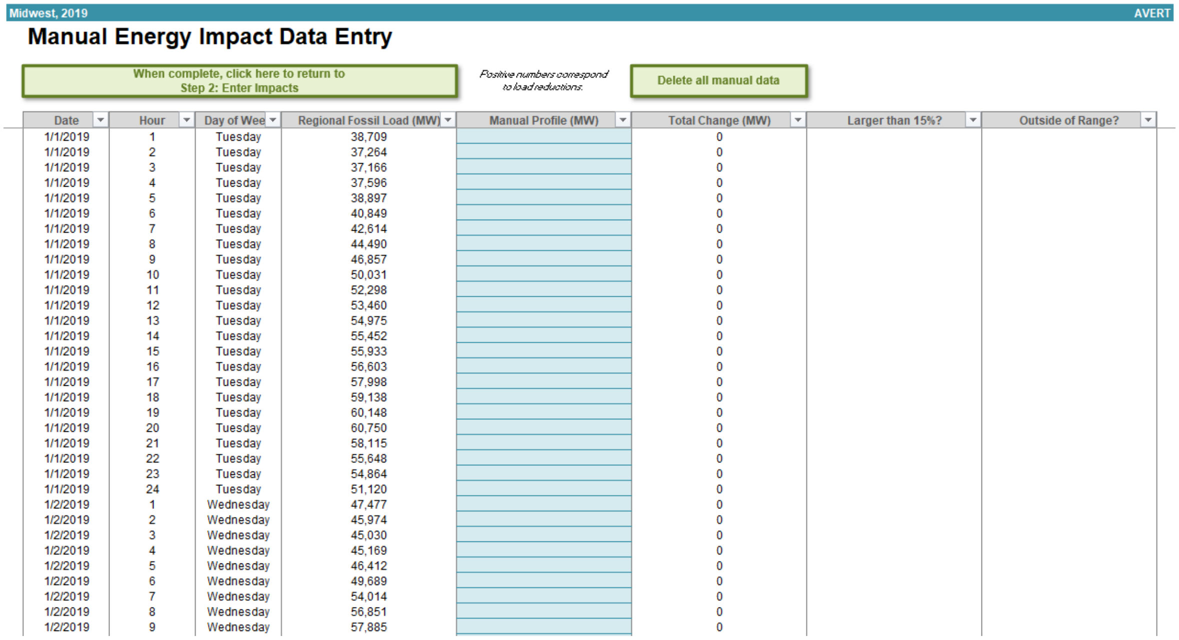
If the hourly energy changes expected from a particular energy policy, program, or measure are known, a customized profile can be created (consisting of 8,760 hourly values for a non-leap year or 8,784 hourly values for a leap year). For example, you might use this approach to test the measured or modeled emission changes from 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. On this page, as with other AVERT inputs, positive values represent displacements. Users who wish to model scenarios with increases in load (for example, a retroactive “what-if” scenario to see what would have happened if a particular energy policy or program had not been implemented) can enter negative displacement values to represent increased loads.

This page also includes two columns that indicate whether a user has exceeded the recommended and/or calculable ranges of hourly load changes. Alerts will appear in these two columns if the data entered by the user a) produces a cumulative load change that exceeds 15% beyond the upper and lower limits of each hour’s original fossil load or b) produces a new load that is outside the range of AVERT’s ability to calculate generation and emissions changes.[46]

[46] AVERT can estimate generation and emissions changes within the range of actual observed load for a certain year. In addition, it uses extrapolated data to estimate the changes that could occur down to a load level of 0 MW and up to a maximum load level associated with all plants within a single region running at full capacity. It is unable to estimate changes outside of this maximum and minimum range.

The “Total Change” column on the manual input page shows the total aggregate hourly energy change from the programs input or selected by the user.

Figure 13. Image of the AVERT Main Module’s “Manual Energy Impact Data Entry” screen.


Midwest, 2019 AVERT

Manual Energy Impact Data Entry

When complete, click here to return to Step 2: Enter Impacts

Positive numbers correspond to load reductions.

Delete all manual data

Date	Hour	Day of Wee	Regional Fossil Load (MW)	Manual Profile (MW)	Total Change (MW)	Larger than 15%?	Outside of Range?
1/1/2019	1	Tuesday	38,709		0		
1/1/2019	2	Tuesday	37,264		0		
1/1/2019	3	Tuesday	37,166		0		
1/1/2019	4	Tuesday	37,596		0		
1/1/2019	5	Tuesday	38,897		0		
1/1/2019	6	Tuesday	40,849		0		
1/1/2019	7	Tuesday	42,614		0		
1/1/2019	8	Tuesday	44,490		0		
1/1/2019	9	Tuesday	46,857		0		
1/1/2019	10	Tuesday	50,031		0		
1/1/2019	11	Tuesday	52,298		0		
1/1/2019	12	Tuesday	53,460		0		
1/1/2019	13	Tuesday	54,975		0		
1/1/2019	14	Tuesday	55,452		0		
1/1/2019	15	Tuesday	55,933		0		
1/1/2019	16	Tuesday	56,603		0		
1/1/2019	17	Tuesday	57,998		0		
1/1/2019	18	Tuesday	59,138		0		
1/1/2019	19	Tuesday	60,148		0		
1/1/2019	20	Tuesday	60,750		0		
1/1/2019	21	Tuesday	58,115		0		
1/1/2019	22	Tuesday	55,648		0		
1/1/2019	23	Tuesday	54,864		0		
1/1/2019	24	Tuesday	51,120		0		
1/2/2019	1	Wednesday	47,477		0		
1/2/2019	2	Wednesday	45,974		0		
1/2/2019	3	Wednesday	45,030		0		
1/2/2019	4	Wednesday	45,169		0		
1/2/2019	5	Wednesday	46,412		0		
1/2/2019	6	Wednesday	49,689		0		
1/2/2019	7	Wednesday	54,014		0		
1/2/2019	8	Wednesday	56,851		0		
1/2/2019	9	Wednesday	57,885		0		

Reduce Generation by a Percent in Some or All Hours[47]

To estimate the emission changes expected from a broad-based EE 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% reduction per hour effectively reduces load by 2% of fossil-fired generation.

To simulate a broad-based efficiency program, enter 100% as the “% of top hours” and an estimated load reduction fraction in the cell labeled “% reduction.” A graph of the selected energy profile—which combines both manual entries and user selections made on the Step 2 page—is shown on this page.

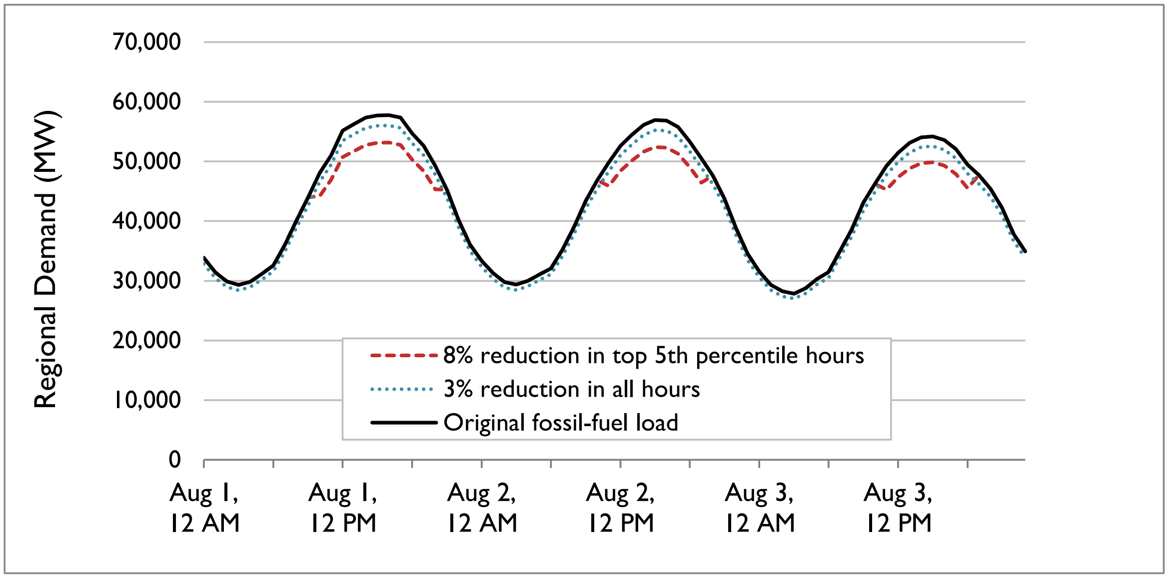
To simulate a peak-reduction targeting program such as demand response, enter a fraction of high-demand hours that the program is expected to affect, and the load reduction (as a fraction of peaking load) that would be targeted in those hours. This type of scenario is recommended for

[47] Users wishing to model load increases (e.g., as a result of hourly load shifting) can enter negative numbers. This applies to all input fields.

programs that emphasize reductions in peak hours. Generally, reductions exceeding 15% of fossil-fired generation are not recommended.[48]

Figure 14 shows a baseline energy profile (in black) and two example load reductions for three days in August. The blue, dotted line represents a 3% reduction in fossil-fired generation requirements in every hour of the year. The red, dashed line represents an 8% reduction in the 5% 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% of regional generation, a user attempting to find the emissions changes of a *regional* load reduction of 3% should double the size of the reduction specified in AVERT's Main Module (i.e., to 6%) 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 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.[49] In all situations where EE is being modeled, AVERT increases the value entered to reflect a transmission and distribution loss factor, under the

[48] 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.

[49] 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% 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%, 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.

assumption that the user is intending to model reductions in sales, even though the impact modeled is calculated based on the quantity of fossil generation in that region.

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 EE 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.

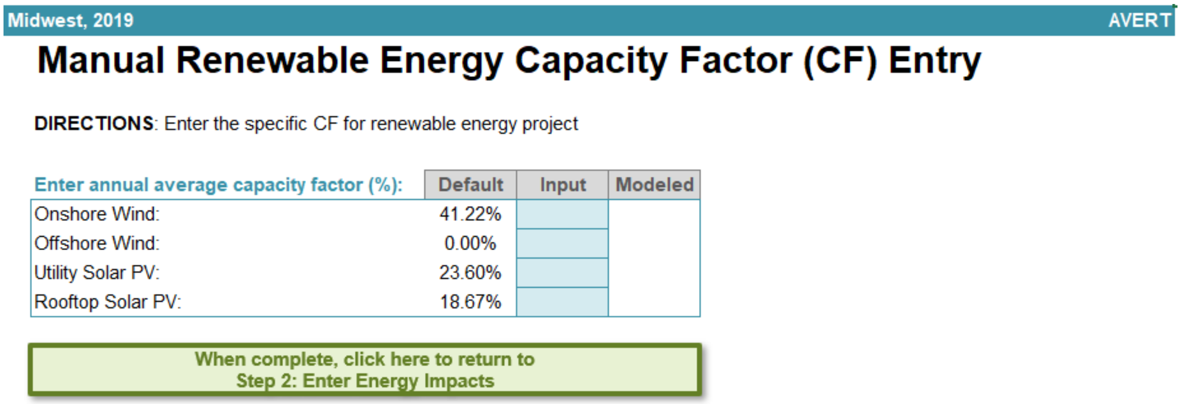
Renewable Energy Proxy

This option allows you to use previously designed energy profiles for region-specific onshore wind, offshore 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% or higher capacity factor on an August afternoon, but a 0% capacity factor at midnight any day of the year. These data do not represent actual or proposed projects. The data and methodology used to develop these capacity factors are described in Appendix C.

You can scale the capacity factors used for each RE technology by clicking on the "Edit capacity factors" button to get to a manual capacity factor entry screen (Figure 15). For each resource, the default average annual capacity factor on this page reflects the average capacity factor across all hours of the year. The user can input their desired average annual capacity factor and the hourly values used in the model will scale accordingly. For example, if the default capacity factor for onshore wind in a region is 25% and a user enters a value of 30%, all hourly capacity factors for that resource in that region are then scaled up by 20%.[50] Capacity factors can be revised upwards or downwards.

[50] In some situations, this change may result in capacity factors that are higher than 100% in some hours. In these cases, capacity factors are bounded at 0 and 100%. If this occurs for many hours, the "modeled" capacity factor may not equal the "input" capacity factor. In these situations, the model will display a warning that the desired annual capacity factor is unable to be modeled.

Figure 15. Image of AVERT's "Manual Renewable Energy Capacity Factor (CF) Entry" screen.

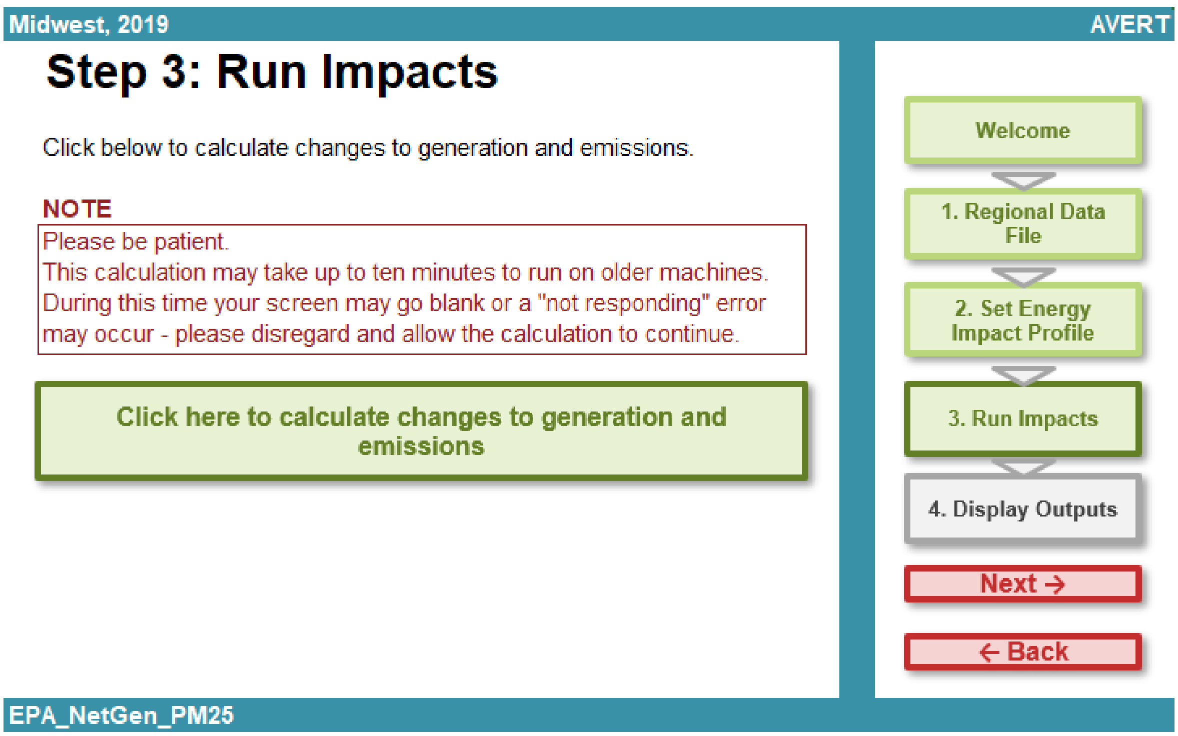


After the energy profile has been designed, click "Next" to move on to the next step.

Step 3: Run Scenario

Step 3 launches the automatic calculation of hourly changes in generation, heat input, and emissions for each EGU in the region as shown in Figure 16.

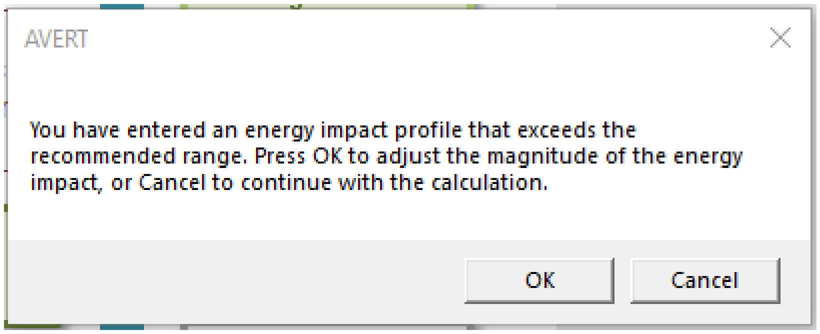
Figure 16. Image of the AVERT Main Module's "Step 3: Run Impacts" page.



Click on the box labeled "Click here to calculate changes to generation and emissions." Because of the large amount of data being processed, this calculation may take several minutes 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.

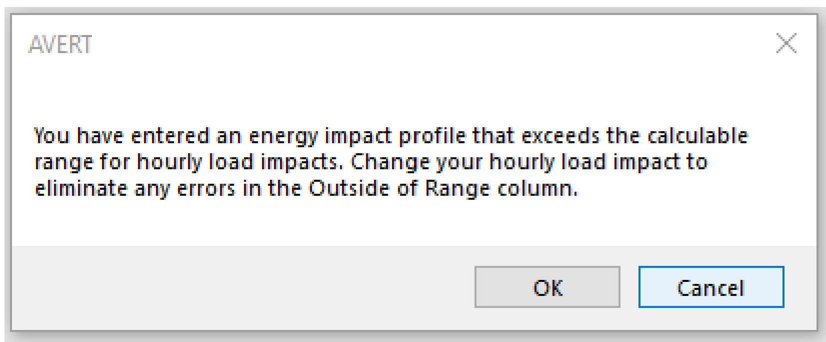
Note that two separate alert boxes may pop up when this box is clicked. The first alert informs the user that for at least one of the hours under consideration, the load decrease or increase is more than 15% of the original hourly load. Users can click “OK” and modify their load changes to be within the recommended range, or click “Cancel” to proceed with the calculation.

