December 2024 – Third Edition

Public Health Benefits per Kilowatt-Hour of Energy Efficiency and Renewable Energy in the United States: A Technical Report

EPA
United States
Environmental Protection
Agency

State and Local Climate
and Energy Program

Contents

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What’s New for the Benefits-per-Kilowatt-Hour Values?

For the Third Edition of this report, the U.S. Environmental Protection Agency (EPA) has updated the Second Edition benefits-per-kilowatt-hour (BPK) values with 2023 data. In addition to updating the data used to calculate the BPK values, EPA has added new features and updated the methodology, including the following:

- Updated data: The BPK values now use data from version 4.3 of the AVoided Emissions and geneRation Tool (AVERT) and version 5.1 of the CO-Benefits Risk Assessment Health Impacts Screening and Mapping Tool (COBRA). These include 2023 power sector data and transmission and distribution loss data.
- Updated version of COBRA: COBRA v5.1 has undergone significant changes since the previous BPK analysis. COBRA v5.1 has an updated source-receptor matrix that improves modeling for ambient fine particulate matter ($PM_{2.5}$) concentration changes. COBRA now also models ambient ozone (O_3) concentration changes. COBRA now uses a default 2 percent (instead of 3 percent and 7 percent) discount rate and contains updated health impact functions and population and incidence data for future years through 2050 (EPA, 2024b).
- Additional energy storage types: EPA developed BPK values for utility-scale and distributed photovoltaic-plus-storage resources (solar photovoltaic, or PV, paired with energy storage).
- Updated definition of peak energy efficiency: The previous BPK report defined peak hours as the hours between 12:00 p.m. and 6:00 p.m. on weekdays, a total of 1,560 hours per year. This Third Edition definition, based on data from more than 30 regional transmission organization (RTO) and utility programs aimed at shifting consumer electric load away from peak hours, distinguishes between summer and non-summer peak hours.

Executive Summary

EPA has developed a set of values that helps state, local, and Tribal government policymakers and other stakeholders estimate the monetized public health benefits of energy efficiency, renewable energy, and PV-plus-storage (EE/RE/ES^+)[1] using the same methods the Agency uses to analyze health benefits at the federal level. These values estimate the potential public health benefits of avoided emissions of $PM_{2.5}$, O_3, and other precursor pollutants derived from the impact of additional EE/RE/ES^+ resources on the grid.

EPA continually reviews methods and assumptions for quantifying the public health benefits of reducing criteria air pollutant emissions. The values presented here, and the associated documentation, have been updated to reflect electricity sector data from 2023. These values will continue to be updated as appropriate to reflect future data, as well as any changes in methods or assumptions.

When to Use the Benefits-per-kWh Values

BPK values are reasonable approximations of the air quality benefits associated with EE/RE/ES^+ investments due to estimated reductions of $PM_{2.5}$, O_3, and other precursor pollutants. These values can be used for preliminary analysis when comparing across state and local policy scenarios to indicate direction and relative magnitude. Examples of analyses where it would be appropriate to use them include:

- Estimating the air quality benefits of regional, state, Tribal, or local-level investments in EE/RE/ES^+ projects, programs, and policies
- Understanding the cost-effectiveness of regional, state, Tribal, or local-level EE/RE/ES^+ projects, programs, and policies
- Incorporating air quality benefits in regional, state, Tribal, or local policy analyses and decision-making

When Not to Use the Benefits-per-kWh Values

BPK values are not a substitute for sophisticated analysis and should not be used to justify federal regulatory decisions. They are based on data inputs, assumptions, and methods that approximate the dynamics of energy, environment, and health interactions and include uncertainties and limitations, as summarized in this technical report and described in greater detail in cited reference material. The BPK methodology produces screening-level values that can be useful reference points to inform discussions and, in the absence of more robust analysis, can help inform state, local, and Tribal policy decisions.

Benefits-per-kWh Values

EPA used a peer-reviewed methodology and tools to develop a set of screening-level regional estimates of the annual dollar benefits per kilowatt-hour (kWh) from eight different types of EE/RE/ES^+ initiatives:

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[1] The term EE/RR/ES^+ is used to represent investments in energy efficiency (EE), renewable energy (RE), and/or PV-plus-storage (ES^+), referring to energy storage paired with solar PV panels. For this analysis, PV-plus-storage scenarios assume that the energy storage modeled charges only from an added solar PV resource.

- **Uniform energy efficiency:** Energy efficiency projects, programs, and policies that achieve a constant level of savings over one year.
- **Energy efficiency at peak:** Energy efficiency projects, programs, and policies that achieve savings when energy demand is high (i.e., from 12:00 p.m. to 8:00 p.m. on weekdays and non-federal holidays in June–September and from 6:00 a.m. to 9:00 p.m. on weekdays and non-federal holidays in October–May).
- **Distributed solar energy:** Projects, programs, and policies that increase the supply of distributed solar energy available (e.g., rooftop solar generation).
- **Utility solar energy:** Projects, programs, and policies that increase the supply of energy available from utility-scale solar.
- **Distributed PV-plus-storage:** Projects, programs, and policies that increase the supply of energy available from distributed PV-plus-storage resources, or distributed energy storage paired with solar generation.
- **Utility PV-plus-storage:** Projects, programs, and policies that increase the supply of energy available from utility-scale PV-plus-storage resources, or utility-scale energy storage paired with solar generation.
- **Onshore wind energy:** Projects, programs, and policies that increase the supply of onshore wind available (e.g., wind turbines).
- **Offshore wind energy:** Projects, programs, and policies that increase the supply of offshore wind available (e.g., wind turbines).

Understand the Values

EPA created BPK values using existing tools, including EPA's AVERT and COBRA Health Impacts Screening and Mapping Tool. BPK values are:

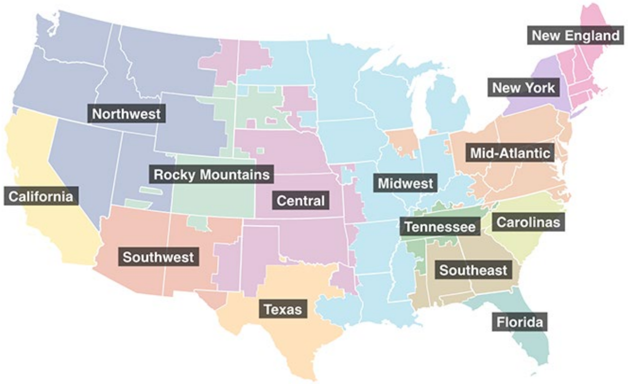

Figure ES-1. AVERT Regions.

- Available for each of the eight project types for each of the 14 AVERT regions.
- Based on 2023 electricity generation data, and emissions, population, baseline mortality incidence rate, and income growth projections.
- Presented in 2023 dollars and reflecting the use of a 2 percent discount rate as recommended by Office of Management and Budget (OMB) Circular A-4 (2023).[2]
- Calculated using the same health impact functions EPA uses for regulatory impact analyses (RIAs). For example, EPA created the BPK values from low and high estimates of mortality using two different health impact functions that have differing assumptions regarding human sensitivity to changes in $PM_{2.5}$ levels.

Using the BPK values, states, local communities, and Tribes can easily estimate the annual dollar value of the outdoor air quality–related health impacts of $EE/RE/ES^+$ scenarios occurring within a five-year time horizon. Users can evaluate many $EE/RE/ES^+$ scenarios by multiplying the BPK

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[2] Available at: https://www.whitehouse.gov/wp-content/uploads/2023/11/CircularA-4.pdf.

values (shown in Table ES-1) by the number of kWh saved from EE or generated from RE. EPA encourages users to review the caveats described within this technical report to ensure these values are appropriate for their use. This report also describes the uncertainties associated with modeled estimates, which users should keep in mind when interpreting or reporting results.

Table ES-1. Benefits-per-kWh Values, Third Edition (Cents per kWh in 2023 USD, 2% Discount Rate)

Region	Project Type	BPK, Low (2023 ¢/kWh)	BPK, High (2023 ¢/kWh)
California	Uniform EE	0.75	1.26
California	Peak EE	0.85	1.42
California	Utility PV	0.69	1.15
California	Distributed PV	0.75	1.25
California	Utility PV-plus-storage	0.74	1.24
California	Distributed PV-plus-storage	0.83	1.37
California	Onshore wind	0.68	1.14
California	Offshore wind	0.69	1.16
Carolinas	Uniform EE	5.13	8.04
Carolinas	Peak EE	5.99	9.40
Carolinas	Utility PV	4.55	7.15
Carolinas	Distributed PV	4.84	7.62
Carolinas	Utility PV-plus-storage	4.51	7.12
Carolinas	Distributed PV-plus-storage	4.79	7.57
Carolinas	Onshore wind	4.66	7.30
Carolinas	Offshore wind	4.66	7.31
Central	Uniform EE	4.63	7.49
Central	Peak EE	5.16	8.03
Central	Utility PV	4.60	7.25
Central	Distributed PV	4.96	7.81
Central	Utility PV-plus-storage	4.65	7.29
Central	Distributed PV-plus-storage	5.02	7.87
Central	Onshore wind	4.14	6.79
Central	Offshore wind	N/A	N/A
Florida	Uniform EE	2.82	4.38
Florida	Peak EE	3.29	5.10
Florida	Utility PV	2.86	4.44
Florida	Distributed PV	3.09	4.80
Florida	Utility PV-plus-storage	2.90	4.50
Florida	Distributed PV-plus-storage	3.13	4.86
Florida	Onshore wind	2.47	3.83
Florida	Offshore wind	N/A	N/A
Mid-Atlantic	Uniform EE	5.26	8.97
Mid-Atlantic	Peak EE	5.95	10.21
Mid-Atlantic	Utility PV	5.23	8.94
Mid-Atlantic	Distributed PV	5.60	9.57
Mid-Atlantic	Utility PV-plus-storage	5.28	9.02
Mid-Atlantic	Distributed PV-plus-storage	5.67	9.68
Mid-Atlantic	Onshore wind	4.73	8.07
Mid-Atlantic	Offshore wind	4.76	8.11
Midwest	Uniform EE	6.27	10.70
Midwest	Peak EE	6.73	11.39
Midwest	Utility PV	5.99	10.18
Midwest	Distributed PV	6.46	10.97
Midwest	Utility PV-plus-storage	5.99	10.17
Midwest	Distributed PV-plus-storage	6.47	10.96
Midwest	Onshore wind	5.75	9.81
Midwest	Offshore wind	N/A	N/A

Region	Project Type	BPK, Low (2023 ¢/kWh)	BPK, High (2023 ¢/kWh)
New England	Uniform EE	1.07	1.81
New England	Peak EE	1.46	2.44
New England	Utility PV	1.07	1.80
New England	Distributed PV	1.13	1.91
New England	Utility PV-plus-storage	1.20	2.01
New England	Distributed PV-plus-storage	1.30	2.18
New England	Onshore wind	0.92	1.56
New England	Offshore wind	0.92	1.56
New York	Uniform EE	4.25	7.91
New York	Peak EE	5.37	9.93
New York	Utility PV	4.28	7.96
New York	Distributed PV	4.56	8.48
New York	Utility PV-plus-storage	4.48	8.34
New York	Distributed PV-plus-storage	4.81	8.95
New York	Onshore wind	3.65	6.79
New York	Offshore wind	3.56	6.62
Northwest	Uniform EE	1.64	2.43
Northwest	Peak EE	1.74	2.56
Northwest	Utility PV	1.40	2.09
Northwest	Distributed PV	1.52	2.27
Northwest	Utility PV-plus-storage	1.44	2.13
Northwest	Distributed PV-plus-storage	1.56	2.32
Northwest	Onshore wind	1.50	2.22
Northwest	Offshore wind	1.52	2.26
Rocky Mountains	Uniform EE	1.80	2.73
Rocky Mountains	Peak EE	1.77	2.66
Rocky Mountains	Utility PV	1.62	2.46
Rocky Mountains	Distributed PV	1.78	2.70
Rocky Mountains	Utility PV-plus-storage	1.62	2.46
Rocky Mountains	Distributed PV-plus-storage	1.78	2.69
Rocky Mountains	Onshore wind	1.66	2.53
Rocky Mountains	Offshore wind	N/A	N/A
Southeast	Uniform EE	3.64	5.00
Southeast	Peak EE	4.59	6.26
Southeast	Utility PV	3.60	4.93
Southeast	Distributed PV	3.88	5.32
Southeast	Utility PV-plus-storage	3.68	5.05
Southeast	Distributed PV-plus-storage	3.99	5.46
Southeast	Onshore wind	2.97	4.10
Southeast	Offshore wind	N/A	N/A
Southwest	Uniform EE	0.88	1.21
Southwest	Peak EE	0.97	1.31
Southwest	Utility PV	0.83	1.14
Southwest	Distributed PV	0.91	1.26
Southwest	Utility PV-plus-storage	0.87	1.20
Southwest	Distributed PV-plus-storage	0.98	1.35
Southwest	Onshore wind	0.77	1.06
Southwest	Offshore wind	N/A	N/A

Region	Project Type	BPK, Low (2023 ¢/kWh)	BPK, High (2023 ¢/kWh)
Tennessee	Uniform EE	3.10	5.42
Tennessee	Peak EE	3.80	6.57
Tennessee	Utility PV	3.20	5.58
Tennessee	Distributed PV	3.41	5.94
Tennessee	Utility PV-plus-storage	3.20	5.57
Tennessee	Distributed PV-plus-storage	3.43	5.95
Tennessee	Onshore wind	2.54	4.45
Tennessee	Offshore wind	N/A	N/A

Region	Project Type	BPK, Low (2023 ¢/kWh)	BPK, High (2023 ¢/kWh)
Texas	Uniform EE	3.13	5.01
Texas	Peak EE	3.56	5.45
Texas	Utility PV	3.09	4.85
Texas	Distributed PV	3.22	5.07
Texas	Utility PV-plus-storage	3.16	4.88
Texas	Distributed PV-plus-storage	3.31	5.10
Texas	Onshore wind	2.89	4.67
Texas	Offshore wind	N/A	N/A

Introduction

State, local, and Tribal government policymakers have increasingly been asking for EPA's help in understanding opportunities for using EE/RE/ES$^+$ to reduce air pollution and improve public health.[3] EE/RE/ES$^+$ projects, programs, and policies can reduce air pollution emissions from the electric power sector either by decreasing demand for electricity generation or by displacing fossil fuel–based generation with non-emitting sources of generation. Avoided emissions of $PM_{2.5}$, O_3, and other precursor pollutants lead to tangible public health benefits, such as reducing the number of premature deaths, incidences of respiratory and cardiovascular illnesses, and missed work and school days.[4] However, in many cases, state and local decision-makers are not quantifying or fully accounting for the health benefits of existing or planned EE/RE/ES$^+$ projects, programs, and policies in their decision-making processes. EPA has found that state, local, and Tribal decision-makers may not be fully aware of or confident in the available quantification tools and methods, or that they lack the time, resources, or expertise needed to quantify the health benefits.

EPA seeks to address this gap by providing state, local, and Tribal governments and their stakeholders with tools and information to estimate the public health benefits of EE/RE/ES$^+$. In particular, EPA has developed screening-level regional estimates of the benefits per kWh of EE/RE/ES$^+$ projects, programs, and policies.[5] The goal of these estimates is to create credible and comparable values (i.e., factors) that stakeholders—such as state, local, and Tribal governments; EE/RE/ES$^+$ project developers; and nongovernmental organizations (NGOs)—can use to estimate the health benefits of EE/RE/ES$^+$ projects, programs, and policies. EPA has also sought to ensure that these values are easy to use and do not require state, local, or Tribal governments or other users to download specific modeling software packages.

In the Second Edition of this report, EPA released public health BPK values with 2019 data that represent screening-level estimates of the air quality benefits from fossil fuel–based generation reduced or avoided because of EE, solar, and wind projects, programs, and policies. This report describes EPA's approach for updating those values with 2023 data and improved modeling platforms. The estimates use a 2023 profile of the electricity system to represent the near-term benefits of EE/RE/ES$^+$ projects, programs, and policies that have already been or are about to be implemented. The resulting BPK values can be used by a wide range of stakeholders to develop a more complete picture of the public health benefits of existing or proposed EE/RE/ES$^+$ projects, programs, and policies. Note that because BPK values provide a screening-level estimate of health benefits of EE/RE/ES$^+$, they may not be appropriate for certain analyses, such as federal air quality rulemaking.

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[3] The abbreviation EE/RE/ES$^+$ reflects the eight different energy efficiency, renewable energy, and PV-plus-storage technologies evaluated in this report.

[4] The Health Effects Institute (2020) estimates that in 2019, 64,000 premature deaths in the United States were attributable to air pollution (including 49,800 due to $PM_{2.5}$ and 14,200 due to O_3).

[5] These estimates include the contiguous United States, but do not include Alaska and Hawaii. These states are not included in AVERT, which EPA used to estimate impacts of EE/RE/ES$^+$ on air pollution emissions, because they do not report emissions data for most of their electric generating units (EGUs) to EPA. Alaska and Hawaii are also not included in COBRA, which EPA used to estimate the health impacts of EE/RE/ES$^+$, because they were not included in the air quality modeling originally used to develop the tool.

Background

In the United States, electricity generation is essential to the economy, but it can also result in significant emissions of air pollution. In 2023, the electricity generation sector emitted more than 840,000 tons of nitrogen oxides (NO_x), 835,500 tons of sulfur dioxide (SO_2), and more than 85,400 tons of $PM_{2.5}$ (EPA, 2023). Emissions of these pollutants can result in serious health impacts, including premature mortality, non-fatal heart attacks, exacerbation of asthma, and other respiratory and related diseases.

While the U.S. electric power sector has historically been a significant source of air pollution, the sector has undergone rapid change in recent years. Between 2007 and 2023, coal and oil generation sources combined have decreased from just over 50 percent of the U.S. generation resource mix to 17 percent. RE sources like wind, solar, and geothermal energy have increased from just over 1 percent to just under 20 percent of the resource mix (Figure 1). Similarly, electricity savings from ratepayer-funded EE programs were over 290 terawatt-hours in 2021, an increase of more than 203 percent from 2008 (Subramanian et al., 2022). These changes amount to a cleaner U.S. electric power sector with reduced emissions and health impacts.