Figure 17. Pop-up alert for an energy profile that exceeds a 15% change in load.



The second alert informs the user that in at least one of the hours where load has been adjusted, the energy profile will be outside the calculable range for AVERT. In these situations, the user must return to Step 2 and reduce his or her load adjustments to avoid producing this alert.[51]

Figure 18. Pop-up alert for an energy profile that exceeds AVERT’s calculable range.



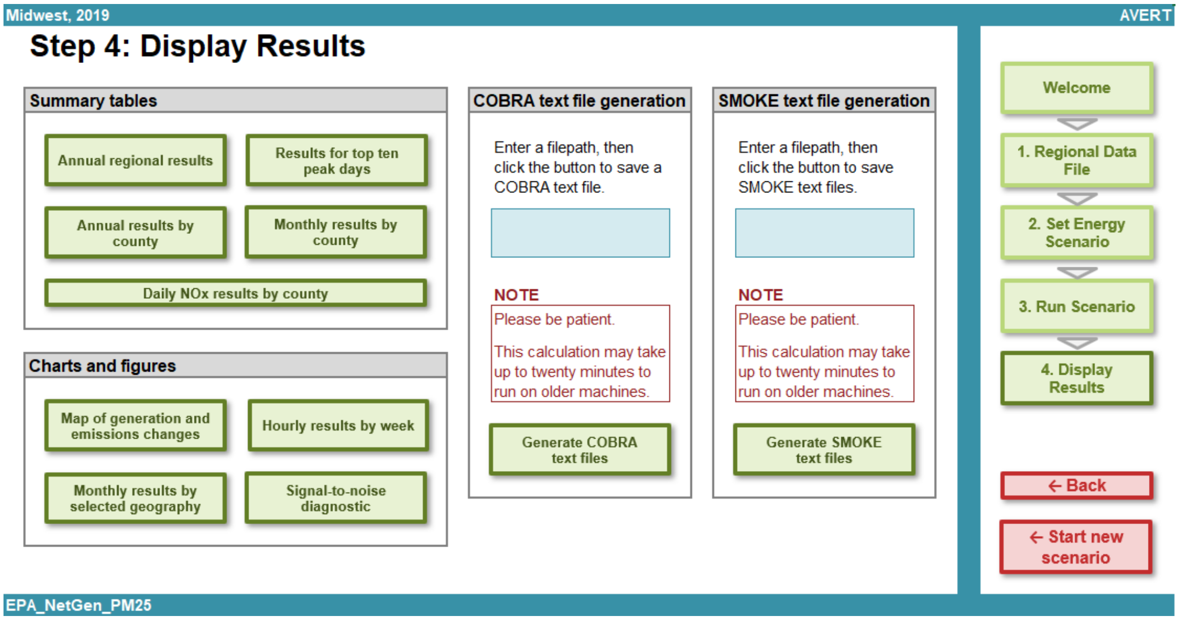
A pop-up box that reads “Calculation complete” will appear once the calculations are complete. Click “Next” to move on to the final step.

Step 4: Display Results

Step 3 of AVERT’s Main Module generates raw data in the form of hourly estimated changes 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 Results” page, as shown in Figure 19.

[51] To remedy this error, users may find it useful to review the rightmost column on the “Manual User Input” page, which produces an alert for specific hours where the load change has exceeded AVERT’s calculable range.

Figure 19. Image of the AVERT Main Module's "Step 4: Display Results" page.



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

Summary Tables

Annual regional results

Figure 20 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 modeled energy change ("Post Change"). The difference between these two scenarios is the total annual expected change from the user-specified energy change. 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 modeled energy change.

All numerical results are shown rounded to the nearest 10 unit.[52] 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 the size of the energy policy will increase the amount of output above the reportable significance level (i.e., reduce the number of dashes in the results datasets).

[52] The Power Sector Emissions Data are reported in integer units of MWh (generation), lbs (NO_x and SO_2), tons (CO_2), and MMBtu (heat input). Results 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.

Figure 20. Image of annual regional results table for an example wind program in the Midwest region.

Midwest, 2019 AVERT

Output: Annual Regional Results

Click here to return to Step 4: Display Outputs

	Original	Post Change	Change
Generation (MWh)	492,254,600	485,047,560	-7,207,040
Total Emissions from Fossil Generation Fleet			
SO_2 (lbs)	705,939,950	694,675,530	-11,264,430
NO_x (lbs)	518,286,020	509,757,610	-8,528,410
CO_2 (tons)	423,535,880	417,335,680	-6,200,210
$PM_{2.5}$ (lbs)	82,292,060	81,168,690	-1,123,360
Fossil Generation Fleet Emission Rates			
SO_2 (lbs/MWh)	1.434	1.432	
NO_x (lbs/MWh)	1.053	1.051	
CO_2 (tons/MWh)	0.860	0.860	
$PM_{2.5}$ (lbs/MWh)	0.167	0.167	

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 results by county

Figure 21 shows a summary of the changes in generation and emissions for each of the counties from each of the states in the region. The Midwest region, for example, contains EGUs in Arkansas, Iowa, Illinois, Indiana, Kentucky, Louisiana, Michigan, Minnesota, Missouri, Mississippi, North Dakota, Oklahoma, South Dakota, Texas, and Wisconsin. A line for each county containing an EGU is displayed.

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

- **Peak Generation Post Energy Change (MW):** The peak (maximum) hourly generation produced by an EGU in the base- or future year scenario after energy changes have been applied.[53]
- **Annual Generation Post Energy Change (MWh):** The total annual generation of an EGU in the base- or future year scenario after energy changes have been applied.
- **Annual Change in Generation (MWh):** The EGUs' estimated change in generation from baseline conditions to post-energy changes over a full year (i.e., the annual increased or decreased generation of this unit).

[53] Note that 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.

- **Annual Change in Heat Input/$PM_{2.5}$/SO_2/NO_x/CO_2 (MMBtu, lbs, or tons):** The EGUs' estimated change in heat input or emissions from baseline conditions to post-energy changes conditions over a full year (i.e., the annual increased or decreased heat input or emissions of this unit).
- **Ozone Season Change in SO_2/NO_x/$PM_{2.5}$ (lbs):** The EGUs' estimated change in emissions from baseline conditions to post-energy changes during the ozone season (May to September, inclusive).
- **Ozone Season, 10 Peak Days Change in SO_2/NO_x/$PM_{2.5}$ (lbs):** The EGUs' estimated change in emissions from baseline conditions to post energy changes during the 10 highest fossil generation days in the ozone season (May to September, inclusive).

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. Negative numbers indicate displaced generation and emissions.

Figure 21. Annual results by county for an example wind program in the Midwest region.

Midwest, 2019

Output: Annual Results by County

Click here to return to Step 4: Display Outputs

State	County	Peak Generation, Post-Change (MW	Annual Generation, Post-Change (MW	Annual Change in Generation (MWh	Annual Change in SO2 (lbs)	Annual Change in NOx (lbs)	Annual Change in CO2 (tons)
AR	Craighead County	74	25,260	-860	-10	-1,370	-540
AR	Hot Spring County	1,249	4,770,860	-36,910	-140	-12,640	-16,560
AR	Independence County	1,402	5,555,760	-55,770	-302,340	-74,740	-64,210
AR	Jefferson County	1,719	8,527,760	-68,760	-337,680	-90,340	-73,790
AR	Mississippi County	1,143	7,155,230	-31,150	-32,890	-18,860	-27,930
AR	Pulaski County	404	349,930	-9,380	-10	-12,750	-4,430
AR	Union County	1,787	11,077,780	-45,790	-150	-2,990	-19,210
IA	Allamakee County	213	449,080	-7,280	-3,730	-2,890	-8,000
IA	Audubon County	84	109,290	-2,260	-150	-2,240	-1,380
IA	Black Hawk County	10	4,260	-110	–	-530	-110
IA	Cerro Gordo County	461	2,525,480	-21,530	-80	-810	-9,490
IA	Des Moines County	193	1,142,450	-4,280	-24,920	-7,370	-5,280
IA	Louisa County	678	3,265,020	-43,410	-137,970	-73,630	-46,360
IA	Marshall County	710	3,742,250	-25,490	-80	-3,320	-11,210
IA	Muscatine County	150	943,160	-4,610	-6,240	-13,000	-5,490
IA	Polk County	313	290,620	-6,310	-40	-830	-4,190
IA	Pottawattamie County	1,351	7,858,440	-59,010	-116,470	-91,640	-62,640
IA	Scott County	39	5,760	-310	–	-590	-210
IA	Story County	27	135,290	-860	-90	-1,210	-580
IA	Union County	35	6,000	-320	–	-3,240	-290
IA	Wapello County	685	3,732,100	-29,180	-22,980	-32,400	-34,580
IA	Woodbury County	1,087	3,140,390	-53,680	-187,060	-107,380	-57,000
IL	Ford County	158	72,750	-2,420	-20	-1,890	-1,550
IL	Fulton County	386	2,253,230	-11,540	-920	-16,720	-13,140
IL	Jackson County	347	989,820	-9,970	-40	-5,580	-4,770
IL	Jasper County	557	3,216,150	-24,740	-82,670	-24,770	-24,300
IL	Madison County	150	25,100	-1,400	-10	-560	-780
IL	Marion County	31	1,840	-170	–	-110	-110
IL	Mason County	402	1,522,570	-16,470	-13,160	-14,720	-18,710
IL	Massac County	900	4,469,360	-38,030	-167,850	-39,640	-38,830
IL	Montgomery County	651	2,728,810	-23,690	-260	-23,310	-24,060
IL	Peoria County	500	3,181,280	-16,200	-71,090	-16,900	-17,150
IL	Perry County	174	79,730	-2,760	–	-2,390	-1,520

Results for top 10 peak days

Figure 22 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 changes in generation, and the simulated changes in generation and 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 22. Results for the top 10 load days for an example wind program in the Midwest.

Midwest, 2019 AVERT

Output: Results for Top Ten Peak Days

Click here to return to Step 4: Display Outputs

Day Rank	Date	Total Fossil Generation (MWh)	Expected Change in Generation (MWh)	Change in Generation (MWh)	Change in NO_x (lbs)	Change in SO_2 (lbs)	Change in CO_2 (tons)	Change in $PM_{2.5}$ (lbs)
1	Jul 19	1,902,830	-17,190	-16,930	-21,110	-19,060	-12,930	-2,490
2	Jan 30	1,868,580	-23,980	-24,250	-21,260	-28,070	-17,680	-3,410
3	Jul 02	1,835,170	-9,510	-9,580	-15,200	-12,200	-7,880	-1,640
4	Jan 31	1,833,870	-29,380	-28,820	-19,490	-32,280	-19,380	-5,010
5	Jul 17	1,833,710	-15,420	-15,580	-24,180	-18,590	-13,690	-2,570
6	Jul 18	1,825,060	-13,490	-13,360	-15,380	-15,450	-11,080	-2,170
7	Aug 06	1,818,660	-10,260	-10,270	-13,940	-12,580	-8,280	-1,620
8	Aug 12	1,808,150	-7,820	-7,800	-10,240	-9,010	-6,570	-1,300
9	Aug 07	1,781,340	-8,520	-8,340	-11,860	-9,500	-7,310	-1,570
10	Aug 19	1,780,230	-9,510	-9,310	-13,820	-11,520	-8,080	-1,510

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 results by county

Figure 23 shows a summary of the change in 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 change in generation) are shown rounded to the nearest 10. Dashes indicate results greater than zero, but lower than the level of reportable significance.

Figure 23. Monthly results by county for an example wind program in the Midwest region.

Midwest, 2019 AVERT

Output: Monthly Results 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. Counties are displayed only if they contain power plants.

State	County	Month	Change in Generation (MWh)	Change in SO2 (lbs)	Change in NOx (lbs)	Change in CO2 (tons)	Change in PM2.5 (lbs)
AR	Craighead County	1	-120	–	-130	-80	-10
AR	Craighead County	2	-150	–	-150	-90	-10
AR	Craighead County	3	-90	–	-100	-60	-10
AR	Craighead County	4	-60	–	-60	-40	–
AR	Craighead County	5	-50	–	-60	-30	–
AR	Craighead County	6	-160	–	-270	-100	-10
AR	Craighead County	7	-490	-10	-990	-310	-30
AR	Craighead County	8	-280	–	-500	-180	-20
AR	Craighead County	9	-110	–	-190	-70	-10
AR	Craighead County	10	-80	–	-90	-50	-10
AR	Craighead County	11	-80	–	-80	-50	-10
AR	Craighead County	12	-80	–	-90	-60	-10
AR	Craighead County	Annual	-1,750	-20	-2,720	-1,120	-120
AR	Hot Spring County	1	-11,430	-40	-4,260	-4,940	-920
AR	Hot Spring County	2	-8,670	-30	-2,740	-3,780	-680
AR	Hot Spring County	3	-5,800	-20	-2,010	-2,510	-440
AR	Hot Spring County	4	-7,680	-20	-1,520	-3,350	-550
AR	Hot Spring County	5	-8,100	-30	-2,330	-3,620	-650
AR	Hot Spring County	6	-7,810	-30	-2,980	-3,640	-680
AR	Hot Spring County	7	-5,800	-30	-3,110	-2,750	-500

Daily NO_x results by county

Figure 24 shows a summary of changes in 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 24. Daily NO_x results by county in the Midwest region.

Midwest, 2019 — AVERT

Output: Daily NOx Results (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. Counties are displayed only if they contain power plants.

Enter up to ten dates in the header column. This page will calculate the NOx changes 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**	**1-Jan**	**2-Mar**	**3-Apr**	**4-Jul**	**5-Aug**	**6-Sep**	**7-Oct**	**8-Nov**	**9-Dec**	**10-Jan**	**Average**
AR	Craighead County	-13	0	-7	-13	-38	-5	-16	-3	-4	-8	-11
AR	Hot Spring County	-167	34	-70	-86	-57	-189	-244	-74	-30	-113	-100
AR	Independence County	-1,217	-172	-499	-671	-94	-684	-698	-1,001	-531	-589	-616
AR	Jefferson County	-1,118	-199	-823	-973	-100	-623	-853	-884	-816	-1,084	-747
AR	Mississippi County	-445	-89	-254	-60	-16	-94	-230	-262	-118	-128	-170
AR	Pulaski County	-76	-48	-138	-165	-94	-109	-35	-70	-27	-37	-80
AR	Union County	-225	21	-686	-10	-2	-30	-364	-32	-369	-38	-174
IA	Allamakee County	-70	3	-22	-82	-15	-15	-14	-45	-45	-37	-34
IA	Audubon County	-29	-7	-21	-26	-10	-17	-28	-2	-13	-18	-17
IA	Black Hawk County	-1	-2	-3	-18	-2	-4	7	-3	-4	-2	-3
IA	Cerro Gordo County	-21	4	-16	9	-2	-1	-31	-8	-20	4	-8
IA	Des Moines County	-84	-26	-158	-10	4	-64	-93	11	18	16	-39
IA	Louisa County	-1,665	-858	-816	-470	-159	-82	-883	-1,039	-605	-476	-705
IA	Marshall County	-22	-22	-27	-55	-58	-4	-27	-13	-27	-46	-30
IA	Muscatine County	-113	-167	-104	18	-89	-16	-179	-195	-214	-186	-125
IA	Polk County	-9	0	-11	-20	-11	-7	-5	-12	-4	-6	-8
IA	Pottawattamie County	-1,907	-736	-1,298	-675	-31	-154	-768	-1,208	-699	-662	-814
IA	Scott County	0	1	0	-12	-18	-1	0	0	0	-1	-3
IA	Story County	-39	-16	-10	-8	-12	-11	-2	-6	-27	-17	-15
IA	Union County	1	-7	-1	-55	-72	-3	-5	-4	1	-60	-21
IA	Wapello County	-499	-309	-258	-355	-116	-125	9	-477	-199	-218	-255
IA	Woodbury County	-1,589	-942	-1,428	-992	-298	-285	-992	-1,347	-1,027	-1,126	-1,003
IL	Ford County	-13	-1	-16	-58	-17	-5	-28	-9	-9	-16	-17
IL	Fulton County	-114	-167	-150	-39	-46	-60	-220	-172	-214	3	-118

Charts and Figures

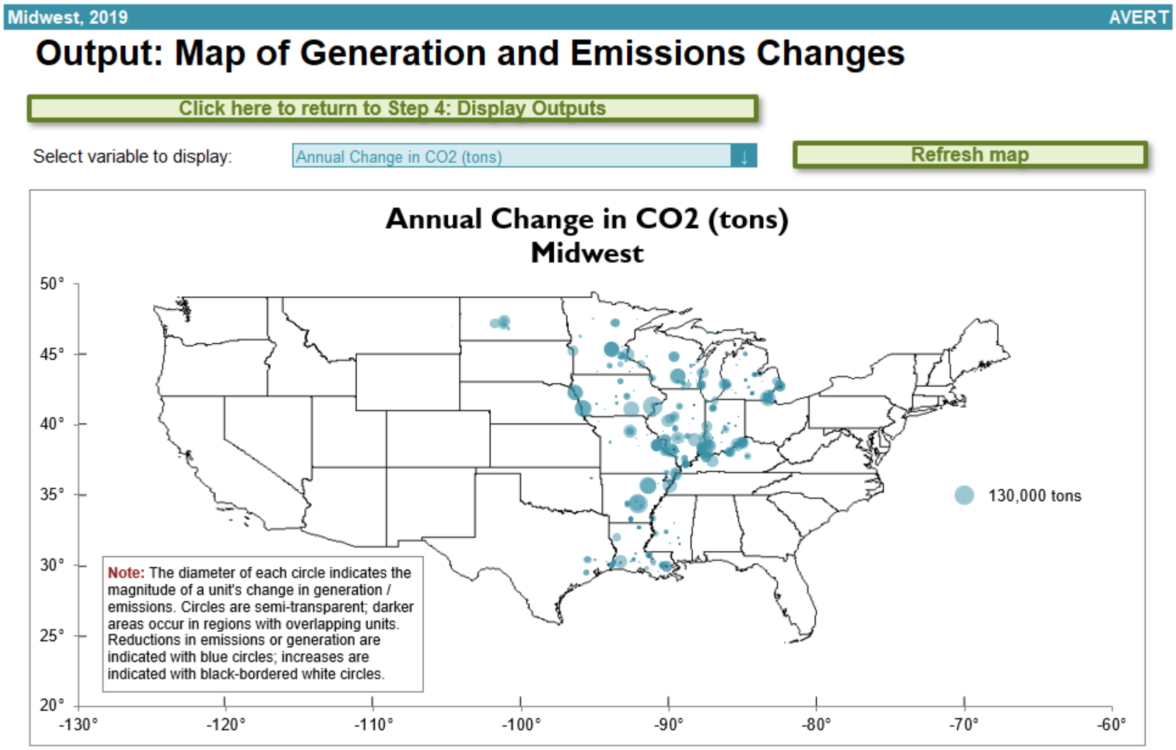
Map of generation and emissions changes

This dynamic map (shown in Figure 25) shows where emissions change 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 change in emissions at specific EGUs in the region. The size of the circles indicates the relative change of each EGU. Circles are semi-transparent. If multiple sources are near the same location, the circle is darker. Emissions increases are shown with black outlines and white interiors; these can occur when the user is modeling an increase in load or can be the result of the timing of maintenance outages in the base-year data (see Appendix G for details).