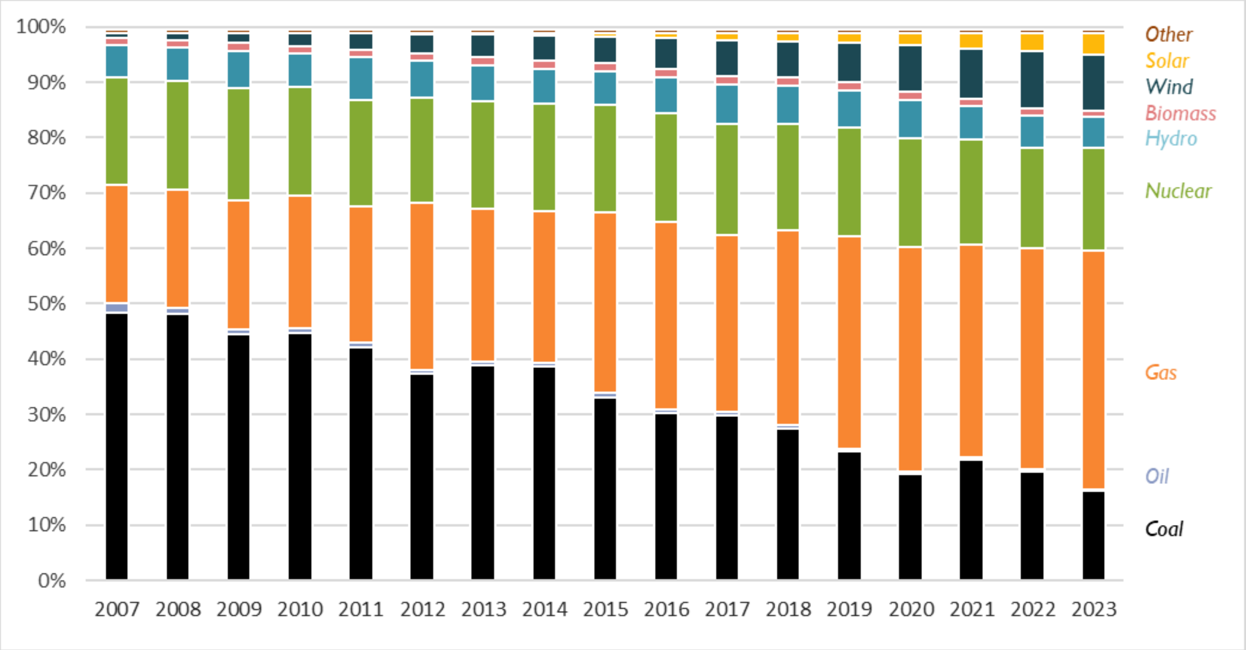

Figure 1. U.S. Electricity Generation Resource Mix, 2007–2023.

Source: U.S. Energy Information Administration (2023). Includes utility-scale generation only.

To help state, local, and Tribal governments quantify the health benefits of EE/RE/ES$^+$, EPA commissioned a literature review that examined more than 60 studies for BPK values to understand the health benefits of EE/RE/ES$^+$ projects, programs, and policies, as well as current methods and best practices (EPA, 2017). Through the literature review, EPA found that the studies' results varied depending on the approach used, the benefits included, and the geographic focus of the analysis. Therefore, the resulting sets of BPK values identified in the literature review were not easily comparable to one another.

Lawrence Berkley National Laboratory (LBNL), for example, published several studies examining both the prospective and retrospective health benefits from wind, solar, and renewable portfolio standard (RPS) programs across the United States (Table 1). The benefits reported in each study are an average value of health benefits calculated using multiple different air quality and health impact models, including the Air Pollution Emission Experiments and Policy Analysis Model (AP2), EPA's benefit-per-ton methodology, EPA's COBRA Health Impacts Screening and Mapping Tool, and the Estimating Air Pollution Social Impact Using Regression (EASIUR) model. Overall, these studies estimate that quantified public health benefits in the United States range between 2.6 cent per kWh and 10.1 cents per kWh for recent years, and between 0.4 cents per kWh and 8.2 cents per kWh prospectively. Other studies included in the literature review generated a range of different results that were not directly comparable to the LBNL estimates, typically because they used a variety of models or included additional benefits. For example, some of the models used in studies identified in the literature review include non-health welfare benefits, such as avoiding damages from decreased timber and agricultural yields, reduced visibility, accelerated depreciation of materials, and reductions in recreation services; results from these studies may be higher than the values calculated using models that focus solely on health benefits.

Table 1. Public Health Benefits from Avoided Fossil Emissions Due to U.S. Wind, Solar, and RPS Programs

Program Evaluated	BPK (¢/kWh)	Source
2013 RPS programs	2.6¢/kWh–10.1¢/kWh	Barbose et al., (2016)
2015 wind energy	7.3¢/kWh	Millstein et al., (2017)
2015 solar energy	4¢/kWh	Millstein et al., (2017)
2015–2050 RPS programs	2.7¢/kWh–8.2¢/kWh	Mai et al., (2016)
2050 wind energy	0.4¢/kWh–2.2¢/kWh	Wiser, Bolinger, et al., (2016)
2050 solar energy	0.7¢/kWh–2.6¢/kWh	Wiser, Mai, et al., (2016)

The literature review also identified two key gaps across all available estimates. While several studies estimated the benefits per kWh in specific regions, particularly the Northeast and California, there is no comprehensive set of monetized health benefits per kWh from EE/RE/ES$^+$ projects for all U.S. regions. It is not appropriate to apply the national numbers provided by LBNL for specific regions, because this would not accurately represent the differences in the specific composition of electricity generation throughout the United States and therefore would not account for regional differences in emissions. Additionally, the values from the literature are not methodologically consistent, and can therefore not be compared with confidence. These gaps limit practitioners' abilities to include health benefits in the assessments of EE/RE/ES$^+$ projects or programs, or policy costs and benefits.

This BPK study fills these gaps identified in the literature review by quantifying and presenting easy-to-use health benefits values for a range of EE/RE/ES$^+$ types; these values are comparable and cover all regions in the United States. EPA calculates these BPK values in a similar fashion to its existing estimates of monetized public health benefits-per-ton (BPT) of emissions reductions. Both the BPT and BPK estimates take health benefits and divide them by the amount of emissions or generation reduced (Fann et al. 2009).[6]

In general, the literature review examined common approaches to estimating BPK values and identified a series of best practices for estimating these values in the United States. The best practices include the following:

1. Establish a set of public health BPK values for interventions in specific regions, rather than a single national value, to account for regional differences in generation and air pollution control technologies.
2. Establish separate BPK values for different types of EE/RE/ES$^+$ projects, programs, and policies, such as wind, solar, uniform EE, and peak EE, to account for how different technologies impact the load (i.e., demand) curve.[7]
3. Establish BPK values for interventions of varying capacity to capture the benefits stemming from EE/RE/ES$^+$ interventions that can displace power from baseload, intermediate load, and peaking units.
4. Account for changes in primary and secondary $PM_{2.5}$ emissions and, whenever feasible, changes in O_3 concentrations in public health BPK values to capture the majority of health impacts from outdoor air pollution.
5. Use emissions, population, and income datasets from the same year to maintain internal consistency.

EPA estimated the BPK values in this report using a method informed by these best practices. EPA also sought input on the methods for this analysis from outside experts in energy modeling, health benefits estimation, electricity system operations, and EE/RE/ES$^+$ policy and deployment. The remainder of this report describes the methods used to estimate screening-level BPK values and the results of the analysis. This report also contains technical appendices with more information on the tools and models used in the analysis, as well as the results of sensitivity analyses performed to address uncertainty in the estimates.

Methods

In this section, EPA provides a general overview of the approach used to estimate the near-term benefits per kWh of EE/RE/ES$^+$ programs,[8] and then discusses in more detail the electricity, emissions, and health impact modeling steps used to develop the BPK values.

Overview of Approach

EPA's approach for estimating the screening-level health benefits per kWh of EE/RE/ES$^+$ projects, programs, and policies involves a six-step process:

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[6] EPA has used the benefits-per-ton (BPT) estimates in multiple regulatory impact assessments for air quality regulations, such as the Mercury and Air Toxics Standards; the New Source Performance Standards for Petroleum Refineries; and the National Emission Standards for Hazardous Air Pollutants for Industrial, Commercial, and Institutional Boilers and Process Heaters. For more information, see https://www.epa.gov/economic-and-cost-analysis-air-pollution-regulations/regulatory-impact-analyses-air-pollution.

[7] See the *Selected Energy Scenarios* section on page 8 of this report for definitions of uniform EE and EE at peak.

[8] The "near term" is defined as approximately the next five years, which is discussed in more detail in the *Limitations* section on page 18.

1. Estimate annual changes in fossil fuel–based electricity generation due to representative EE/RE/ES$^+$ projects, programs, and policies.
2. Estimate annual changes in air pollution emissions (NO_x, SO_2, $PM_{2.5}$, and volatile organic compounds [VOCs]) due to changes in fossil fuel–based generation.
3. Estimate annual changes in ambient concentrations of air pollution due to changes in emissions of primary $PM_{2.5}$, precursors of secondary $PM_{2.5}$, and O_3.[9]
4. Estimate annual changes in public health impacts due to changes in ambient concentrations of $PM_{2.5}$ and O_3.
5. Estimate the monetary value of changes in public health impacts.
6. Divide the monetized public health benefits by the size of the intervention (in kWh) to determine the air quality–related health benefits per kWh in 2023 (in cents per kWh).

This approach follows well-established methodologies for estimating the magnitude and economic value of public health benefits of air pollution emissions reductions, which have been documented in literature—for example, in Dockins et al. (2004) and Fann et al. (2012)—and used in recent EPA RIAs.[10] Based on these established methodologies, EPA did not include reductions of carbon dioxide (CO_2) in this analysis because those reductions are generally only included in studies that assess climate and welfare impacts in addition to public health impacts.

To quantify public health benefits in the near term, EPA developed a set of values for the year 2023. To carry out the approach for these estimates, EPA used two peer-reviewed EPA tools, AVERT v4.3[11] and COBRA v5.1.[12] Figure 2 depicts the approach outlined above as it relates to the tools used in this analysis. These tools are described further in *Appendix A: AVoided Emissions and geneRation Tool (AVERT)* and *Appendix B: CO-Benefits Risk Assessment (COBRA) Health Impacts Screening and Mapping Tool*.

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[9] Primary $PM_{2.5}$ refers to the direct emissions of PM from EGUs. Secondary $PM_{2.5}$ is created as emissions of SO_2 and NO_x (and other pollutants such as ammonia [NH_3] and VOCs) undergo chemical reactions in the atmosphere.

[10] See https://www.epa.gov/system/files/documents/2024-04/utilities_ria_final_111_2024-04.pdf for an example.

[11] EPA AVERT; see https://www.epa.gov/statelocalenergy/avoided-emissions-and-generation-tool-avert.

[12] EPA COBRA Health Impacts Screening and Mapping Tool; see https://www.epa.gov/statelocalenergy/co-benefits-risk-assessment-cobra-screening-model.

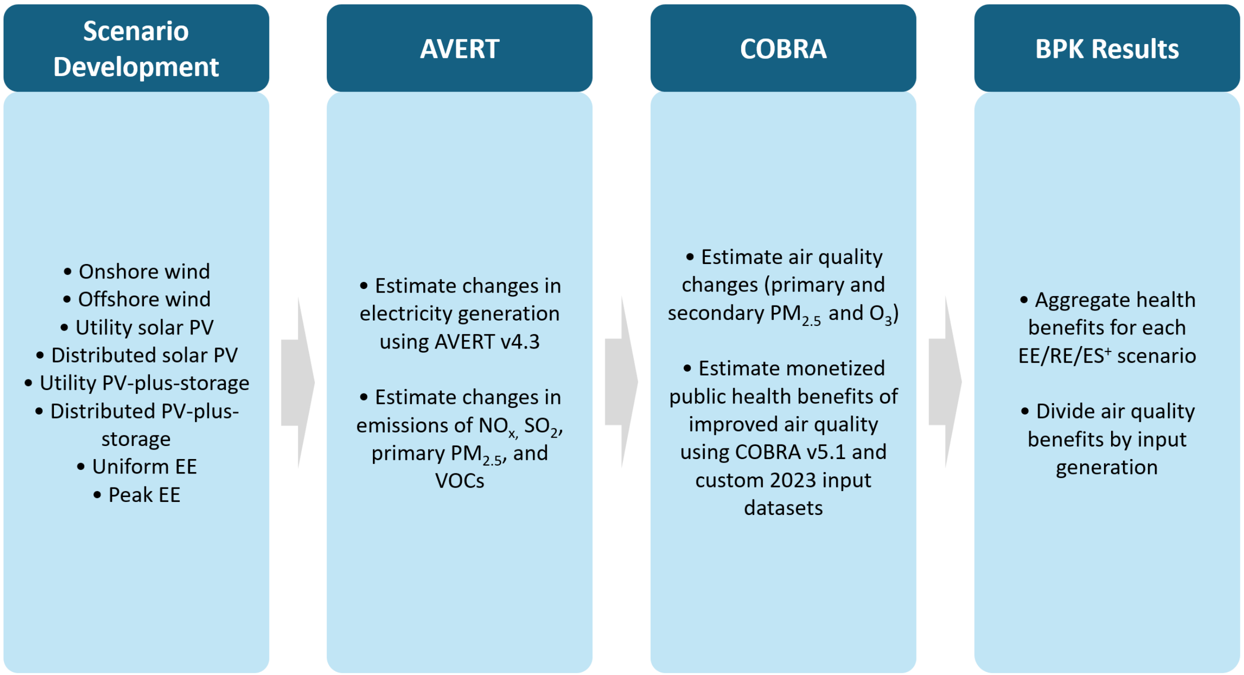

Figure 2. BPK Approach.

Scenario Development

EPA considered multiple scenarios to estimate changes in electricity generation and emissions due to EE/RE/ES$^+$ projects, programs, and policies. During the scenario development process, EPA sought input from technical experts in EE/RE/ES$^+$ modeling and analysis and refined the scenarios based on their comments. For a description of how EPA used these scenarios w to estimate changes in electricity generation and emissions, see the *Electricity and Emissions* Modeling section on page **Error! Bookmark not defined.**, as well as *Appendix A: AVoided Emissions and geneRation Tool (AVERT)*.

Background on Modeling Energy Scenarios

Different scenarios encompass resources that have different impacts on the grid. The AVERT model allows us to consider these differences, including differences in hourly impacts, marginal impacts, and avoided transmission and distribution (T&D) losses. The timing of interventions also impact which fossil fuel resources are displaced and when. The types of electric generating units (EGUs) that typically operate on the margin during peak hours often differ from those that operate on the margin at other times of the day.[13] Because emissions from these types of power

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[13] EPA defines EGUs on the margin as "the last units expected to be dispatched, which are most likely to be displaced by energy efficiency or renewable energy." For more information, see chapter 3 of the EPA report, *Quantifying the Multiple Benefits of Energy Efficiency and Renewable Energy: A Guide for State and Local Governments*: https://www.epa.gov/statelocalenergy/quantifying-multiple-benefits-energy-efficiency-and-renewable-energy-guide-state.

plants can vary significantly, emissions reductions will likely also vary for different types of EE/RE/ES$^+$ interventions.[14]

In addition, certain resources create impacts on the wholesale grid, while others create impacts at the retail or meter level. Resources that create impacts at the retail or meter level can avoid more generation and emissions than resources creating impacts at the wholesale level (on a per-megawatt-hour [per-MWh] basis) due to their ability to also avoid losses associated with transmission and distribution of electricity.

Selected Energy Scenarios

EPA modeled four technology types for RE: onshore wind, offshore wind, utility solar, and distributed solar. Utility solar refers to larger scale solar arrays installed by private developers or utilities. Distributed solar refers to the smaller scale arrays that are more commonly installed on a residential level, such as rooftop solar.

EPA modeled distributed and utility-scale ES paired with solar PV (PV-plus-storage). The PV-plus-storage resource in AVERT pairs storage with solar generation and limits ES to only charge from the added solar resource.

EPA modeled two types of EE: uniform EE and peak EE. Uniform EE evenly applies a constant reduction in electricity demand to all hours of the year. This assumes that an EE intervention would reduce demand for electricity to the same degree during all hours of the day and for all seasons. For example, installing energy-efficient exit signs (which operate 24 hours a day, seven days a week) will result in constant or uniform reductions, because the signs lower energy demand during all hours of the year.

The peak EE scenario assumes that EE reductions occur only during certain times of the day when demand is highest (often called “peak hours”). For example, installing an energy-efficient heat pump in place of less efficient electric heating and cooling equipment will reduce demand for electricity different amounts depending on the season and time of day. To evaluate the impact of reducing electricity during peak hours, it is necessary to define which hours of the day are considered peak hours. There is currently no universally accepted definition of peak hours, and different regions of the country are faced with different variables that impact when peak hours occur. In states with warmer climates, peak hours are often the afternoon hours in the summer (i.e., when demand for air conditioning is high), while colder states have peak hours during winter mornings; some states have both morning and afternoon peak hours, and some have both summer and winter peaks.

Based on a review of more than 30 RTO and utility programs aimed at shifting consumer electric load away from peak hours, EPA has created a definition that identifies peak hours as those that (a) occur on weekdays, (b) do not occur on federal holidays, (c) occur from 12:00 p.m. to 8:00 p.m. from June through September, and (d) occur from 6:00 a.m. to 9:00 a.m. and from 5:00 p.m.

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[14] For example, natural gas simple cycle turbines are well suited to serve peak load because of their quick start-up capability, but these units generally have higher NO_x emissions than natural gas combined-cycle plants, which are more efficient and typically serve intermediate or even baseload demand.

to 9:00 p.m. from October through May. The rationale behind this new definition of peak hours is explained further in *Appendix G: 2023 Peak EE Definition.*[15]

The Third Edition BPK values use the intervention generation from EE/RE/ES$^+$ sources, and therefore account for the impacts of T&D losses. BPK values are intended to be multiplied by a project's intervention generation. Therefore, the denominator of the BPK value calculation should be based on intervention generation rather than displaced generation at the site of the end user. This approach applies to distributed resources (i.e., uniform EE, peak EE, distributed solar, and distributed PV-plus-storage), and allows stakeholders to more easily estimate the health benefits of their EE/RE/ES$^+$ projects and policies.

Project, Program, and Policy Size Assumptions

In prior versions of the BPK values, EPA evaluated whether the size of the EE/RE/ES$^+$ intervention had a meaningful impact on which EGUs were displaced and tested the linearity of the relationship between avoided emissions and public health benefits. In 2019, EPA conducted a sensitivity analysis for five different project sizes and found that across all project sizes modeled, BPK values were nearly constant.[16] The full results for this sensitivity analysis are shown in *Appendix C: Sensitivity Analyses on Project, Program, or Policy Size and Peak Energy-Efficiency Definition*.

For the Third Edition BPK values, EPA changed the resource size to be the quantity of megawatt-hours (MWh) that is equal to 0.5 percent of regional fossil load, in order to be consistent with the scenarios EPA publishes annually in the "Avoided Emission Rates Generated from AVERT" document.[17] The resulting size of the range of resources modeled in this edition of the report is similar to the range analyzed in the Second Edition of this report.