Figure 25. Map of generation and emissions changes for an example wind program in the 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.

Monthly results by selected geography

Monthly results can be viewed over the entire region or a specific state or county within the region (see examples in Figure 26 and Figure 27). 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 26. Monthly results (chart) for an example wind program in the Midwest region.

Midwest, 2019 AVERT

Output: Monthly Results by Selected Geography

Click here to return to Step 4: Display Outputs

Counties are displayed only if they contain power plants

Select level of aggregation: State
Select state: IA

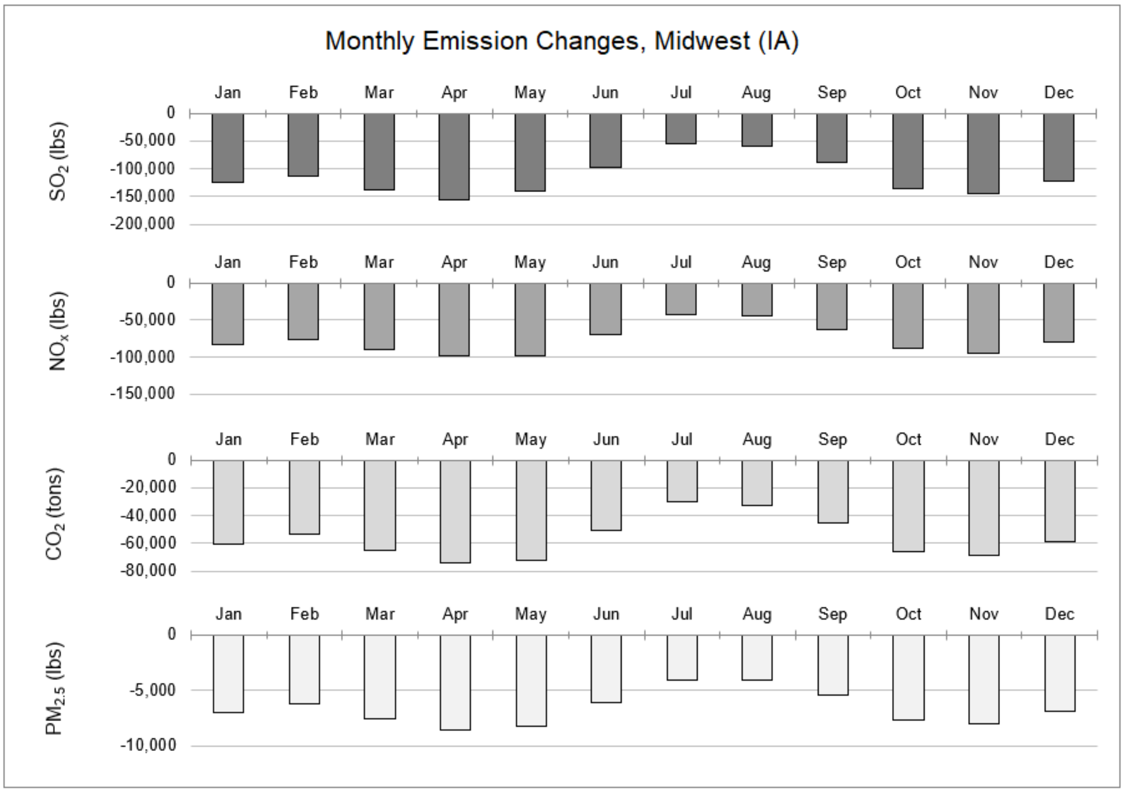


Figure 27. Monthly results (table) for an example wind program in the Midwest region.

Monthly Generation and Emission Changes, Midwest (IA)

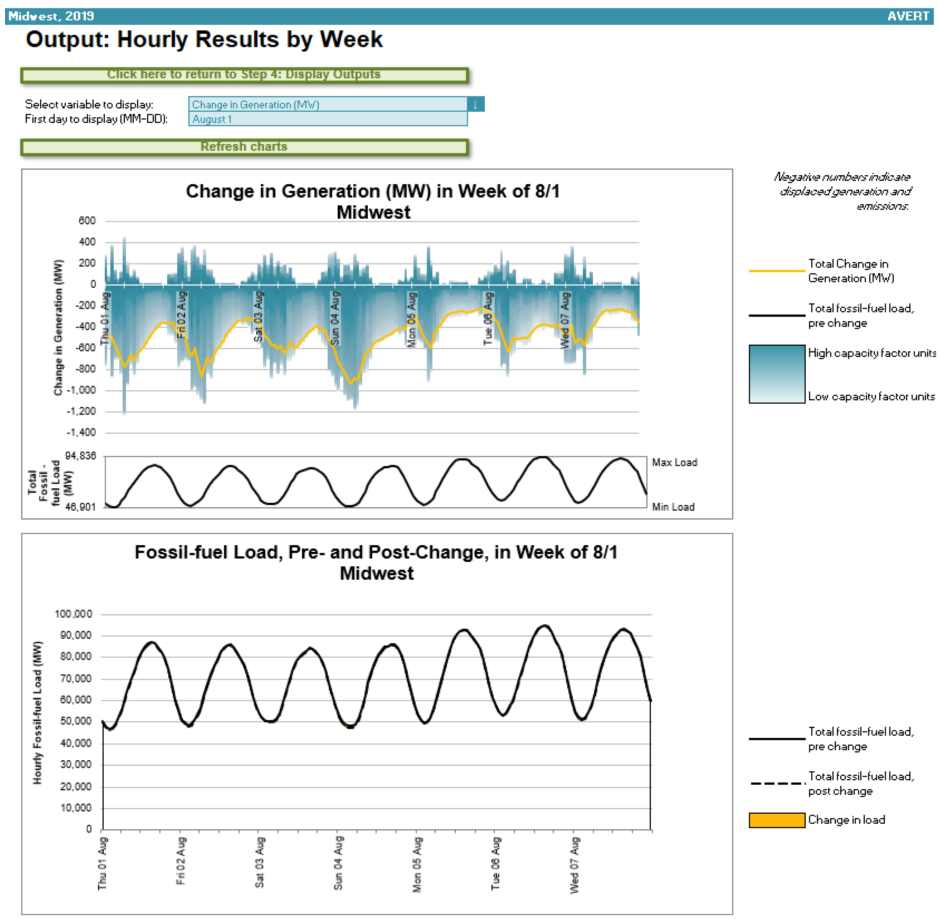
	Gen (MWh)	SO_2 (lbs)	NO_x (lbs)	CO_2 (tons)	$PM_{2.5}$ (lbs)
Jan	-64,190	-124,040	-83,740	-60,870	-6,970
Feb	-55,270	-112,620	-77,100	-53,680	-6,240
Mar	-68,330	-137,220	-90,380	-65,380	-7,630
Apr	-78,080	-155,820	-98,360	-73,760	-8,550
May	-74,980	-139,810	-98,070	-71,870	-8,270
Jun	-53,580	-98,130	-70,630	-50,970	-6,120
Jul	-32,210	-54,000	-42,890	-30,080	-4,070
Aug	-34,750	-59,790	-44,850	-32,670	-4,130
Sep	-48,000	-89,250	-63,130	-45,560	-5,390
Oct	-69,880	-135,670	-87,600	-65,770	-7,680
Nov	-70,960	-145,820	-94,300	-68,380	-8,060
Dec	-61,980	-121,650	-80,040	-59,030	-6,850
Total	*-712,000*	*-1,374,000*	*-931,000*	*-678,000*	*-80,000*

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 results by week

Figure 28 is a dynamic representation of hourly changes in EGU operation. 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.[54] 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 28 shows the same week-long energy profile as above, but presents the change in generation in reference to the total fossil-fuel generation. This chart illustrates the degree of change represented by the energy policy 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 energy change has been modeled.

Figure 28. Hourly results for an example wind program in the Midwest region.



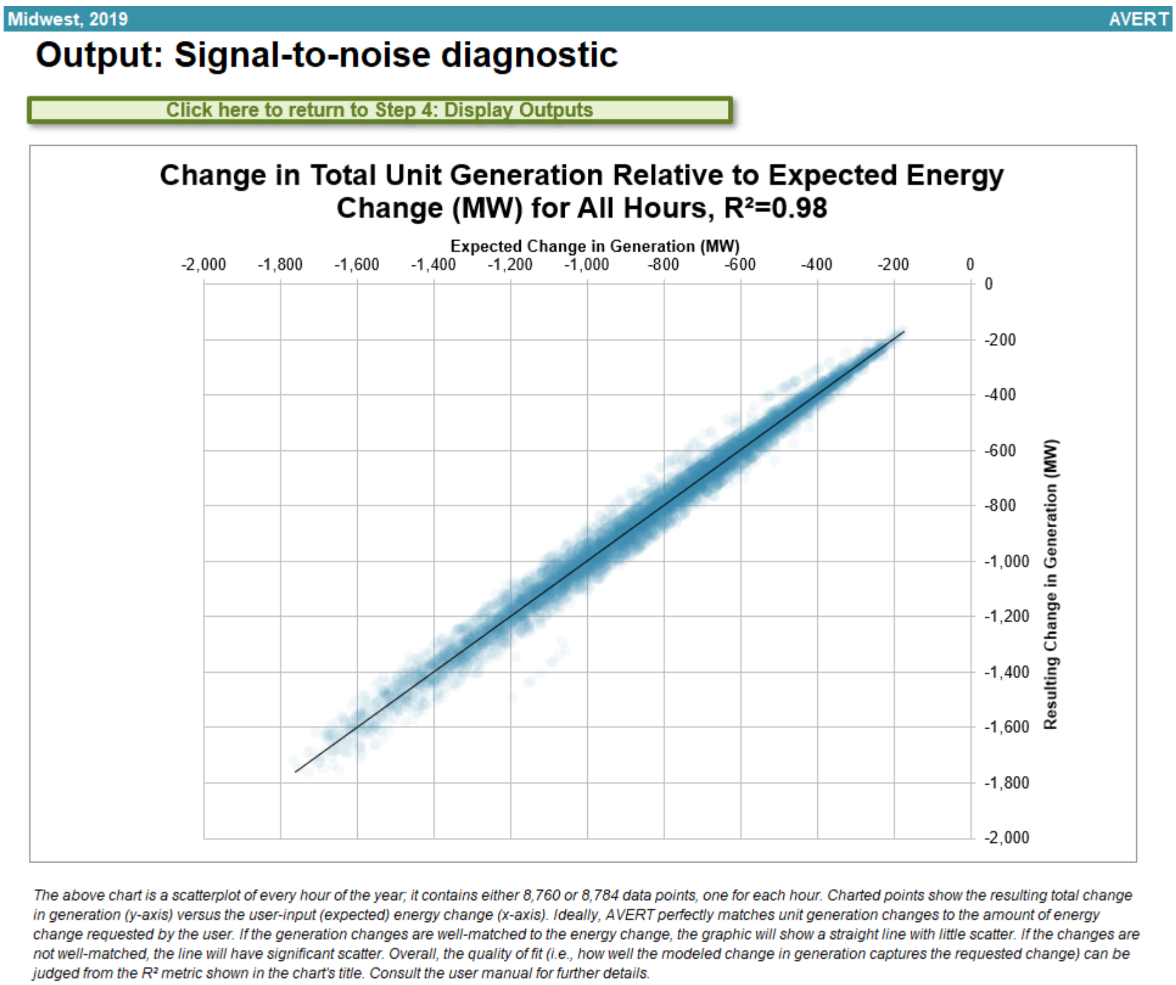
Signal-to-noise diagnostic

The signal-to-noise diagnostic shown in Figure 29 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

[54] Gradations are relative. 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. Most regions include several hundred units, so 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.

year, 8,784 points), showing calculated total change in generation in each hour (y-axis) against user-input, expected energy changes in each hour (x-axis). Ideally, AVERT perfectly matches modeled change in unit generation to the amount of energy changes requested by the user. This graphic shows where that assumption holds and where it does not hold, and to what extent. If the generation change is well-matched to the user-input energy change, the graphic will show a straight line with little scatter. If the changes are not well matched, the line will have significant scatter. Overall, the quality of fit (i.e., how well the model captures the requested energy change) can be judged from the R^2 metric shown in the chart title.[55] Highly scattered data points should be viewed with less weight than well-constrained data points.

Figure 29. Signal-to-noise diagnostic for an example wind program in the Midwest region.



Note that flat load changes (i.e., the same MW increase or decrease in every hour of the year) will result in a very different pattern than shown here. In this unique circumstance, the expected energy changes (the x-axis in this graphic) will be a single value, while there will be variance along the

[55] 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 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% of the energy change expected by the user (i.e., noise accounts for 1% of the observed variability).

"resulting change 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 results.

COBRA Text File

Analysts can use EPA's COBRA Health Impacts Screening and Mapping Tool to estimate the public health impacts of the changes in criteria pollutants generated from a scenario analyzed in AVERT. Go to "Step 4: Display Results" sheet and double-click on the blue box to enter a file path under "COBRA text file generation." Then click the "Generate COBRA text files" green button. One CSV file will be saved in the selected file folder. It will include county-level emission impacts for NO_x, SO_2, and $PM_{2.5}$ that can be easily uploaded into COBRA. For COBRA input instructions, refer to COBRA's main webpage at https://www.epa.gov/cobra and EPA's COBRA user manual.

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 Results" 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-energy change, while the second set of files details information post-energy change. For more detailed instructions on how to interpret and use SMOKE outputs from AVERT, see the tutorial and step-by-step instruction slides available on EPA's website at https://www.epa.gov/avert.

Advanced Outputs

Though 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 results 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,[56] 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 emissions and generation changes 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.

[56] 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 generation and emission changes (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, "The AVERT Analysis Structure."

Main Module

AVERT's Main Module estimates the change in emissions likely to result from energy policies 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 v16.38. 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 change in emissions for energy policies modeled in reference to a historical base year; however, you will need all three AVERT modules to model change in 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. EPA recommends that users not use any other computer functions (e.g., copy-paste) during this time in order to speed the calculation and avoid errors.

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.xlsm." Download the workbook at https://www.epa.gov/avert.
- The RDF for the region under analysis.
    - Default RDFs developed for use by EPA are labeled "AVERT RDF [DataYear] EPA_NetGen_PM25 ([Region]).xlsx"; they can be obtained at https://www.epa.gov/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 RDF:

- "Region" refers to one of 14 regions defined for the purposes of this tool. AVERT's regions are described in Section 3 of this manual, under "AVERT Regions" (page 17). 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 2017 through 2019 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 Power Sector Emissions Data to generate output files used to model emissions changes 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 2017 through 2019, 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 change in emissions from energy policies.

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 Power Sector Emissions Data from CAMD.[57]

For the purposes of tracking and verifying emissions, and monitoring emissions trading programs, CAMD 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).[58] CAMD data include reported gross generation (in MWh per hour),[59] steam output (in tons, from combined heat and power facilities), heat input (in million metric British thermal units, or MMBtu), and emissions of SO_2, NO_X, and CO_2. (Note that $PM_{2.5}$ emission rates come from a different source, the National Emissions Inventory, as described later in this section.) 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.[60]

Each power plant reports a "method of determination code" (MODC) for each pollutant for each hour. These MODCs reflect how emissions data were determined, which can vary based on power plant operation and emissions monitoring circumstances. Generally, the data are either classified as "measured" data or "substitute" data. While the vast majority of this data are classified as measured, occasionally power plants report substitute data when measured data are not available. A subset of these substitute data is the "maximum potential concentration" (MPC), the most conservative value power plants are required to report in certain circumstances (e.g., when the emissions monitor is bypassed). The MODCs that correspond to MPC are MODC 12, 18, and 23. To improve reliability of AVERT's results, data in hours and for pollutants coded with MODC 12, 18, and 23 have been removed from the text-based dataset. [61]

A MATLAB®-based preprocessing engine converts these hourly text files into compact data arrays and a reference EGU records file.[62] The preprocessing engine calls an Excel-based spreadsheet populated with ancillary information about each EGU, with most information gathered from the CAMD "facility information" records. The spreadsheet is populated with ancillary lookup information about each EGU that has reported to CAMD.