Each BPK run is created using the following methodology:

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[15] In the 2019 BPK analysis, EPA reviewed definitions of peak hours from several utilities in different parts of the country to determine which definition to use. The definitions of peak hours differed slightly among the utilities (e.g., some are from 2:00 p.m. to 6:00 p.m., some include morning hours, some differ by season). EPA conducted a sensitivity analysis by modeling the same generation reduction for each utility's definition of peak, including seasonal variations. After conducting a sensitivity analysis on two different methods to define peak EE (referred to as "top 200 hours" and "hour of the day" approaches), EPA chose to use the general definition of 12:00 p.m. to 6:00 p.m. on weekdays for peak hours. In 2019, EPA also considered defining peak hours as the top 200 hours in the year and conducted a sensitivity analysis to compare the "hour of the day" and "top 200 hours" approaches. The results of this sensitivity analysis show large differences in the emission rates in some regions. The full results of this sensitivity analysis are discussed in *Appendix C: Sensitivity Analyses on Project, Program, or Policy Size and Peak Energy-Efficiency Definition.* After consulting with energy sector experts, EPA determined that the "hour of the day" approach was more relevant for the analysis. Results for the "top 200 hours" approach can be found in *Appendix D: Top 200 Hours of Demand 2017 Benefit-per-kWh Results*.

[16] The sensitivity analysis included project sizes ranging from 100 megawatts (MW) of added capacity to 2,000 gigawatt-hours (GWh) of displaced generation. AVERT cautions against modeling small project sizes to minimize noise in the results. See pages 135–136 of the AVERT v4.3 User Manual, available at: https://www.epa.gov/system/files/documents/2024-04/avert-user-manual-v4.3.pdf.

[17] For more, see https://www.epa.gov/avert/avoided-emission-rates-generated-avert.

1. For each region, we determine the quantity of MWh that is equal to 0.5 percent of regional fossil load, *G*.[18] This level of load is sufficient to produce results in AVERT with minimal noise and is also representative of the size of EE or RE programs that users are likely to model in AVERT.

Common conversions used throughout this report.

Original Units	Multiply By	To Obtain
¢/kWh	1,000	¢/MWh
¢/kWh	1,000,000	¢/GWh

2. For each resource *i* within each region *r*, we calculate the MW necessary to produce the MWh quantity *G* using AVERT's default capacity factors (*CF*) for each region. Using these capacity factors in the following formula, we can determine the input capacity *C* for each resource.

Equation 1. Formula for determining capacity C *for a given region* r *and resource* i *using input MWh* G *and capacity factor* CF.

$$C_{r,i} = \frac{G_r}{8{,}760 \times CF_{r,i}}$$

There are different methodologies for determining capacity factors and capacities for each resource:

a. For onshore wind resources, this capacity factor ranges from 16 to 38 percent; for offshore wind resources, this capacity factor ranges from 25 to 45 percent; for utility PV resources, this capacity factor ranges from 19 to 30 percent; and for distributed PV resources, this capacity factor ranges from 15 to 23 percent. These regional values are based on information from the National Renewable Energy Laboratory, EPA, and the Bureau of Ocean Energy Management, and are documented in detail in Appendix C of the AVERT user manual.[19]

b. For uniform EE, we assume a capacity factor of 100 percent. This effectively spreads the quantity *G* equally over each of the 8,760 hours modeled in a year.

c. For peak EE, we assume that the quantity *G* is concentrated in a specific number of hours: hours that (a) occur on weekdays, (b) do not occur on federal holidays, (c) occur between the hours of 12:00 p.m. and 8:00 p.m. from June through September, and (d) occur between the hours of 6:00 a.m. to 9:00 a.m. and 5:00 p.m. to 9:00 p.m. from October through May. This definition of EE at peak is based on a review of over more than 30 RTO and utility programs aimed at shifting consumer load away from peak hours. For 2023, this calculation identifies 1,827 hours. The quantity *G* is divided evenly over each of these 1,827

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[18] Note that we assume 0.5 percent of regional fossil load, which is different than total regional load. This is because AVERT operates under the assumption that fossil fuel–fired plants are marginal and will represent the load that is displaced by the interventions modeled in this analysis.

[19] AVERT User Manual v4.3. Available at https://www.epa.gov/system/files/documents/2024-04/avert-user-manual-v4.3.pdf. See Appendix C.

hours. For more information on how EPA defined EE at peak, see *Appendix G: 2023 Peak EE Definition.*

d. For utility PV-plus-storage and distributed PV-plus-storage, we use the same default capacity factor described above. Then, to account for round-trip losses from paired storage systems which would otherwise shift the quantity *G* to something other than 0.5 percent, the following equation is used:

Equation 2. Formula for determining capacity C *for solar component of paired solar and storage resources.*

$$C_{Solar,r} = \frac{G_r}{(8{,}760 \times CF) + \frac{(H \ \times E)}{R} \times (1 - D)}$$

Where:
H *is the number of hours that the storage is active (using the AVERT defaults of 4-hour storage, dispatched 150 times per year, or 600 hours)*
E *is the round-trip efficiency of the storage (using the AVERT default of 80%)*
D *is the depth-of-discharge of storage (using the AVERT default of 85%)*
R *is the assumed ratio of solar MW to storage MW (using an assumption of 1.65, based on values reviewed in the literature)*

The corresponding storage quantity (in MW) is then computed as:

Equation 3. Formula for determining capacity C *for storage component of paired solar and storage resources.*

$$C_{Storage,r} = \frac{C_{Solar,r}}{R}$$

3. For each resource and region, EPA inputs the capacity value *C* into the AVERT model, where AVERT analyzes it for emission impacts.

4. County-level emission impacts are then passed to COBRA, where COBRA analyzes the public health benefits.

5. For each resource and region, monetized public health benefits are then divided by the initial MWh value *G* to determine BPK values.

Electricity and Emissions Modeling

To estimate the changes in electricity generation and associated changes in emissions due to EE/RE/ES$^+$ projects, programs, and policies (steps 1 and 2 in the overall approach), EPA used AVERT v4.3. AVERT uses hourly emissions and generation data from EGUs to determine the air pollution emissions per kWh from each generating unit, as well as the probability that a given unit will be operating during a given hour.[20] AVERT uses this information to estimate which fossil fuel–fired units will likely be affected by EE/RE/ES$^+$ projects, programs, and policies, as

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[20] Facilities are required under 40 CFR Part 75 to report information on emissions, heat rate, and generation to EPA's Clean Air and Power Division (CAPD) for EGUs that are 25 MW or larger.

well as the amount of emissions displaced or avoided. The results from AVERT are the estimated emissions reductions of NO_x, SO_2, $PM_{2.5}$, VOCs, and NH_3 from the modeled EE/RE/ES$^+$ project, program, or policy. The results from AVERT are presented at the county, state, and regional levels.

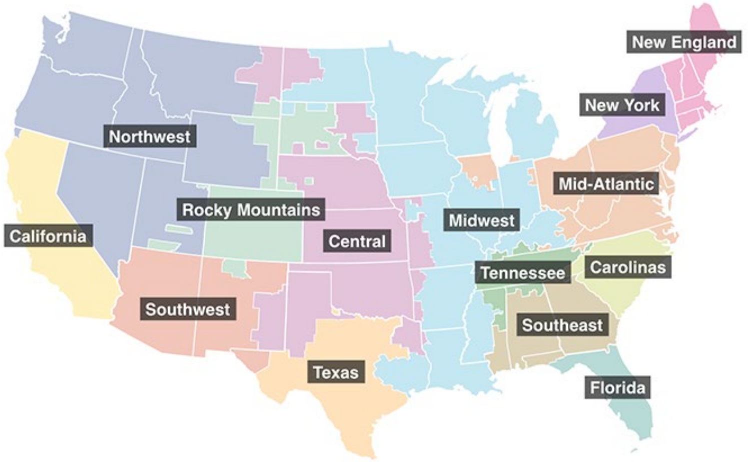

Figure 3. AVERT Regions.

The Third Edition BPK estimates in this analysis were developed using actual emissions and generation data from fossil fuel–fired EGUs in 2023, which are built into the latest version of AVERT. The assumptions about how AVERT uses historical data to estimate emissions reductions are discussed in more detail in *Appendix A: AVoided Emissions and geneRation Tool (AVERT)*.

EPA developed separate estimates for each of the 14 AVERT regions (Figure 3) to account for regional differences in generation power plant fuel mixes and air pollution control technologies.[21] These regions are based on aggregations of one or more balancing authorities. EPA modeled each scenario, outlined above, in each region in 2023, then developed 76 estimates of emissions reductions.

Air Quality and Health Impact Modeling

Once EPA developed estimates of emissions reductions by applying AVERT for all scenarios, EPA used the COBRA Health Impacts Screening and Mapping Tool v5.1 to complete steps 3, 4, and 5 of the approach—estimating changes in ambient air quality, impacts on public health, and monetized health benefits from emissions reductions.

COBRA uses a reduced-form Source-Receptor (S-R) Matrix air quality model (Pattern Constructed Air Pollution Surfaces, or PCAPS), developed by EPA (Baker et al., 2023) to develop screening-level estimates of how changes in emissions at source counties will affect ambient $PM_{2.5}$ and O_3 concentrations in receptor counties. EPA developed the S-R Matrix using the Comprehensive Air Quality Model with Extensions' (CAMx's) source apportionment feature, which tracks the contribution of air pollutant emissions at sources to concentrations at receptors (EPA, 2024d).

COBRA uses concentration-response (C-R) functions from epidemiological literature to determine how changes in ambient $PM_{2.5}$ and O_3 concentrations will impact health outcomes, such as premature mortality, non-fatal heart attacks, exacerbation of asthma, and other respiratory symptoms. Finally, COBRA uses established valuation functions from economic

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[21] Note that AVERT implicitly accounts for control technologies because it uses unit-level emissions data to estimate emissions from electricity generation.

literature to estimate the monetary value of each health outcome. C-R and valuation functions used in COBRA are consistent with those used in EPA's Environmental Benefits Mapping and Analysis Program (BenMAP) and in RIAs conducted by the Agency. COBRA assumes that National Ambient Air Quality Standards (NAAQS) are met in all states and counties, and, therefore, estimates incremental health benefits from reduced exposure below the standards.[22] The result from COBRA is the estimated avoided air quality–related public health outcomes from emissions reductions and the monetary value of those avoided public health outcomes. The results from COBRA are presented at the county level. For more information on the COBRA tool, see *Appendix B: Co-Benefits Risk Assessment (COBRA) Health Impacts Screening and Mapping Tool.*

AVERT provides results for changes in generation in 2023, while COBRA v5.1 includes default datasets for the years 2016, 2023, and 2028. EPA chose analysis year 2023 in COBRA to maintain consistency between the datasets used in AVERT and COBRA. This differs from the Second Edition BPK values, which used AVERT generation data from 2019 and required interpolation between 2016 and 2023 for COBRA's baseline emissions inventory, population, health incidence, and valuation datasets.