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

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

[58] For the purposes of CAMD data 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. CAMD unit designations are often, but not always, the same as DOE unit designations. CAMD's data guide with more information can be accessed at https://www.epa.gov/sites/production/files/2020-02/documents/camds_power_sector_emissions_data_user_guide.pdf.

[59] 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%, depending on the unit. Emissions, however, are "at stack" and represent total emissions released to the atmosphere.

[60] CAMD 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 dataset generally does not include data from biomass generation or most small diesel backup generators.

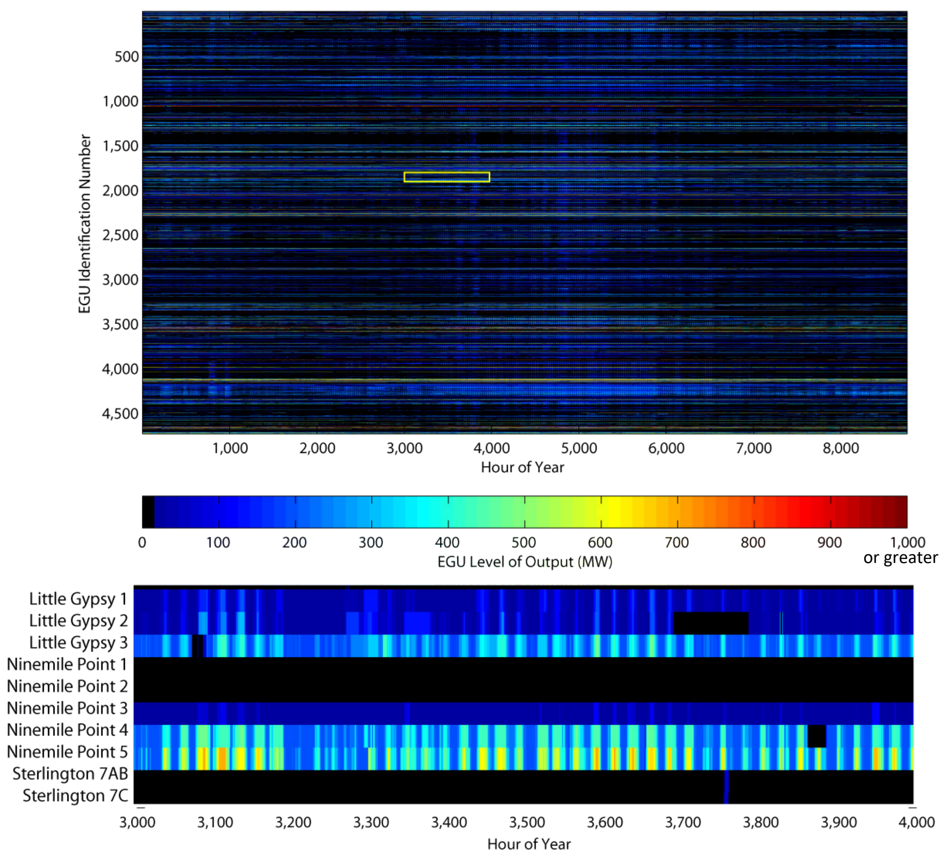
[61] To learn more about Method of Determination Codes, see 40 CFR Part 75.57, Table 4a.

[62] https://www.mathworks.com/products/matlab.html.

generation[63] and by-plant net generation[64] using 2015 data.[65] 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 combined cycle unit with the same gross generation is assumed to export 96.7 GWh.

The six data arrays store two-dimensional matrices of net generation, steam output,[66] heat input, $PM_{2.5}$, SO_2, NO_x, and CO_2 organized by EGU and by hour of the year. Figure 30 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 CAMD 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 30 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 30. 2011 gross generation output (in MW) for each EGU in each hour of the year.



Colors represent the level of EGU generation.

[63] As reported to CAMD.

[64] As reported to EIA on Form 923 (https://www.eia.gov/electricity/data/eia923/).

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

[66] AVERT does not use steam output.

The reference EGU records file (a structural array in MATLAB®) holds the name, ORISPL number (a value assigned to each plant site by DOE), EPA unit ID, a lookup table (LUT) pointer to the two-dimensional matrices, locational information, and fuel information for each EGU. Table 3 shows an example record for the Handley Generation Station, Unit 5. The "Unique ID" shown in Table 3 is a unique identifier created within AVERT, consisting of the ORISPL number concatenated with the EPA unit identification number as a string.[67] In addition, each record stores a lookup value (not shown in Table 3), which codes for the location of the plant in the two-dimensional data files.[68]

Table 3. 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

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 CAMD on an hourly basis.

$PM_{2.5}$ emissions rates are calculated using plant-specific point source emissions data from the 2014 National Emissions Inventory,[69] combined with heat input data as reported to CAMD. 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

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

[68] Due to coding limitations in Excel and MATLAB, a small number of units have modified UnitIDs relative to the UnitID that appears in CAMD data. For example, units with a UnitID of "1-1" in CAMD data may instead use a UnitID of "N1" in AVERT.

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

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 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.

AVERT 3.0 divides the contiguous United States into 14 distinct regions.[70] These regions are aggregates of one or more balancing authorities. Each balancing authority is an entity tasked with the actual operation of the electric grid and ensures that the demand for electricity in every minute of every day is met by adequate supply from the grid's power plants. In effect, these entities are the smallest discrete component of the grid's operation. There are about 75 balancing authorities active in the United States today, with each of the nation's 4,400 emitting power plants assigned to one of these entities.

Within AVERT, these 75 balancing authorities—and their constituent power plants—are assigned to one of 14 regions. These assignments were developed according to delineations based on geography (e.g., all balancing authorities in California are assigned to the "California" region) or electrical transmission (e.g., balancing authorities in Florida's panhandle). In many situations, an AVERT region is based around a "core" balancing authority (e.g., PJM, MISO, CAISO) with other smaller balancing authorities grouped with that larger entity for convenience or because there may be substantial transfers of electricity between regions. In most situations, AVERT's regional assignment is closely based on the regional assignments from EIA's 930 dataset.[71] Using EIA's 930 dataset and EIA's 861 dataset for 2018, we match each electric utility with a balancing authority, and each balancing authority with an AVERT region.[72] Each electric utility is assigned to one and only one balancing authority, and each balancing authority is assigned to one and only one AVERT region. Retail sales from each utility are grouped by state and AVERT region to determine how each state's electricity sales are split up across the 14 AVERT regions. This is done in order to inform users how they may wish to allocate electricity impacts across different AVERT regions, in situations where a state spans more than one region (see Appendix G for more information). Finally, using data from EIA's 860 dataset for each analysis year, we match each EGU with a balancing authority and an AVERT region for purposes of creating RDFs.[73]

Analysis based on smaller regions, such as eGRID subregions, 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 changes too widely, making it difficult to ascribe load changes at a particular location to a reasonable cohort of EGUs.

---

[70] These regions include the 48 contiguous states plus Washington, D.C. Power plants in Alaska and Hawaii are not required to report hourly data to EPA's Continuous Emissions Modeling System (CEMS) dataset used by AVERT and are thus excluded from analysis in the tool.

[71] See https://www.eia.gov/beta/electricity/gridmonitor/.

[72] See https://www.eia.gov/electricity/data/eia861/.

[73] See https://www.eia.gov/electricity/data/eia860/.

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 RE 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. Hourly capacity factors can also be scaled to reflect an annual capacity factor specified by the user.

Rooftop and Utility-Scale PV

Annual hourly capacity factors for rooftop PV and utility PV were obtained from the National Renewable Energy Laboratory's PVWatts v.1 tool.[74] Each hourly capacity factor assembled for each AVERT region is based on the average PV capacity factor for one to 16 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.

Onshore Wind

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.[75] 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 31.

[74] National Renewable Energy Laboratory. n.d. PVWatts: A Performance Calculator for Grid-Connected PV Systems. Accessed December 14, 2012. https://pvwatts.nrel.gov/.

[75] Vestas Wind Systems. 2013. *3 MW Platform*. https://www.nhsec.nh.gov/projects/2013-02/documents/131212appendix_15.pdf. In AVERT's Main Module v3.0, onshore wind capacity factors for a given region are based on the onshore wind capacity factors for the AVERT region in v2.3 that most closely correspond to the 14-region topology.

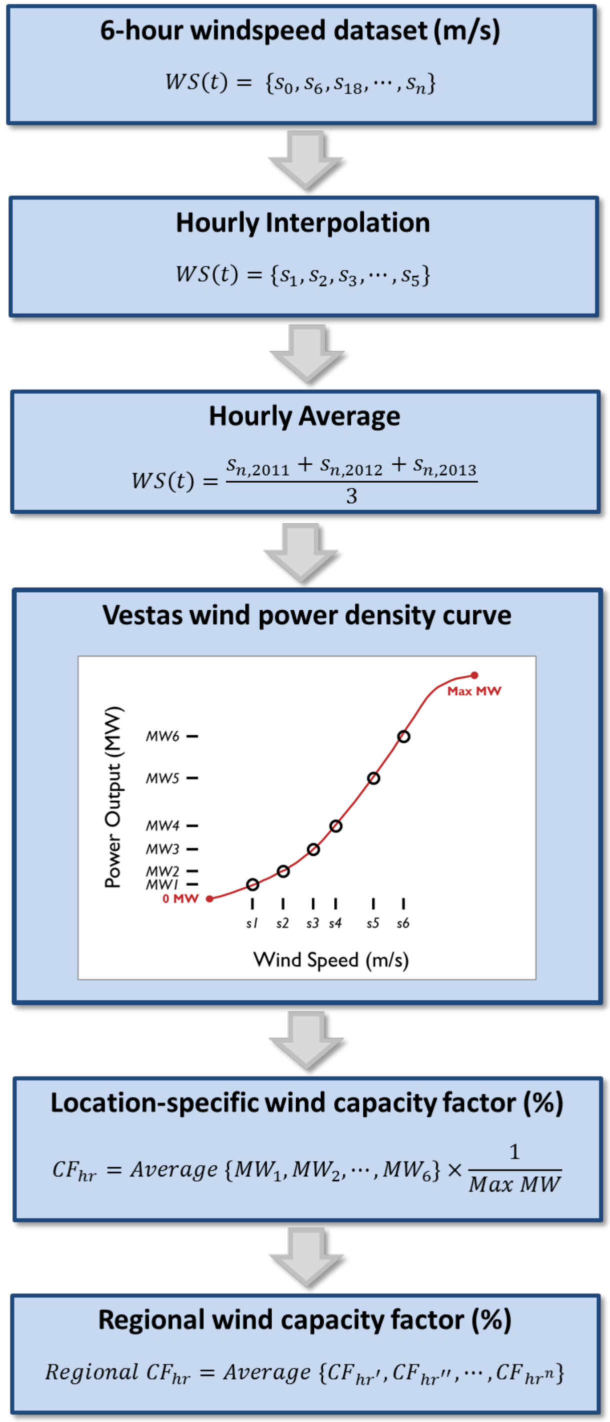


Figure 31. Flowchart for converting onshore wind speed data into hourly regional capacity factors for onshore wind.

Offshore Wind

Offshore wind speed data were assembled using information from the Bureau of Ocean Energy Management (BOEM) 2019 modeled hourly offshore wind dataset.[76] These data were downloaded in GIS point format. Figure 32 shows the coverage of the wind speed data in gray.

Figure 32: Map of offshore wind data and lease regions coded by AVERT region.

Next, wind speed data were filtered using a dataset of actual and proposed wind lease areas.[77] Each screened BOEM lease area contains thousands of wind speed data points. Each one of these points contains 24-hour wind speed data for each month, which represents a typical hourly wind speed for a representative day for any given month.

BOEM lease areas were then assigned to each AVERT region—some AVERT regions comprise one single BOEM lease area, while other AVERT regions have many BOEM lease areas. Next, the average hourly wind speed (for each 24-hour interval) was calculated from all data points across the lease areas within each AVERT region. Each 24-hour period was then replicated over the course of the entire month to develop a single hourly wind speed dataset for each AVERT region, containing one data point for each hour of the year.

Using data from NREL's 2016 report *Offshore Wind Energy Resource Assessment for the United States*, the developers of AVERT applied a gross power curve and estimated losses to each hourly wind speed data point to estimate the net power output for each windspeed.[78] The team then divided the net power output by the nameplate capacity of the representative power curve to determine a scalable net hourly capacity factor for each of the hourly data points for each of the AVERT regions.

[76] Bureau of Ocean Energy Management. 2019. Renewable Energy GIS Data: Hourly Wind Speeds. https://www.boem.gov/Renewable-Energy-GIS-Data/.

[77] Bureau of Ocean Energy Management. 2019. Renewable Energy GIS Data: Wind Planning Areas, Wind Energy Areas and Renewable Energy Leases. https://www.boem.gov/Renewable-Energy-GIS-Data/. This dataset describes the areas that are most likely to be developed with offshore wind in the next several years. This aligns with the time horizon modeled in AVERT. In other words, it is unlikely that areas outside the current designated and proposed BOEM lease zones would be developed with offshore wind in the near future (e.g., more than 5 years from the present day).

[78] National Renewable Energy Laboratory. 2016. *2016 Offshore Wind Energy Resource Assessment for the United States.* Section 7.3.1, Figure 9. https://www.nrel.gov/docs/fy16osti/66599.pdf.

Only AVERT regions with proximity to actual or proposed offshore wind lease areas can model the addition of offshore wind generators. For example, the Gulf Coast and the Great Lakes do not have actual or proposed offshore wind lease areas, so they are not included in this analysis. AVERT provides offshore wind capacity factors for the New England, New York, Mid-Atlantic, Carolinas, California, and Northwest AVERT regions. AVERT does not provide capacity factor data for the Texas, Midwest, Central, Florida, Southeast, Southwest, Tennessee, or Rocky Mountains AVERT regions. When users enter a non-zero capacity for offshore wind in AVERT regions that do not have hourly offshore wind capacity factors, the model will simply display a change of 0 MW for each hour. Note that currently, BOEM's wind planning areas are located only in certain areas of the United States coastline. For example, there are no BOEM wind planning areas in Florida or Texas, which means that the AVERT regions that largely encompass these states do not have offshore wind profiles.

Users are encouraged to develop site-specific capacity factor profiles for RE options whenever the data are available. It is important to note that AVERT is *not* a tool for formal greenhouse gas accounting or establishing who may take claim credit for emission reductions of RE programs or projects. It is recommended that companies follow the protocols from the World Resources Institute's GHG Protocol and the Federal Trade Commission's *Guides for the Use of Environmental Marketing Claims* for the purposes of greenhouse gas and carbon footprint accounting.[79]

[79] Federal Trade Commission. 2012. *Guides for the Use of Environmental Marketing Claims.* https://www.ftc.gov/sites/default/files/documents/federal_register_notices/guides-use-environmental-marketing-claims-green-guides/greenguidesfrn.pdf.

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.

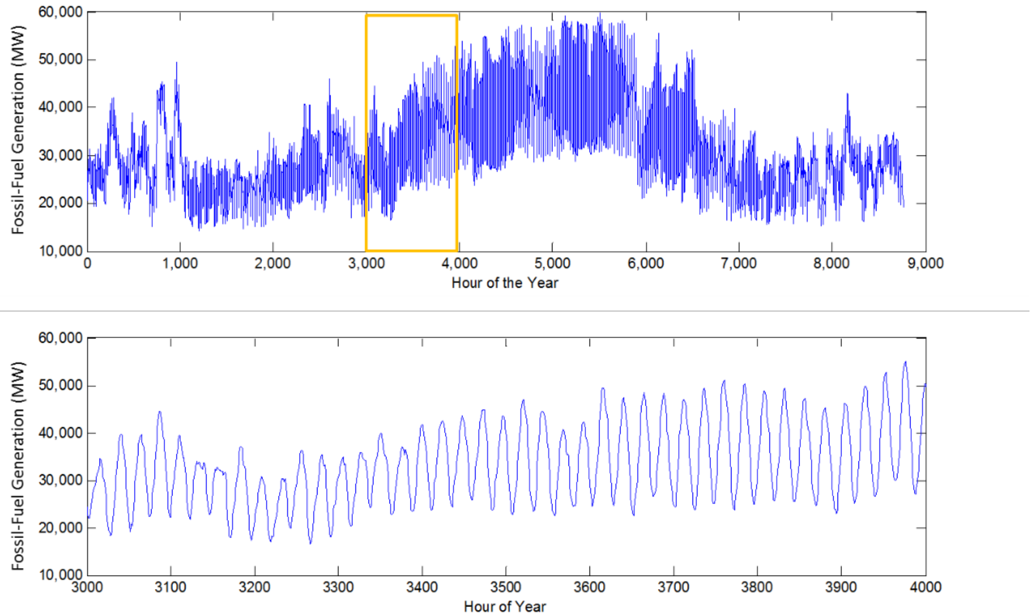
The Statistical Module is also equipped to estimate how fossil-fuel EGUs respond to regional load requirements given changes in the fleet of EGUs available in future years. The module inputs information from AVERT's Future Year Scenario Template to identify existing EGUs to be retired, the expected impact 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 33, which includes a detail of hours 3,000 to 4,000).[80]

[80] Hour 3,000 = May 5. Hour 4,000 = June 15.