County-level emissions reductions from each AVERT run were entered into the "Fuel Combustion from Electric Utilities" tier in COBRA. This tier is one of 14 different tiers in COBRA, which represent the emissions sources tracked in EPA's National Emissions Inventory. These tiers include information regarding the height of emissions (i.e., the stack height for EGUs), which has implications for the transport of emissions from source counties to receptor counties.

COBRA also accounts for the population density of each county. Counties with a higher population density will, with the same change in $PM_{2.5}$ and O_3 concentrations, have larger health benefits per change in air quality than counties with lower population density.

COBRA v5.1 uses a 2 percent discount rate to express future economic values in present terms because not all health effects and associated economic values occur in the year of analysis—COBRA assumes changes in adult mortality and non-fatal heart attacks occur over a 20-year period. COBRA discounts the benefits of avoiding these health effects back to the analysis year so that the results from COBRA represent annual benefits. For more information on discounting in COBRA, see the COBRA User Manual. EPA ran scenarios using a 2 percent discount rate, as recommended by OMB Circular A-4 (2023).[23]

COBRA reports a low and high estimate of the monetary value of the health benefits impacts based on the use of different C-R functions (e.g., different mortality functions). Specifically, the low and high estimates are derived using two sets of assumptions from the literature about the sensitivity of adult mortality and non-fatal heart attacks to changes in ambient $PM_{2.5}$ and O_3 levels. EPA used these low and high estimates with the 2 percent discount rate to report the total health benefits of all scenarios as a range.

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[22] NAAQS are not set at a zero-risk level, but a level that protects public health; both EPA and the Integrated Science Assessment for Particulate Matter have acknowledged that health risks exist at levels below the level of the standard. Therefore, emissions reductions below the standard will still result in health benefits.

[23] See https://www.whitehouse.gov/wp-content/uploads/2023/11/CircularA-4.pdf.

Developing the Benefits-per-kWh Estimates

AVERT presents results at the county and electricity grid regional levels, whereas COBRA presents results at the county, state, and national levels.[24] EPA aggregated the total county-level results from each COBRA scenario and developed the monetized health BPK estimates (in cents per kWh) for each region and each scenario by dividing the total monetized health benefits (in U.S. dollars) from COBRA by the total regional-level input kWh from AVERT. If users wish to apply these regional BPK values to a state that spans multiple AVERT regions, they can weigh the regional BPK values by the percentage of their state that is covered by each region using AVERT's table of state apportionment by AVERT region.[25]

While the inputs to COBRA are based on emissions reductions occurring in each AVERT region, the COBRA results also include health benefits that occur outside the region(s) where modeled emissions reductions occur. This is because COBRA accounts for the transport of pollution to airsheds located downwind of an emissions source. For example, emissions reductions from EGUs in the Mid-Atlantic region will likely result in health benefits within that region and in neighboring regions downwind of the power plant smokestacks, such as the New York region, due to the interstate transport of air pollution. In the BPK calculations, EPA aggregated the total health benefits calculated by COBRA for each scenario to account for all health benefits that occur both within the AVERT region where the emissions reductions occur and in other regions that also experience health benefits from those emissions reductions. This approach is consistent with other EPA estimates of monetized public health benefits per ton of emissions reductions (Fann et al., 2009).

EPA estimated screening-level health benefits per kWh for each scenario using *Equation 4*:

Equation 4. Formula for calculating BPK values.

$$BPK_{t,r} = \frac{HealthBenefits_{t,US}}{InterventionkWh_{t,r}}$$

Where:

$BPK_{t,r}$ = Annual monetized public health benefits per kWh (¢/kWh) for each EE/RE/ES^{+} technology type (*t*) and AVERT region (*r*).

$HealthBenefits_{t,US}$ = Aggregated monetized public health benefits from emissions reductions for each EE/RE/ES^{+} technology type (*t*) for the contiguous United States (*US*) in 2023 dollars.

$InterventionkWh_{t,r}$ = Input change in kWh for each EE/RE/ES^{+} technology type (*t*) and AVERT region (*r*).

If users wish to derive state-specific BPK values for a state (*s*) that spans multiple AVERT regions, they can sum the product of each AVERT region and a state's power sector apportionment to each region, as in *Equation 5*.

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[24] At this time, the model domain of COBRA is the contiguous United States.

[25] See https://www.epa.gov/avert/avert-tutorial-getting-started-identify-your-avert-regions.

Equation 5. Formula for estimating state-level BPK values.

$$BPK_{t,s} = \sum_{r} BPK_{t,r} \times A_{r,s}$$

Where:

$BPK_{t,s}$ = Annual monetized public health benefits per kWh (¢/kWh) for an EE/RE/ES^+ technology type (t) and state (s).

$A_{r,s}$ = Power sector apportionment (%) for a state (s) to each AVERT region (r).

The Third Edition BPK values use the input kWh from EE/RE/ES^+ sources and therefore account for T&D losses. Input kWh, or intervention kWh, are different from displaced generation on the wholesale grid, which is an output of AVERT. For certain resources, the amount of displaced generation is greater than the intervention kWh because of avoided T&D losses. BPK values are intended to be multiplied by a project's intervention kWh. Therefore, the denominator of the BPK value calculation should be based on intervention kWh rather than wholesale grid impacts. This change only affects benefits of the EE, distributed solar, and distributed PV-plus-storage technology types, and it will allow stakeholders to estimate the health benefits of their EE/RE/ES^+ projects and policies more accurately.

Uncertainty

As described above, EPA calculated the BPK values using a suite of models that are each affected by various sources of uncertainty. While data limitations prevent EPA from quantifying these uncertainties, the Agency can qualitatively characterize the sources and magnitude of the uncertainties from electricity and emissions modeling and air quality and health impact modeling. In this section, EPA discusses these sources of uncertainty, as well as steps the Agency and the models have taken to mitigate this uncertainty. This discussion also includes an assessment of whether each source of uncertainty leads to an overestimate or underestimate of the BPK values, where possible. In addition, this section includes a discussion of the uncertainty over the length of time into the future that these values can be used for analysis. EPA does not attempt to quantify the uncertainty in the BPK values (e.g., by calculating a confidence interval around each estimate). Readers interested in reviewing a comprehensive quantitative analysis of the uncertainty of the impacts of particulate matter on public health should consult the RIA for the particulate matter NAAQS (EPA, 2024c).

The following subsections discuss the three main sources of uncertainty in this analysis: Uncertainty in electricity and emissions modeling; in air quality and health impact modeling; and modeling in future policies, programs, and projects.

Uncertainty in Electricity and Emissions Modeling

EPA identified three main sources of uncertainty stemming from estimating EE/RE/ES^+–related emissions reductions using AVERT: uncertainties in EGU operation, EGU curtailment, and those stemming from project size. First, uncertainties exist in the cohort of marginal units AVERT simulates when there are changes in demand or RE generation within an AVERT region. The core emissions, heat rate, and generation information AVERT uses is based on historical datasets that utilities report to EPA's Clean Air and Power Division (CAPD) for EGUs that are 25 MW or larger. AVERT's statistical module uses probability distributions of how EGUs operated historically in every hour of a base year to determine which EGUs are on the margin. Refer to *Appendix A: AVoided Emissions and geneRation Tool (AVERT)* for more details on AVERT's operations.[26] Additionally, AVERT does not report results for cases that are not above the level of reportable significance. This prevents AVERT from falsely reporting emissions outcomes of very minor EE/RE/ES$^+$ project, program, or policy impacts. For example, AVERT does not report any emission changes less than 10 pounds of a criteria air pollutant and does not report any changes less than 10 tons of CO_2. Furthermore, there is some uncertainty in how the regions are defined. Although AVERT regions are based on aggregations of balancing authorities, the electricity grid is interconnected and there are transfers of electricity across regions. AVERT does not currently account for these transfers since this could lead to isolating impacts within a region that may affect power plants outside the region. This could result in either an overestimate or an underestimate of the emission impacts, depending on which regions are transferring electricity.

Additionally, AVERT only considers fossil fuel–generating units when modeling energy changes to the grid from EE/RE/ES$^+$ interventions. However, some states, such as California, experience a curtailment of generation from renewable sources when there is an oversupply of electricity generation during certain hours of the year. Curtailment is defined as "a reduction in the output of a generator from what it could otherwise produce given available resources, typically on an involuntary basis" (Bird et al., 2014, p. 1). By assuming that only fossil fuel sources are displaced and not accounting for the fact that some renewable sources could be displaced, the BPK results could overestimate the health benefits of EE/RE/ES$^+$ interventions. For more information on this issue, see the *Limitations* section on page 24.