Figure 33. 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 34).[81] 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.[82] Bin thresholds (the fossil-fuel load levels dividing the bins) and bin medians vary by region.[83]

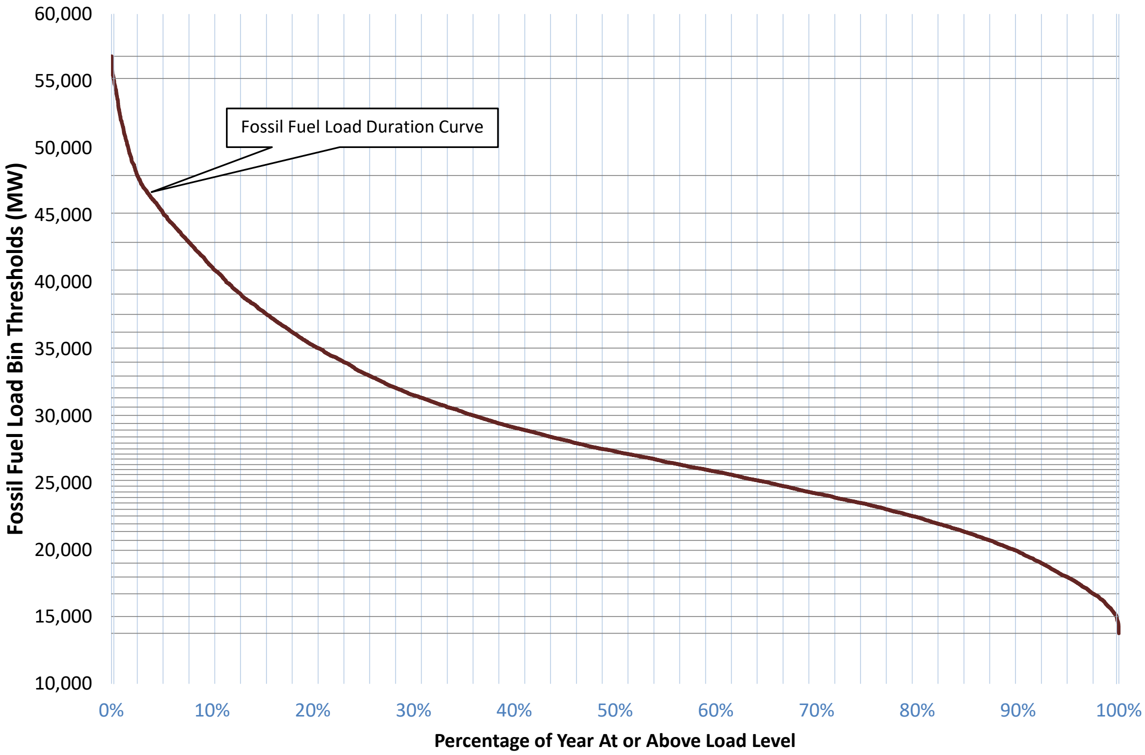
Figure 34 illustrates how the bins are formed relative to total system fossil-fuel load. The figure shows a typical “load duration curve” in dark red for fossil generation in Texas in 2011. This curve represents all fossil-fuel load levels of the year (8,760 data points) in declining order. The horizontal axis represents the fraction of time that fossil generation is at or above a certain level (e.g., fossil generation only exceeds the 20% marker in 20%, or 1,752, hours). The vertical axis shows the fossil-fuel load for each point on the curve.

[81] “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.

[82] 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.

[83] AVERT results include 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 34. 2011 fossil fuel load duration curve for the 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%,[84] capturing 224 or 225 hours each. In other words, each of these bins represents slightly over 2.5% 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% 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.[85]

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 34) 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 34 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 corresponding fossil-fuel load bin, and the points in each bin (apart from the end binds, as discussed above) represent roughly 2.5% of hours in the year.

---

[84] Each line represents a demarcation of 2.56%.

[85] 20 hours is represented by 0.23% and 99.77% on this axis.

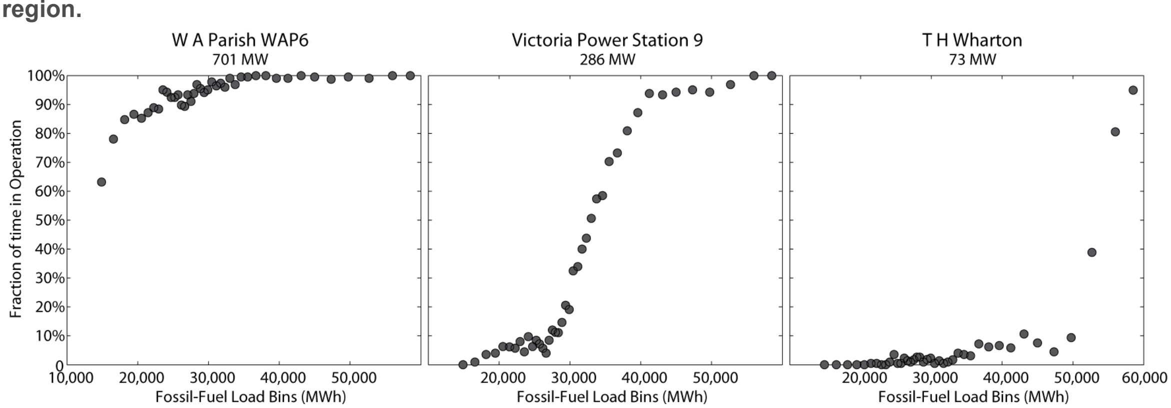
Collecting Statistical Information

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 35 shows the frequency of operation for three EGUs in the Texas region in 2011.

Figure 35. 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% 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

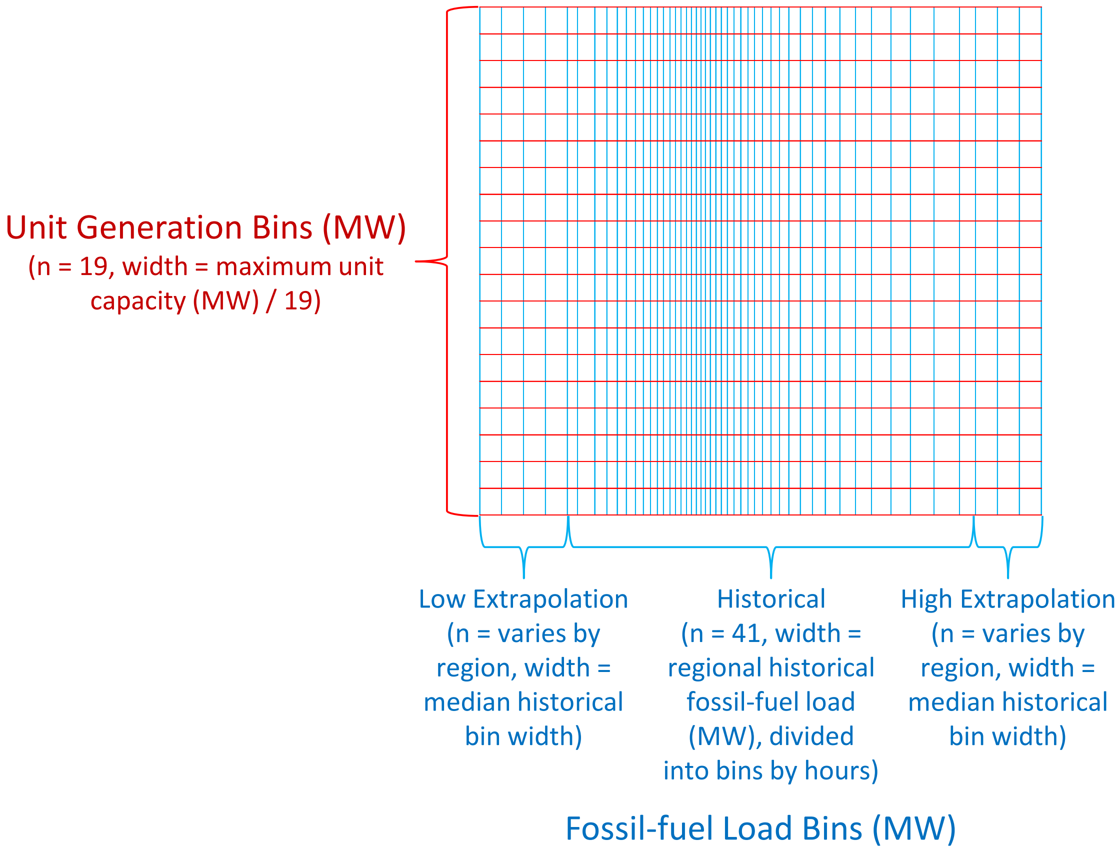
The second set of probability distributions calculated by AVERT describes generation output for each EGU in operation in each fossil-fuel load bin.[86] AVERT divides each EGU's generation into 19 evenly spaced "unit generation bins."[87] Figure 36 depicts the intersection of these two types of bins. Smaller fossil-fuel load bins (where the vertical lines are closer together) indicate a higher concentration of hours at those load levels.

---

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

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

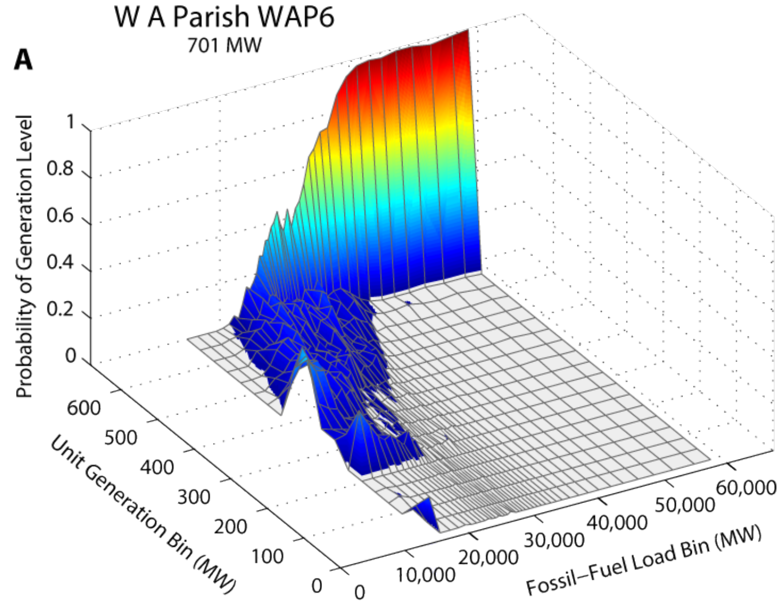
Figure 36. Schematic of unit generation bins and fossil-fuel load bins.

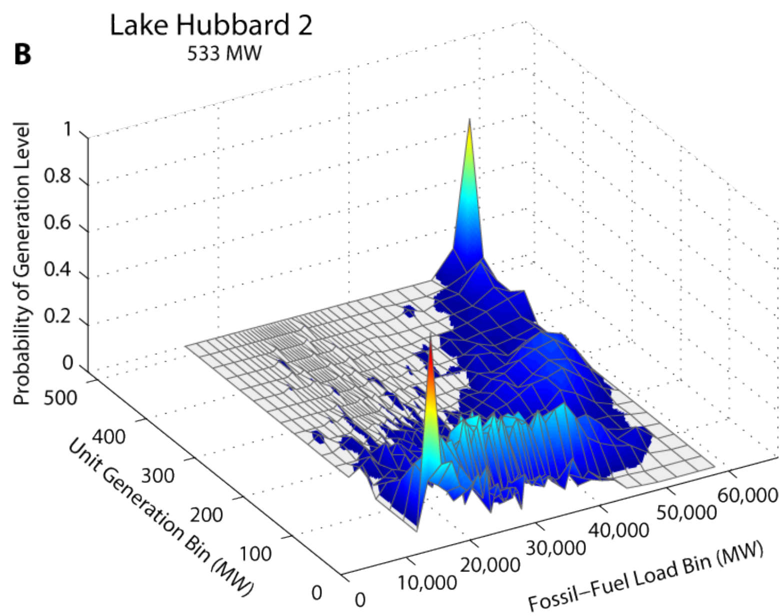


For each of the 41 fossil-fuel load bins, AVERT determines the number of hours in which the unit generated at an amount within each of the 19 unit generation bins. In this way, the model creates a discrete probability distribution of generation for each fossil-fuel load bin during all hours in which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

Figure 37 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 37. 2011 generation level by fossil-fuel load bin and unit generation bin for two indicative EGUs in the Texas region.

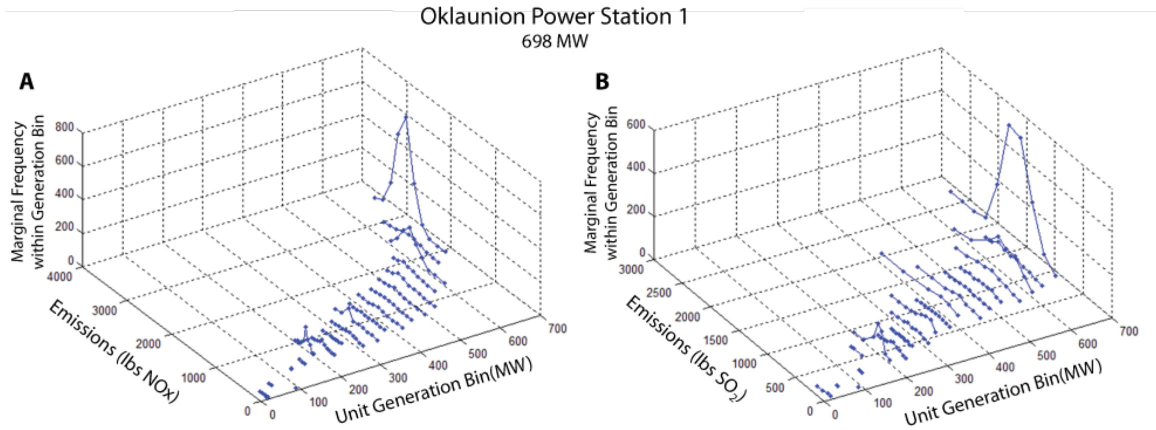




Heat Input and Emissions by Generation Level

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.[88] 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. It also calculates $PM_{2.5}$ data 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 38 displays a single EGU's emissions of SO_2 and NO_x relative to its generation level.

Figure 38. 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 changes resulting from recent historical or expected/proposed near-future energy policies. In either case, the range of fossil-fuel load requirements in the base year may be insufficient to represent all scenarios of interest. For example, a scenario 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 emission changes from policies 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 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 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

[88] Where "ozone season" is considered to be 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.

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.[89] 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.

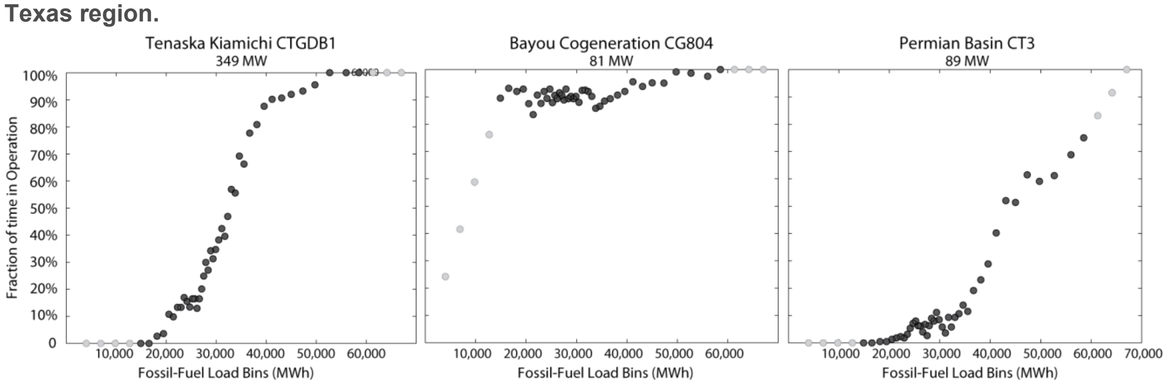
Extrapolating the Probability of Operation

The minimum amount of potential generation is zero, a level that would require zero generation from all EGUs being modeled in the RDF. 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, all EGUs in the region need to be operating at their full capacity. EGUs that have a 100% 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% is extrapolated linearly up to the potential maximum from the probability at the highest recorded load level.

Figure 39 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 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.

Figure 39. 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.

[89] The number of fossil-fuel load bins outside 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.

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.