Finally, estimates in AVERT are calculated using project sizes that vary depending on the region's fossil fuel generation. These estimates could, therefore, underestimate or overestimate reductions if applied to larger or smaller projects. However, as discussed in the *Project, Program, and Policy Size Assumptions* section on page 16, EPA addressed project size uncertainty in 2019 by conducting sensitivity analyses varying the project size from 100 to 2,000 MW of added capacity for wind and utility solar and varying definitions of EE. This analysis, discussed in detail in *Appendix C: Sensitivity Analyses on Project, Program, or Policy Size and Peak Energy-Efficiency Definition*, shows that changes in project size (within the range of project sizes commonly considered by state, local, and Tribal governments) do not have a large impact on the resulting BPK values. Uncertainty may still exist when modeling projects outside of the recommended sizes. For more information, see the *Limitations* section on page 24.

Uncertainty in Air Quality and Health Impact Modeling

EPA identified sources of uncertainty from using COBRA to model changes in air quality, health impacts, and the value of those impacts. The largest source of uncertainty in the COBRA tool is the S-R Matrix, which consists of fixed transfer coefficients that reflect the relationship between emissions at source counties and ambient air pollution concentrations at receptor locations. Even

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[26] For more information on AVERT's statistical module, refer to Appendix D in the AVERT User Manual: https://www.epa.gov/avert/avert-user-manual.

though the S-R Matrix was developed as a screening-level tool using a more advanced model (CAMx), it still represents a simplification of the transport of air pollution, and it is less sophisticated than a photochemical grid model, such as the Community Multiscale Air Quality Modeling System (CMAQ),[27] which would quantify the non-linear chemistry governing the formation of $PM_{2.5}$ in the atmosphere. Due to the uncertainty surrounding the S-R Matrix, COBRA is considered a screening-level tool; for more detailed estimates of air quality changes, more sophisticated models should be used.[28] However, COBRA has been used extensively in the peer-reviewed literature and has been compared favorably to the estimates from CALPUFF, a more sophisticated air quality model (Levy et al., 2003). It is not clear whether the uncertainty with the S-R Matrix leads to an overestimate or underestimate of the BPK values.

The C-R and valuation functions COBRA uses to estimate and monetize public health impacts are another source of uncertainty. The functions used in COBRA do not represent the complete body of epidemiological literature but are consistent with those used in recent EPA RIAs. Additionally, COBRA addresses uncertainty in some C-R functions by using two separate approaches to estimate the incidence of mortality and nonfatal heart attacks and reports high and low values. The valuation function that accounts for a vast majority of the benefits is the value of a statistical life, which is a well-established value that has been used in many EPA RIAs.[29]

Uncertainty in Modeling into the Future

The baseline conditions used in AVERT are constructed from emissions and generation data reported to EPA for the year 2023. Estimating health benefits for future years using Third Edition BPK values results in some uncertainty. EPA suggests that AVERT not be used to estimate emissions reductions more than five years into the future; this limitation is discussed in the *Limitations* section below. In most cases, forecasting the electricity sector is based on assumptions about demand growth, future fuel prices, emissions constraints, electricity markets, and technological advancements, as well as other aspects of the U.S. economic and regulatory systems. These factors can be used in sophisticated analyses to forecast retirements and additions of EGUs and determine dispatch. AVERT, however, does not take these factors into account, which limits its ability to forecast future changes in emissions. The average emission rates from electricity generation have been declining over the past several years for most regions. If these trends continue, the Third Edition BPK values may be higher than the average health benefits of $EE/RE/ES^+$ in future years on a per-kWh basis, pending population dynamics.

Limitations

The BPK values are subject to the same limitations as the results of the AVERT and COBRA tools. Limitations discussed in this section include the time frame for which the BPK values may be used; types of projects, programs, or policies that can be evaluated; modeling limitations

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[27] More information on CMAQ can be found here: https://www.epa.gov/cmaq.

[28] For more information on other, more sophisticated options for modeling the health benefits of EE and RE, see chapter 4 of the EPA report *Quantifying the Multiple Benefits of Energy Efficiency and Renewable Energy: A Guide for State and Local Governments*: https://www.epa.gov/statelocalenergy/quantifying-multiple-benefits-energy-efficiency-and-renewable-energy-guide-state.

[29] For more information on the value of a statistical life, please see EPA's Mortality Risk Valuation webpage: https://www.epa.gov/environmental-economics/mortality-risk-valuation.

regarding the curtailment of renewables; modeling limitations regarding energy storage; pollutants that are included in the analysis; and benefits beyond the scope of the tools.

Time Frame of the BPK Values

Estimates of emissions reductions from AVERT are based on actual 2023 emissions data reported to EPA by EGUs that are 25 MW or larger, while the emissions baseline in COBRA is based on a projection for 2023. Therefore, there are limitations in using the estimates produced by these tools to evaluate future projects, programs, and policies. For example, if the electricity grid continues to get cleaner, resulting in fewer emissions per kWh of generation, then, all else being equal, the BPK values would decrease. EPA recommends not using AVERT to evaluate scenarios more than five years into the future; the BPK values have a similar limitation. The emission rates at EGUs will likely continue to change in the coming years in response to regulations, fuel prices, and changes in electricity demand, such as from electric vehicles. These BPK values should therefore not be used to estimate the benefits of EE/RE/ES$^+$ interventions past 2028.

EPA has also explored developing BPK values for future years. As EE/RE/ES$^+$ projects, programs, and policies are often planned years in advance, it would be useful to have BPK values that are based on electricity and emissions modeling projections for years after 2028 (the limit of the Third Edition values). However, EPA decided to focus on developing the 2023 BPK values before developing a set of future values. Future BPK values, if developed, will be based on the most up-to-date electricity and emissions modeling data that is available to EPA.

Size of Project, Program, or Policy

EPA advises against using AVERT to estimate emissions reductions for projects that are too small (approximately 1 MW) or too big (no greater than 15 percent of regional fossil fuel generation). The size of an individual project, program, or policy can range widely before hitting that limit, depending on the amount of fossil fuel generation in each region. These suggested limits on capacity are set because, as a historical dispatch model, AVERT is limited in its ability to estimate emissions reductions for projects, programs, or policies that may significantly alter the generation mix in a region. Capacity added beyond this 15 percent cap may have a different impact on emissions that is not captured by the model. EPA also recommends users avoid estimating emissions reductions for projects less than roughly 1 MW because the resulting emissions reductions estimated by the model are too small to be distinguished from the underlying variation in the baseline data. For this reason, the BPK values will have the same limitations in terms of the size of the project, program, or policy for which they can be used.

Load Profile of Project, Program, or Policy

AVERT has different default load profiles for each type of resource modeled. BPK values assume AVERT defaults for all resources. Users may wish to model projects, programs, or policies with load profile definitions, capacity factors, or other resource-specific parameters that differ from the defaults in AVERT. For example, if an EE project, program, or policy results in generation reductions during a different time period than that chosen for this analysis, then it may have a different emissions profile (and therefore, different health benefits) than the types of EE interventions modeled in this report. In particular, it is worth noting that different users may have different definitions of peak EE, and there is no widespread consensus on a single definition. (The definition of peak EE used for this analysis is described in the *Selected Energy*

Scenarios section on page 15.) Analysts have the option of developing their own custom BPK estimates using AVERT and COBRA if the estimates EPA provides do not fit their unique circumstances.

Modeling Limitations Related to Curtailing Renewable Energy Generation

AVERT models emissions reductions resulting from the displacement of fossil fuel–generating units by EE/RE/ES$^+$ sources. However, the real-world dispatch of EGUs is not this simple, and as renewables continue to be added to the electricity supply, some states are beginning to see the curtailment of RE sources in periods of oversupply of generation. Generators are curtailed to ensure the reliability of the grid, usually when there is more electricity generation than demand or when there is transmission congestion. Because fossil fuel units have higher marginal costs than renewables (due to the cost of the fuel), they are typically curtailed more often than renewables. However, in some states with a large proportion of generation from renewables, such as California, there have been curtailments of renewables.[30] Because AVERT does not model existing RE sources, it cannot capture the potential curtailment of renewables. For this reason, the emissions reductions and BPK values from EE/RE/ES$^+$ projects, programs, and policies may be overestimated in regions that regularly curtail renewables.

In addition, AVERT does not account for significant changes in dispatch that may be driven by policies, such as a binding emissions cap, or by EGU retirements. For this reason, BPK values should not be used to examine large-scale policies that will significantly alter the generation mix or the methods by which EGUs are dispatched in any particular region. As discussed above, EPA recommends that BPK values not be used for changes in generation greater than 15 percent of fossil fuel generation in any hour. See the AVERT User Manual for more information on limitations to how AVERT models dispatch of existing EGUs.

Modeling Limitations Regarding Energy Storage

This document provides BPK values for PV-plus-storage resources, as distributed and utility-scale energy storage were added as resources to AVERT v4.3. AVERT operates under the assumption that for PV-plus-storage resources, energy storage charging is limited by the available generation from a paired solar resource. In reality, it is possible for energy storage devices to charge from fossil sources even when co-located with solar. The BPK analysis also assumes that for PV-plus-storage resources, energy storage is dispatched for 150 days over the course of a year and has a four-hour battery storage duration, a round-trip efficiency of 85 percent, and a depth-of-discharge of 80 percent (EPA, 2024a). In AVERT, users can modify these defaults and select the charging profile of the storage system and whether to pair the storage with solar generation or model standalone storage. Other runs that use different sets of default values for these parameters would result in different BPK values.

Pollutants Beyond the Scope of the Tools

AVERT models emissions of CO_2; however, EPA has not yet included reductions of CO_2 in this analysis. Reductions in CO_2 are generally only included in studies that assess climate and welfare impacts in addition to public health impacts. Climate and welfare impacts associated with CO_2 were beyond the scope of this study. Although emissions of CO_2 and climate change may be linked with

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[30] See, for example, a fact sheet on curtailments from the California Independent System Operator (CAISO): https://www.caiso.com/Documents/CurtailmentFastFacts.pdf.

some public health impacts, such as increased heat stress or incidence of vector-borne diseases, COBRA does not estimate those health impacts.