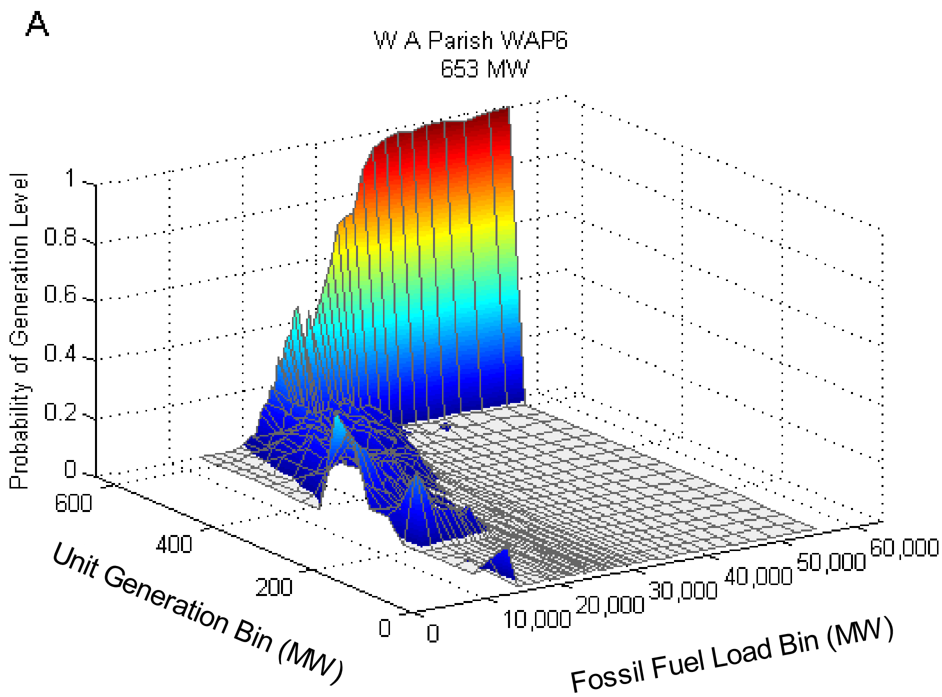
The extrapolated space encompasses fossil-fuel load bins that extend to the highest possible coincident peak generation (i.e., all EGUs in a region operating at maximum capacity simultaneously) and down to zero. New fossil-fired load bins are created at intervals equal to four times the size of the median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

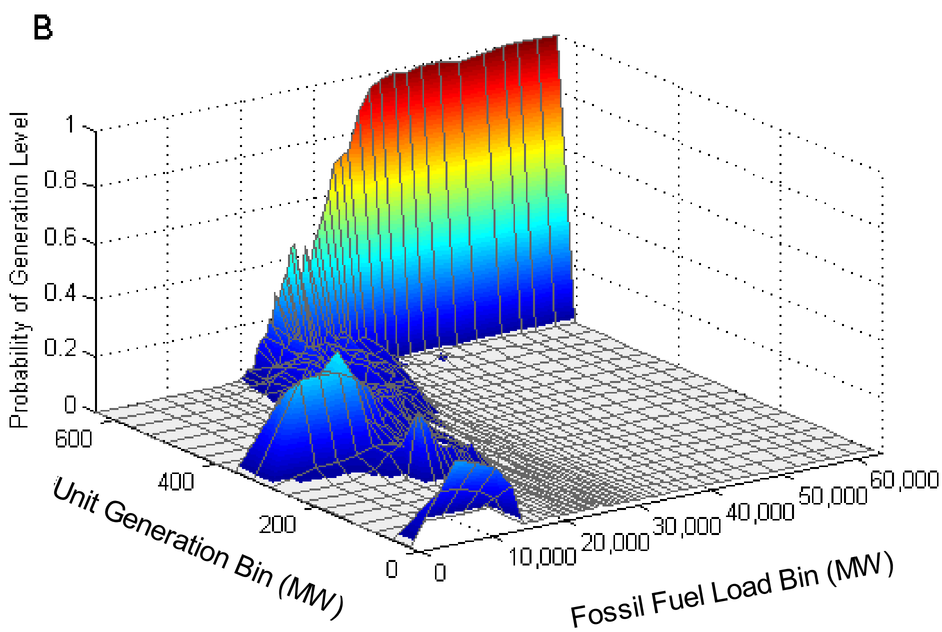
To extrapolate to potential higher fossil-fuel load bins, AVERT assumes that each unit will have a 100% probability of generating at its highest output if fossil load is at its theoretical maximum, and 0% of generating at any other level of output given maximum fossil load. For each level of generation (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 40 (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 in 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 toward 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 40. 2011 base year (A) and extrapolated (B) probabilities of generation levels for an indicative EGU in the Texas region.





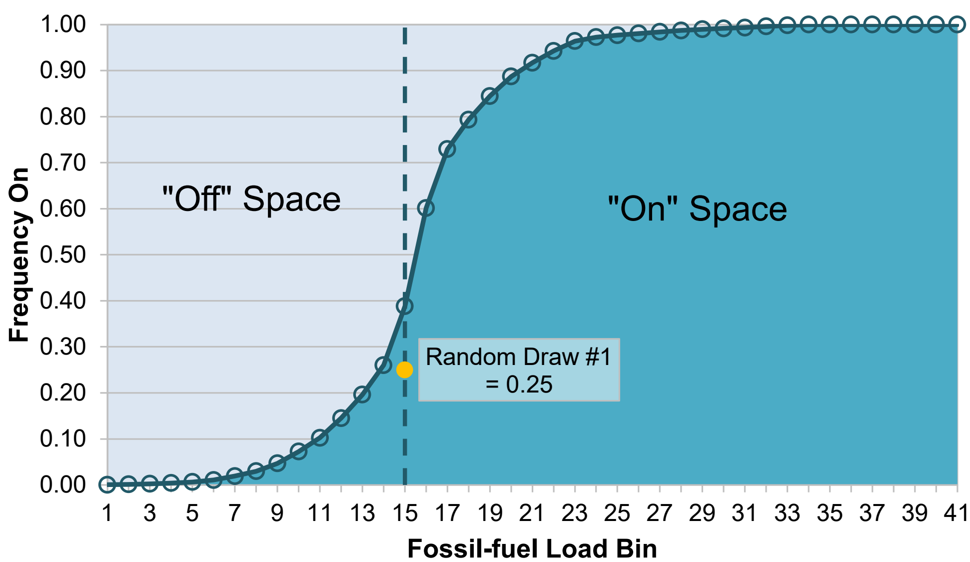
Statistical Analysis

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:

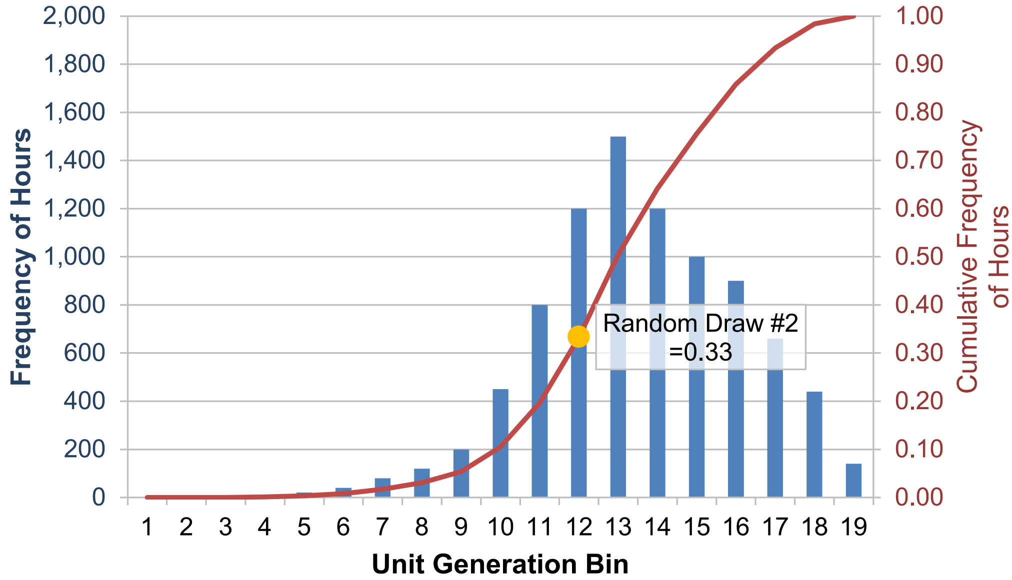
- The first number drawn is compared to the EGU's probability of operation at the selected fossil-fuel load bin. If the number drawn is greater than the probability of operation, the EGU is turned off and draws two and three are not conducted. If the number drawn is less than the probability of operation, the EGU is turned on. Figure 41 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 41. EGU frequency of operation and example of random draw selection.



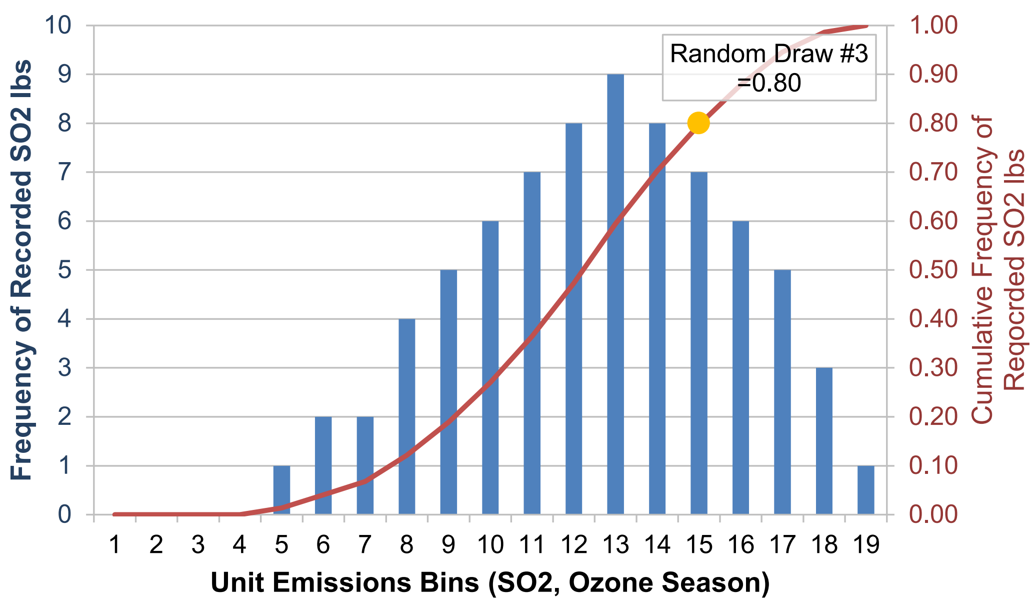
- The second number drawn is compared to the discrete *cumulative* distribution function of EGU generation for each fossil-fuel load bin. The model selects the EGU's unit generation bin as the next highest EGU output greater than the cumulative probability value indicated by the number drawn. Figure 42 illustrates this step: the random draw is 0.33, which results in the selection of unit generation bin 12.

Figure 42. 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 43, the third random draw is 0.80 and unit emissions bin 15 is selected.

Figure 43. 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.[90] Each of these runs repeats the process described above of

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

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 44 and Figure 45.

Figure 44. 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).

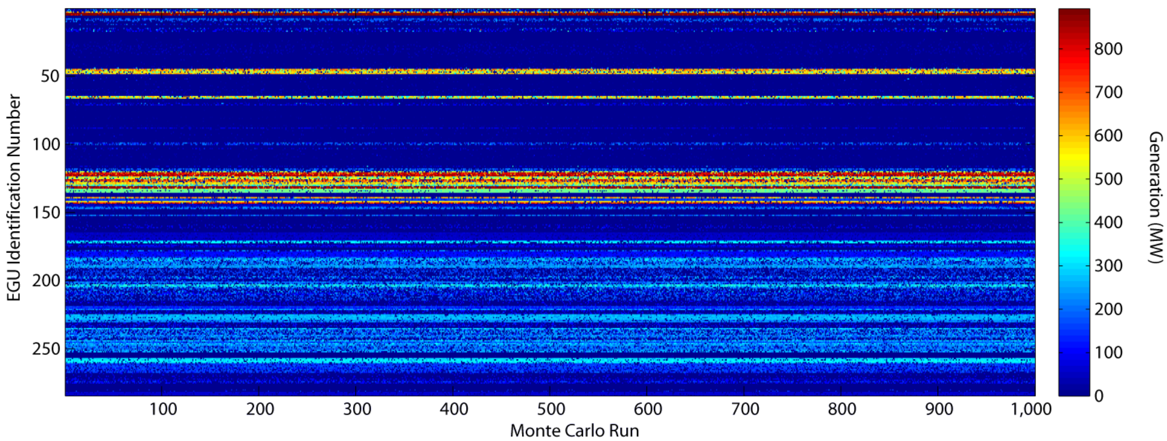
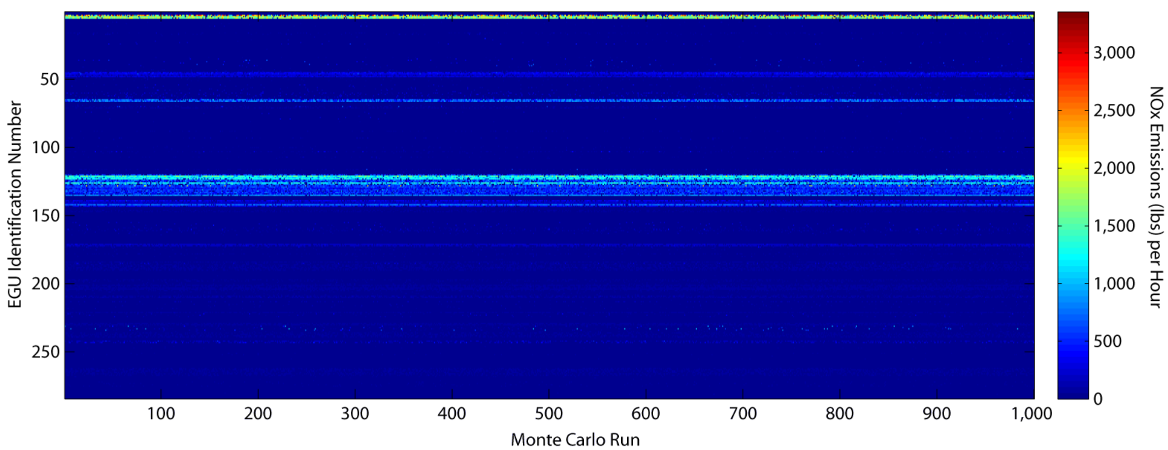


Figure 45. NO_x ozone season emissions (lbs) for 1,000 Monte Carlo runs at 270 EGUs in the Texas region at a fossil-fuel load of 30,000 MW (2011).



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.

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)[91]
- CO_2 emissions (tons, non-ozone season)

[91] 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, changes in 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 Your Windows Operating Environment

The Statistical Module is designed to work in a 64-bit operating system environment, so you will first need to 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. In Windows 10, press the Start button, type "Settings," select "System," select "About," and check under "Device specifications." Instructions for determining your Windows environment can be found at https://support.microsoft.com/en-us/help/15056/windows-32-64-bit-faq..

Step 2: Download the Statistical Module Executable

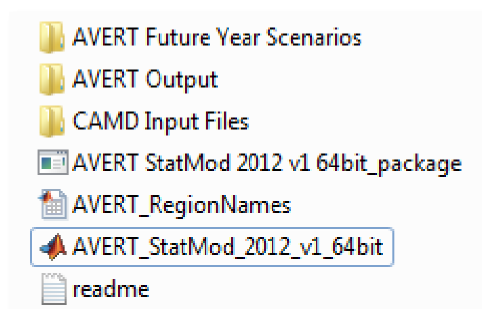
Download the following two files and save them to your computer:

1) **AVERT's Statistical Module executable package:**
"AVERT StatMod [Year] 64bit_package." Download this MATLAB executable at https://www.epa.gov/avert.

2) **The MATLAB Compiler Runtime (MCR).** Download the Windows 64-bit version of the MCR for R2012b from the Mathworks website at https://www.mathworks.com/products/compiler/matlab-runtime.html.

Do not download a newer version of the MCR even if one is available from the Mathworks website. It is important to download version R2012b, also known as version 8.0. 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 RDFs 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 [Year] 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 the CAMD Database

The Statistical Module package contains, by default, the most recent data year of data. If another year is desired, additional CAMD Power Sector Emissions Data compatible with AVERT are available at https://www.epa.gov/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 the MATLAB Compiler Runtime

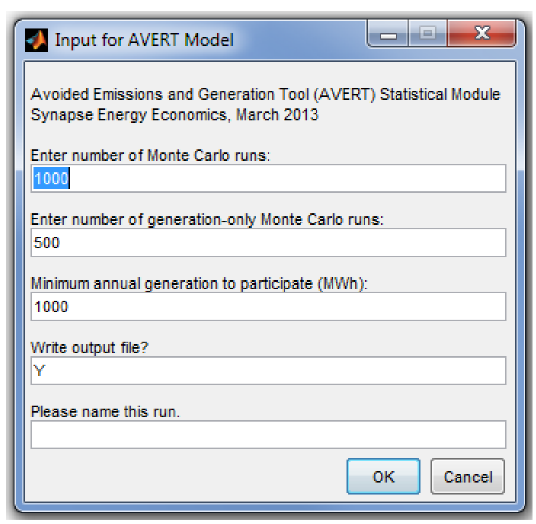
The Statistical Module executable requires additional, free MATLAB software in order to function. For additional instruction on how to verify that the MCR is installed properly on your computer, consult the readme.txt file. As noted on the previous page, it is critical to download and install the correct 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

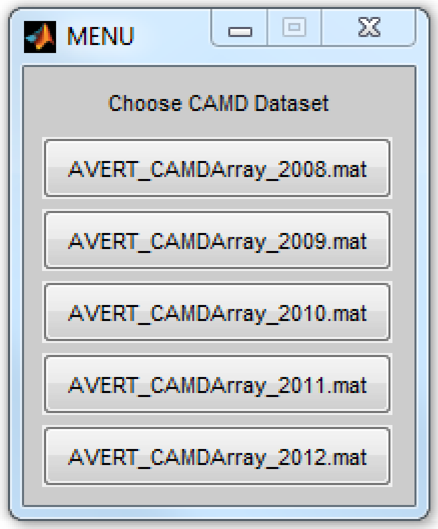
The Statistical Module can create either a base-year or a future year scenario (i.e., a scenario in which some EGUs are retired, new EGUs are brought online, and other EGUs change emissions rates). The process of creating a Future Year Scenario Template is described in Appendix F. A template for the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



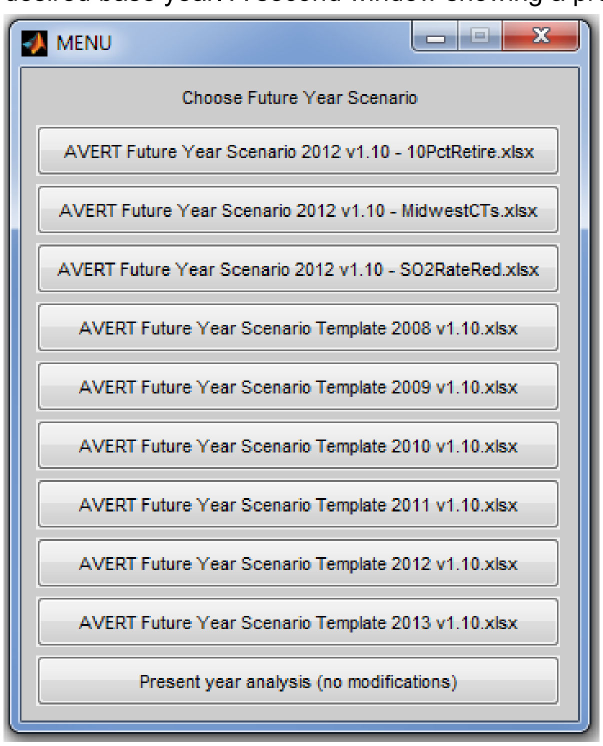
- The number of Monte Carlo runs (default value is 1,000).
- The number of generation-only Monte Carlo runs (default value is 500).
- The minimum annual generation for an EGU to be considered in the model (default value is 1,000 MWh).
- Whether or not an output file should be written. Choose "Y" to create 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.



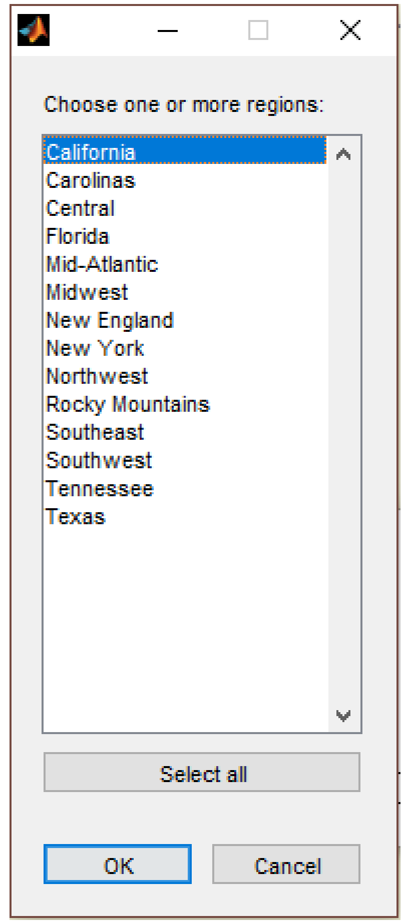
Step 8: Choose a Base- or Future Year Scenario

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 2012 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 14 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.

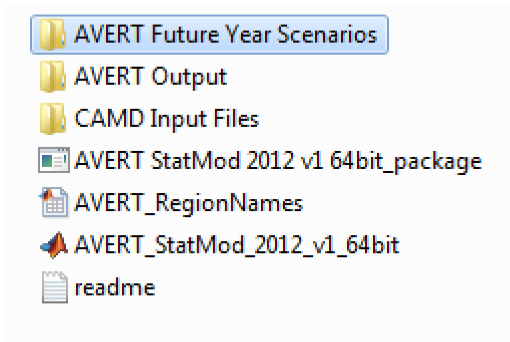
Each region is complete when the status bar reads “Finished with [Region].” If more than one region is chosen, the program automatically proceeds to the next region.

Appendix F: AVERT's Future Year Scenario Template

AVERT is equipped to estimate change in 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/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 46).

Figure 46. 2011 Screenshot of example EGUs in the “Additions” worksheet.

										Either select a county from the dropdown, or enter manually		
#	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
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. Because 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.[92] 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.

[92] 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

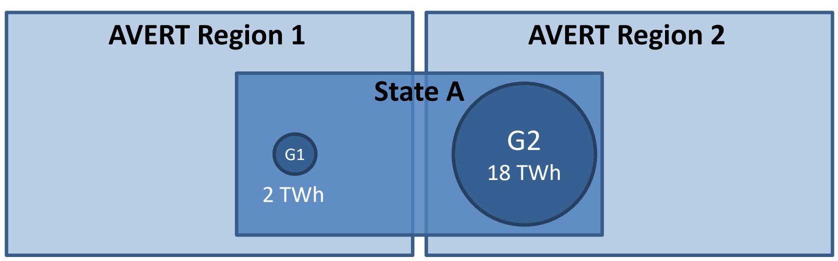
AVERT 3.0 divides the contiguous United States (including Washington D.C., but not Alaska, Hawaii, or other territories) into 14 distinct regions. These regions are aggregates of one or more balancing authorities. Refer to Appendix B for additional detail on how the regions were developed.

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 2018 edition of EIA's 861 database. Electrical boundaries do not necessarily represent political boundaries. As such, only 24 states and the District of Columbia are encompassed entirely within one AVERT region. The remaining states straddle two or more AVERT regions. Refer to Table 1 (on page 18) 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 emission changes of the programs only on generators that are contained within that AVERT region. AVERT regions are defined not by state geography but by the electric sales that occur within their borders, as defined by utility-reported sales to EIA. To capture the emission changes of a state-wide energy policy across two or more AVERT regions, the energy policy must be parsed between the two (or more) AVERT regions straddled by the state.

Figure 47 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 sales are located in and serve AVERT region 2. With some exceptions, as an approximation, the effects of the energy policy should be split into the two AVERT regions ratably, such that 90% of the program (represented by 90% of the sales) is run within AVERT region 2, and 10% of the program is run within AVERT region 1.

Figure 47. 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 energy projects, programs, or policies and can readily identify the region into which they will fall using the map in Figure 3.

Table 4 indicates, by state, the approximate fraction of electricity sales found in each AVERT region. This table was constructed by reviewing how much fossil electricity was sold in 2018 in each AVERT region. 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 1,475 MW in the Midwest region, and once with 525 MW in the Central region—and then aggregate the results of these runs. An Arizona air quality planner, conversely, would run AVERT only once, with all the energy changes attributed to the Southwest region.

Table 4. State apportionment in AVERT regions, based on electricity sales in 2018.

State	Region													
	California	Southeast	Carolinas	Florida	Tennessee	Mid-Atlantic	New England	New York	Northwest	Rocky Mountains	Southwest	Texas	Midwest	Central
Alabama		74%			26%									
Arkansas													74%	26%
Arizona											100%			
California	100%													
Colorado										100%				
Connecticut							100%							
District of Columbia						100%								
Delaware						100%								
Florida		6%		94%										
Georgia		98%			2%									
Iowa													94%	6%
Idaho									100%					
Illinois						65%							35%	
Indiana						21%							79%	
Kansas														100%
Kentucky					15%	30%							55%	
Louisiana													93%	7%
Massachusetts							100%							
Maryland						100%								
Maine							100%							
Michigan						4%							96%	
Minnesota													99%	1%
Missouri													65%	35%
Mississippi		23%			32%								44%	
Montana									91%	2%				7%
North Carolina			96%			4%								
North Dakota													53%	47%
Nebraska										4%				96%
New Hampshire							100%							
New Jersey						100%								
New Mexico										5%	60%			35%
Nevada									100%					
New York								100%						

State	Region													
	California	Southeast	Carolinas	Florida	Tennessee	Mid-Atlantic	New England	New York	Northwest	Rocky Mountains	Southwest	Texas	Midwest	Central
Ohio						100%								
Oklahoma													5%	95%
Oregon									100%					
Pennsylvania						100%								
Rhode Island							100%							
South Carolina			100%											
South Dakota										25%			25%	50%
Tennessee					98%	2%								
Texas											1%	86%	5%	7%
Utah									97%	3%				
Virginia						100%								
Vermont							100%							
Washington									100%					
Wisconsin													100%	
West Virginia						100%								
Wyoming									62%	38%				

Appendix H: Frequently Asked Questions

AVERT Inputs

Are users restricted to the energy 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 energy profiles that reflect their regions and assumptions. Such profiles can be copied into the manual entry page of the Main Module.

Can I review RE 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 sections. For example, if you want to model the expected changes resulting from 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 changes in non-emitting, must-take baseload renewables like geothermal or hydroelectricity in AVERT using the "annual GWh" setting in Step 2. This means you are essentially modeling an EE program as a proxy for baseload renewables.

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 EPA's Power Sector Emissions Data.

AVERT is not currently equipped to estimate the emissions of emitting generators that do not report to CAMD. 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 energy profile 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 the estimated energy profile for the CHP generator and associated stack emissions.
2. Input the energy profile for CHP generator into AVERT under "manual energy profile entry" in Step 2.
3. Run the Main Module to determine emissions offset due to new CHP generator.
4. Subtract the CHP stack emissions from emissions offsets to determine the total change in emissions.

net emissions reduction from CHP generator = AVERT displaced emissions + CHP stack emissions

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

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

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 onsite 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 energy profile that reflects this energy storage assumption. As with all other assumptions in AVERT, users are encouraged to create a time-series of energy changes that fits their region and assumptions.

DOE has an emissions calculator that uses AVERT as its engine. This web-based tool is called Grid Impact Emissions Quantification (GRIDPIQ). It specifically models storage and other distributed energy resources scenarios; however, the outputs are only regional. For more information, visit https://gridpiq.pnnl.gov/app/#!/.

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 change that is appropriate to model?

No. In the current version of AVERT, users can review the output chart titled "Hourly Results by Week" for an indication of how closely their expected energy changes are captured in hour-to-hour unit changes for one week. At very small scales of production, this graphical interface will indicate a rougher hour-to-hour energy profile—i.e., the resulting change in generation will look less like the amount of energy change expected. For a more comprehensive check, the user should view the

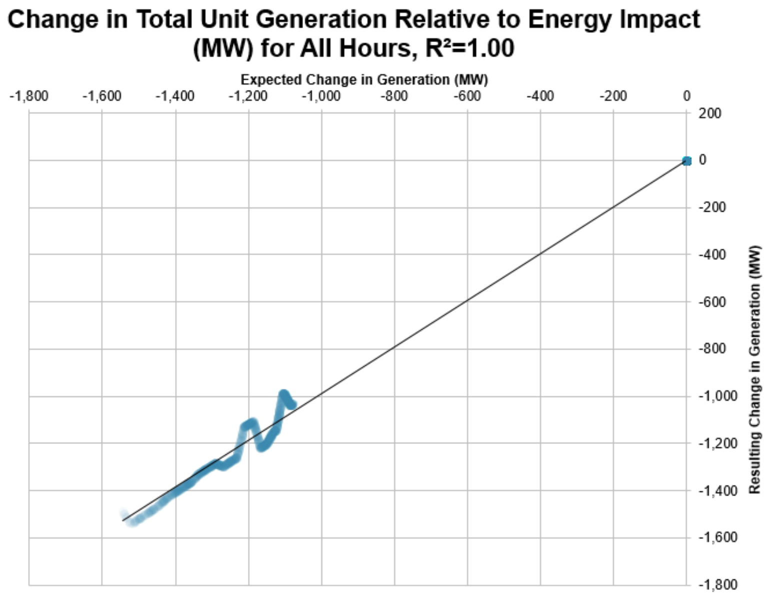
"Signal-to-noise diagnostic," found on the "Display Results" page of AVERT's Main Module. As described in this manual (p. 43), this scatter plot shows the changes in generation calculated by AVERT (on the y-axis) against the energy change input by the user. More reasonable results (from a program size perspective) will appear closer to 1:1 lines. Smaller load changes have more noise (i.e., scatter) in this plot, while larger load changes have a straighter line relationship. The R^2 value in the title of the chart indicates how much of the change in generation can be explained by the user-input energy change. For examples, an R^2 value of 0.9 indicates that AVERT has captured 90% of the change in generation required by the user, while a value of 0.7 indicates that AVERT has only correctly captured 70% of the energy change input by the user (i.e., noise accounts for 30% of the observed variability).

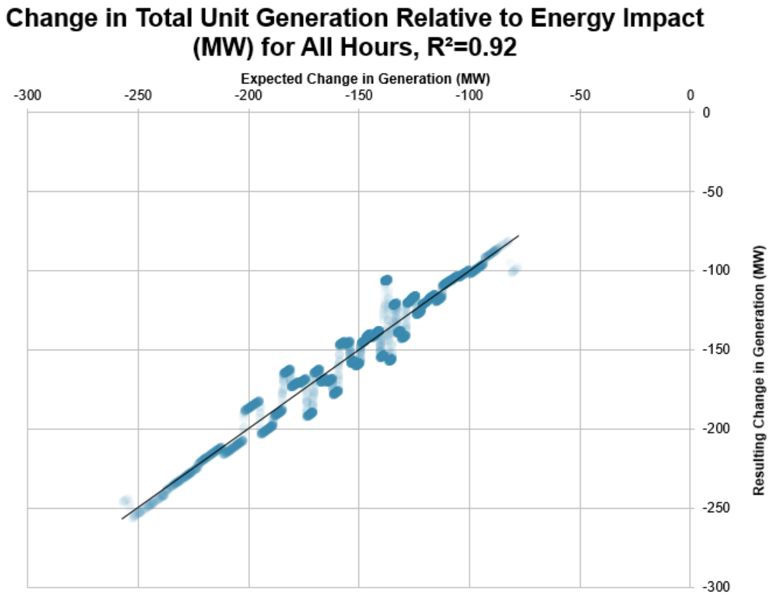
Figure 48 shows two different energy profiles with very different R^2 values from the same region, and designed similarly. The graph on the top is a 1.5% load reduction during the peak 20% of hours. The reduction is sufficiently sized such that the generation reduction is able to match the requirement very closely—over 99% of the reduction in generation is a direct result of the energy change input. The graph on the bottom is a 0.25% 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 92% of the generation reduction can be attributed to the energy policy—the rest is noise.

Note that all numerical results are shown rounded to the nearest 10 unit.[93] Dashes indicate that AVERT reported a value greater than zero, but lower than the level of reportable significance. In some cases, no reasonably sized energy policy will result in reportable changes. For example, the review of monthly results 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 energy policy 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).

[93] The Power Sector Emissions Data are reported in integer units of MWh (generation), lbs (NO_x and SO_2), tons (CO_2), and MMBtu (heat input). Results in AVERT are rounded to the closest 10 MWh, lbs NO_x and SO_2, tons CO_2, and MMBtu fuel input.

Figure 48. Examples of two different load reductions with different R^2 values in the signal-to-noise diagnostic. Top: 1.5% load reduction in peak 20% of hours. Bottom: 0.25% load reduction in all hours.





Is there a bound on the largest change that is appropriate to model?

There is not a formal bound on the largest project, program, or policy 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 changes achieved by energy policies, and thus under-predict emissions changes. It is recommended that programs generally not exceed 15% 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.

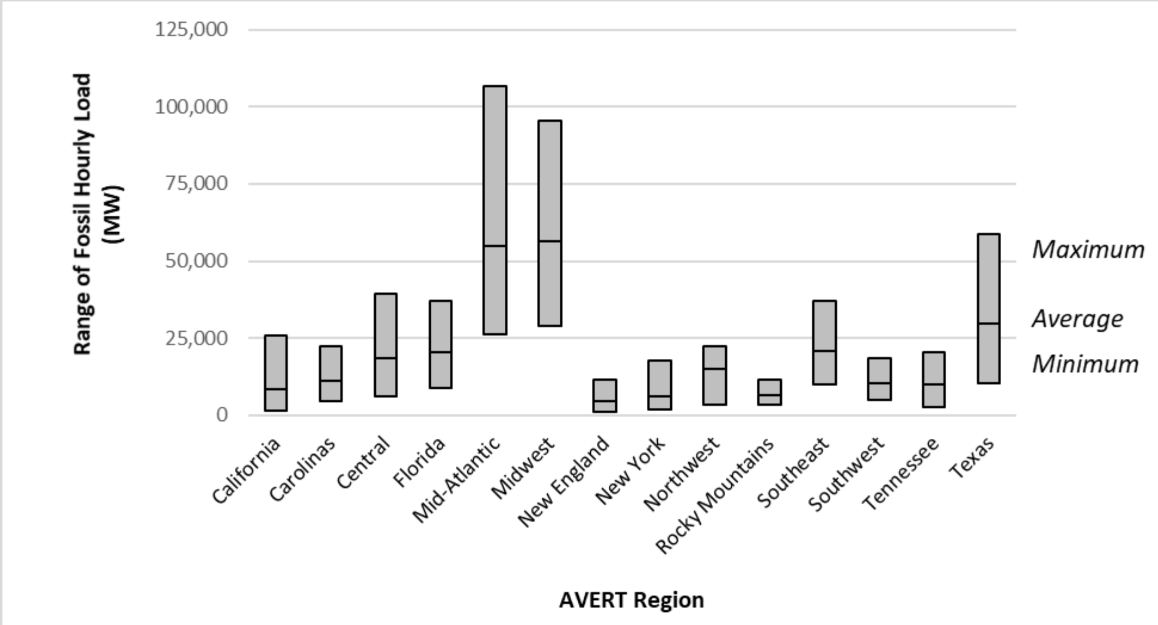
In addition, users may encounter situations in which their selected change to load produces a new hourly load that is outside the range calculable by AVERT. This may occur in situations where load is reduced by 50% or more relative to the hour with the lowest load (i.e., well outside the recommended threshold of 15%). In situations where load is increased, users may encounter this issue at load increases as low as 10% for some regions. In these situations, users should refine their load changes such that an error is not produced on the "Manual User Input" page.

For reference, Table 5 provides each AVERT region's total annual load, in GWh. Knowing the total annual load in each region may be helpful when using AVERT's "reduce generation by X% in all hours" option to model the impacts of a broad-based EE program. Figure 49 identifies the distribution of hourly loads in each of the 14 AVERT regions, using data from 2019. Table 5 also shows the maximum and minimum possible load levels able to be modeled in AVERT. These values provide helpful context if one knows the absolute size of a project, policy, or program in units such as MW and one wants a sense of the percentage of regional load that it represents. Note that fossil loads in Table 5 and Figure 49 have *not* been adjusted to reflect the transmission and distribution losses inherent to each region. Demand-side measures (such as EE or distributed solar) avoid not only electricity demand, but also the electricity associated with transmission and distribution losses. As a result, demand-side programs increase the avoided fossil load by an additional 5–9%, depending on the region and the year being analyzed.

Table 5. Total regional fossil loads in AVERT regions, 2019.

AVERT Region	Total Annual Fossil Load (GWh)	Maximum Possible Hourly Load (MW)	Minimum Possible Hourly Load (MW)
California	75,293	25,899	1,567
Carolinas	96,818	22,276	4,585
Central	161,924	39,326	6,148
Florida	180,196	37,002	8,863
Mid-Atlantic	480,994	106,639	26,160
Midwest	492,541	95,473	28,906
New England	38,613	11,620	968
New York	53,023	17,565	1,981
Northwest	132,324	22,553	3,579
Rocky Mountains	58,368	11,492	3,482
Southeast	182,623	37,247	9,919
Southwest	91,801	18,320	4,833
Tennessee	87,062	20,360	2,804
Texas	260,970	58,736	10,340

Figure 49. Characteristics of regional hourly fossil loads, 2019.



Why might actual planned offshore wind projects trigger a warning in AVERT?

The Excel Main Module gives the user a warning when they have entered an energy profile that collectively exceeds 15% of load in at least one hour of the year. This warning could appear when modeling certain large policies, programs, or projects, including ambitious offshore wind projects that may be implemented in the near future. However, this warning will not prevent the user from modeling large quantities of offshore wind—the user can simply ignore the warning message if desired.

Are energy changes 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, energy changes are assumed to have change emissions throughout the selected AVERT region. A limitation of AVERT is that it is insensitive to the physical location within a region of new projects, programs, or policies, despite the fact that real-world dispatch decisions may be quite sensitive to specific locations of resources resulting from energy policies as well as EGUs. AVERT assumes that energy changes are spread across the modeled region. It cannot currently identify the differential effects of local versus regional energy changes. Such differentiation requires the use of a production cost model.

For more information, see “Limitations and Caveats” in Section 2 of this manual. Detail on changes at the state and county level are available on the output sheet “Annual Results by County.”

AVERT Results

Does AVERT account for losses?

Yes, AVERT accounts for three types of losses. First, gross generation as collected in the Power Sector Emissions Data 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 EE and distributed PV (and increases in fossil load from increased demand) are corrected to account for avoided grid (transmission and distribution) losses, using region-specific, year-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. Finally, additional loss factors are assumed for offshore wind due to the fact that these resources are commonly located far from load centers, and because associated transmission lines may be underground or underwater. Using loss estimates from NREL, these factors act to reduce the hourly capacity factors of offshore wind resources.[94] See Appendix C for more detail on how offshore wind capacity factors have been developed in AVERT.

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 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 change in 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 than 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

[94] These loss factors include wake losses, electric losses, availability losses, and other loss categories, as defined by NREL in National Renewable Energy Laboratory. 2016. *2016 Offshore Wind Energy Resource Assessment for the United States*. Section 7.3.1, Figure 9. https://www.nrel.gov/docs/fy16osti/66599.pdf.

load is reduced from very low load periods. This pattern is almost always observed in trough periods.

AVERT Statistical Module

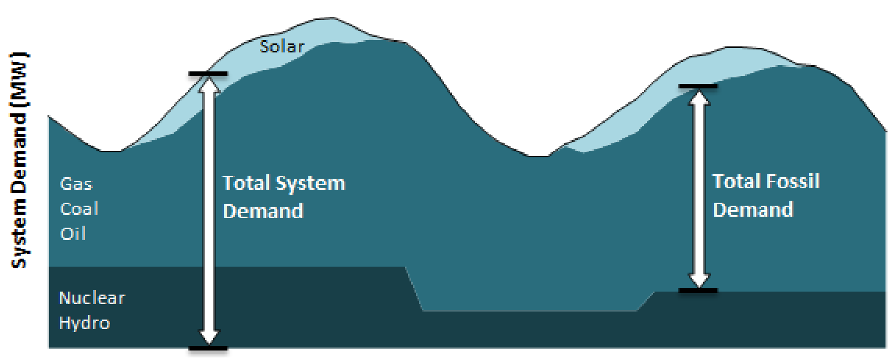
Why is the model driven by system fossil generation instead of by demand or total load?

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, determining 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 or RE policies are assumed to reduce the demand for fossil resources. Figure 50 below illustrates the difference between total system demand and demand for fossil resources.

Figure 50. 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 or RE programs in AVERT. However, an EGU that ramps from high output in the daytime to low output on off-peak 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 that 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 37 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 or 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 were 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 changes in emissions aside from AVERT?

You can model generation and emissions changes caused by new energy policies 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 alternative, publicly available tool to estimate changes in emissions in near-term years. Users who wish to conduct analyses more than 5 years from the baseline must use AVERT's statistical module and future year scenario template. This type of analysis requires access to future year hourly, unit-specific generation and emissions data (e.g., from an electric-sector dispatch model designed to forecast future generation) that can be entered in place of AVERT's historical data.

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 2017 but a future year template of 2019) risks accidentally using proxy "new" EGUs that did not exist in 2017, and thus will not be incorporated into a 2017 analysis.

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

AVERT considers EGUs that report to EPA's CAMD only. This may exclude generators with less than 25 MW of capacity or generators that did not operate in a particular year.

Why do some generators appear in the Future Year Scenario Template but not in the Regional Data File?

AVERT's Statistical Module allows users to exclude small, low-generation units from consideration in the 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 0.5% of all possible operational hours.

In the future scenario demo, do the total avoided emissions include the impact of retired units, or just the energy impacts adjusted for retirements?

Results from AVERT runs using the Future Year Scenario Template do not include changes in emissions at 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 energy change modeled.

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

At this time, EPA is not providing EPA projections for use in AVERT. Future scenarios are meant to be developed by users. You can use AVERT's future year scenario template to make known changes in the regional dataset. Users who wish to conduct analyses more than 5 years from the baseline must use AVERT's statistical module and future year scenario template. This type of analysis requires access to future year hourly, unit-specific generation and emissions data (e.g., from an electric-sector dispatch model designed to forecast future generation) that can be entered in place of AVERT's historical data.

Along these lines, EPA has partnered with the Eastern Regional Technical Advisory Committee (ERTAC), a group of state environmental agency senior staff and multi-jurisdictional organizations (e.g., LADCO, MARAMA, WESTSTAR, SESARM, NESCAUM), to provide AVERT-compatible RDFs for ERTAC-specified custom future years.

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 RDFs in the second quarter of each year.

Appendix I: Web-Based AVERT

In 2018, EPA released a web-based version of the AVERT Main Module. The web edition provides a streamlined interface with much of the same functionality as the downloadable Excel-based Main Module, without the need to use Excel software or upload separate RDFs. The web edition relies on the most recent year of input data and has a more limited range of input and output options. It uses the same underlying methods, calculation algorithms, and regional data inputs, and it reflects the same assumptions as the Excel-based Main Module.

Differences Between the Web Edition and the Excel Main Module

The web-based Main Module has the following limitations:

- The web edition relies on the most recent year of input data, whereas the Excel versions can incorporate data from any year that is posted on the AVERT website.
- The web version does not allow the user to manually input a custom load profile with 8,760 hourly values, model increases in generation or load, or scale RE capacity factors, like the Excel version does.
- The web version uses built-in default RDFs, so it does not support future year scenario planning.
- The web version provides a more streamlined range of result formats than the Excel version, consisting of two data tables, three graphs, downloadable CSV data, and a COBRA CSV file.

However, the web version also offers several advantages over the Excel-based Main Module:

- The web-based version provides some accessibility advantages because it can run in any major web browser, without the need for Excel software or the need to download, save, and upload separate RDFs.
- The graphs in the web version have some dynamic capabilities that allow the user to customize the geographic area displayed and save a variety of formats (e.g., JPG, PDF) to display in presentations or reports.
- The web version can run an analysis for a single state, in addition to running an analysis for an AVERT region (see below for more detail). The Excel version analyzes one region at a time, thus requiring manual post-processing for aggregation if users want to model state-level energy changes in states that cross regional boundaries (see Appendix G for more information on these analyses).

Ultimately, some users will find that the web edition meets their needs, while others who wish to use different data years, custom load profiles, future RDFs, or additional result formats should use the Excel version.

Web AVERT State Analysis

For states that span more than one region, the web version allocates energy changes across regions and performs the multiple regional analyses simultaneously. This section describes how the web edition performs analyses for states that cross regional boundaries. The methodology for analyses in states that are entirely in one AVERT region is essentially the same as the methodology for analyses of a region.

For states that span more than one region, AVERT apportions the energy changes from the applied scenario proportionately to the two or more regions. For all input options except a percentage reduction (EE by percent), the user-input amount is prorated to the relevant AVERT regions based on the state's electricity sales in each region. Table 4 shows state apportionment in AVERT regions based on electricity sales in 2018. The web edition then performs one or more regional analyses as normal using these prorated inputs.

For percentage generation reduction ("Percentage reductions in some or all hours"), AVERT uses 2018 state and regional sales data to calculate the proportion of each region's sales that originated in the selected state. The user-specified percentage is scaled by this amount. This means that a percentage reduction in a state that crosses regional boundaries typically corresponds to a smaller percentage reduction when considered at a regional level. For example, Alabama is in both the Southeast and Tennessee AVERT regions. Alabama's 2018 fossil sales constituted 66.6 terawatt-hours (TWh) of the 228.1 TWh of fossil sales in the Southeast region. A 10% reduction in electricity use in Alabama therefore corresponds to a 6.66 TWh reduction in the Southeast region, which represents a 2.9% reduction in total Southeast region sales. AVERT will therefore model 2.9% for the Southeast.

Within "Percentage reductions in some or all hours," the web edition applies a simplifying assumption when modeling a targeted program (i.e., percentage reduction during a peak percentage of hours). To streamline the analysis, AVERT applies the reduction to the top X% of hours in each individual region. These may or may not be the exact same hours that constitute the top X% of hours in terms of state-specific loads.

Some states that cross regional boundaries are in at least one region that has capacity factors available for offshore wind and at least one region that does not. In these situations, the entire offshore wind capacity entered by the user is allocated to the region that supports offshore wind. This is the case regardless of whether the state has coastline adjacent to potential offshore wind sites or even has any coastline at all. The rationale for allowing landlocked states to model offshore wind is that such states may still invest in offshore wind capacity elsewhere, and their electric regions may still import electricity from offshore wind generation.

Input Validation

To ensure the user's inputs are realistic and within the calculable range, web AVERT implements two rounds of input validation:

- **First pass:** Check each individual input to make sure it is a valid positive number. Users who want to model reverse EE/RE scenarios (negative inputs) should use the Excel Main Module.
- **Second pass:** Check the aggregate load shape after all inputs have been combined to ensure that it is within AVERT's recommended range. There are three possible outcomes:
    - If any individual hour has a load reduction that amounts to 15% or more of that hour's regional generation, AVERT gives a warning but allows the user to proceed.

- If any individual hour has a load reduction that amounts to 30% or more of that hour's regional generation, AVERT gives an error message and prevents the user from proceeding until they revise their inputs to get the resulting load shape below the 30% threshold.
- Otherwise, the user can proceed without any warning.

For state-specific AVERT runs that involve multiple AVERT regions, the program creates a separate new energy impact profile for each affected AVERT region. These regional energy impact profiles are aggregated to create a single graph onscreen, but the region-specific profiles are what actually feed into the AVERT displacement calculations, which are performed by region. The second pass validation step independently tests each new region-specific energy impact profile against the corresponding regional hourly loads in the RDF. AVERT returns a warning or error message, respectively, if any region in the analysis sees an exceedance of 15% or 30%.

Appendix J: Version History

EPA has added several enhancements to AVERT since the first release in 2014. Table 6 catalogs the version history of AVERT in reverse chronological order and notes key changes. For a detailed description of what is new in the most recent version of AVERT, see "What's New in AVERT 3.0?" in the beginning of this user manual.

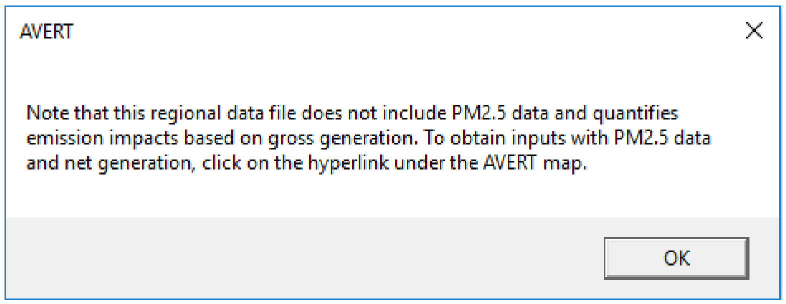
Table 6. AVERT version history.

Version #	Release Date	Updates, Bugfixes, and Notes
3.0	September 15, 2020	Updates: • Revised AVERT regions to reflect the modern electric grid. The 14 new AVERT regions are based on aggregations of one or more balancing authority(ies). Note: Prior to AVERT 3.0, there were 10 AVERT regions based on aggregations of the 26 eGRID regions (also in use in EIA's Annual Energy Outlook from 2011 to 2019). The switch to a new regional topology in AVERT 3.0 was driven by the fact that these regions are in some cases out of date as the electric grid has evolved and because certain data on electricity demand are not readily available for these regions. • Added offshore wind. • Added the ability to scale RE capacity factors (Excel-based AVERT only). • Added statewide analysis functionality (web AVERT only) (see Appendix I). Bugfixes: • Removed "worst-case" substitute emissions data points from the underlying CAMD input files.
2.3	May 30, 2019	Updates: • Incorporated line loss factors from EIA, which provides unique values for each year. Note: AVERT 2.3 is a deprecated version of AVERT with 10 regions and fewer features than the most recent version of AVERT. EPA is no longer supporting data updates, enhancements, or bugfixes to this version of AVERT. However, for users who want to use this previous version of AVERT, the Main Module, RDFs for years 2007–2018, Statistical Module packages for years 2007–2018, and user manual are available for download at www.epa.gov/avert.
2.2	March 4, 2019	Updates: • Users can now output AVERT calculations to COBRA and SMOKE formats even if the modeled changes in load exceed AVERT's recommended limit of 15% of regional load in any hour.
2.1	October 19, 2018	Updates: • Added new columns on "Manual Energy Profile Entry" page that tell the user when the entered generation change exceeds both the recommended and calculable ranges of AVERT in each hour. • Added new pop-up box to "Step 3: Run Impacts" that explains how a user can remedy entered generation change that exceeds both the recommended and calculable ranges of AVERT.

<table>
<tr><th>Version #</th><th>Release Date</th><th>Updates, Bugfixes, and Notes</th></tr>
<tr><td>2.0</td><td>May 31, 2018</td><td>Updates:
• Added output files compatible with EPA's COBRA Health Impact Screening Tool.

Bugfixes:
• Corrected code in the Statistical Module to ensure that AVERT will work with the newest version of MATLAB.</td></tr>
<tr><td>1.6</td><td>July 31, 2017</td><td>Updates:
• Added $PM_{2.5}$.

Note: RDFs 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 an RDF produced in 2017 or earlier, another pop-up box will alert you to these considerations and suggest that you download a newer RDF from EPA's website.

RDF import pop-up example for data files produced prior to summer 2017.


• Adjusted the Statistical Module and RDFs to account for additional generation impacts associated with parasitic loads at the point of generation.
• Improved the way data are extrapolated for peak hours.

Bugfixes:
• Corrected summation of annual NO_x values.
• Removed mismatches in CAMD data-to-AVERT data import pipeline.</td></tr>
<tr><td>1.5</td><td>March 6, 2017</td><td>Updates:
• Added adjustment factor to account for avoided line losses associated with EE and distributed RE profiles.
• Added daily avoided NO_x by county results.
• Improved data display on map figure.
• Modified rounding of results to tens rather than hundreds place.
• Added caution message for larger-than-recommended energy profiles.
• Updated compatibility to Excel for Mac 2016.

Bugfixes:
• Corrected unit labeling of NO_x and SO_2 data blocks in RDFs.
• Corrected peak-day-finding formula in post-processing sheets.</td></tr>
<tr><td>1.4</td><td>April 25, 2016</td><td>Updates:
• Added compatibility with Excel for Mac 2011.</td></tr>
</table>

Version #	Release Date	Updates, Bugfixes, and Notes
1.3	April 28, 2015	Updates: • New pop-up box depicts percent generation in each state within an AVERT region. Instructions added for states that reside in multiple AVERT regions. Bugfixes: • Corrected SMOKE output function bug.
1.2	November 21, 2014	Updates: • Modified default wind capacity factor data to more closely represent measured wind speeds. Bugfixes: • Corrected transposition of NO_x and SO_2 columns in the Monthly Impact Data by County table in Step 4.
1	February 18, 2014	Original public version of AVERT.