Benefits Beyond the Scope of the Analysis

Finally, the health benefits due to emissions reductions discussed in this report do not include other types of benefits one might expect from these types of interventions. Such benefits include avoiding damages from air toxics, heavy metals, reduced visibility, reduced water quality, and reductions in recreation services.

Results

In this section, EPA presents the results of the electricity and emissions modeling in AVERT, as well as the Third Edition BPK values subsequently derived from COBRA.

Emissions Reductions

EPA used AVERT to estimate changes in fossil fuel–generated electricity and emissions reductions from EE/RE/ES$^+$ projects, programs, and policies. AVERT outputs used in this analysis include intervention generation (MWh) and emissions reductions of SO_2, NO_x, $PM_{2.5}$, and VOCs (in pounds). Complete regional-level outputs from AVERT can be found in *Appendix E: Detailed Benefits-per-kWh Results*. Note that while AVERT also estimates avoided emissions of NH_3, starting with COBRA v5.0, the air quality model included in COBRA does not consider NH_3 as an input to estimate changes in $PM_{2.5}$ concentrations. Therefore, NH_3 emissions reductions are not discussed in this section.

On average, the SO_2 emissions reductions from EE/RE/ES$^+$ interventions in 2023 were approximately 0.41 pounds per MWh, with high regional variation. In general, the regional variation in emissions reductions is greater than the variation across EE/RE/ES$^+$ technology types. The California region had the smallest reduction in SO_2 emissions per MWh for all types of EE/RE/ES$^+$ projects, programs, and policies (Figure 4). In 2023, the largest reduction in SO_2 emissions per MWh for all types of EE/RE/ES$^+$ interventions occurred in the Central region.

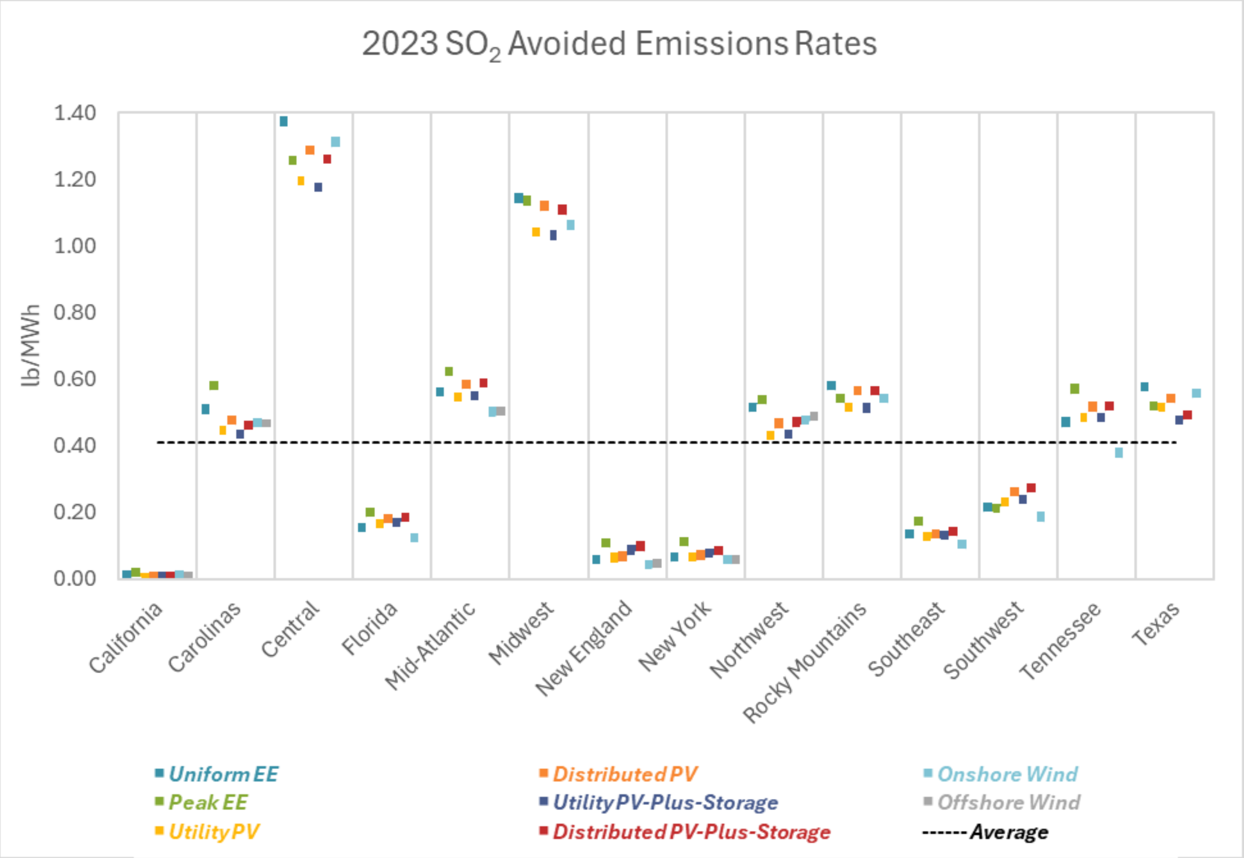


Figure 4. Avoided SO_2 Emission Rates for EE/RE/ES$^+$ Projects, Programs, and Policies in 14 AVERT Regions in 2023.

There is also substantial regional variation in the NO_x avoided emission rates, with an average of 0.56 pounds per MWh in 2023. Again, the California region had the smallest reduction in NO_x emissions per MWh, and the Central region saw the largest reduction in emissions for all types of EE/RE/ES$^+$ projects, programs, and policies (Figure 5). Peak EE projects resulted in the largest NO_x avoided emission rates in 12 out of 14 regions, followed by distributed PV-plus-storage in most regions.

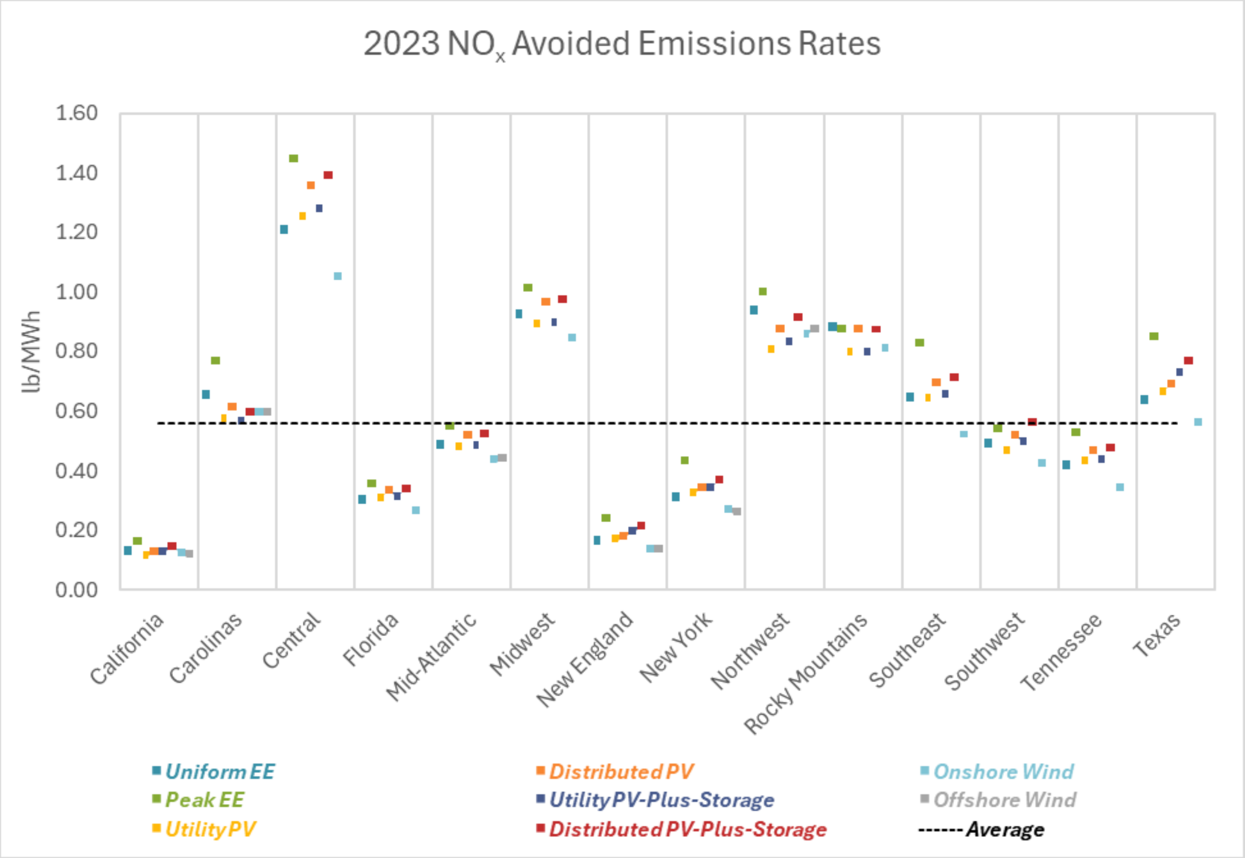


Figure 5. Avoided NO_x Emission Rates for EE/RE/ES$^+$ Projects, Programs, and Policies in 14 AVERT Regions in 2023.

The New England region had the lowest rate of $PM_{2.5}$ reductions per MWh, at 0.04 pounds per MWh on average across resources. The Tennessee region had the highest rate across resources at 0.18 pounds per MWh on average (Figure 6).

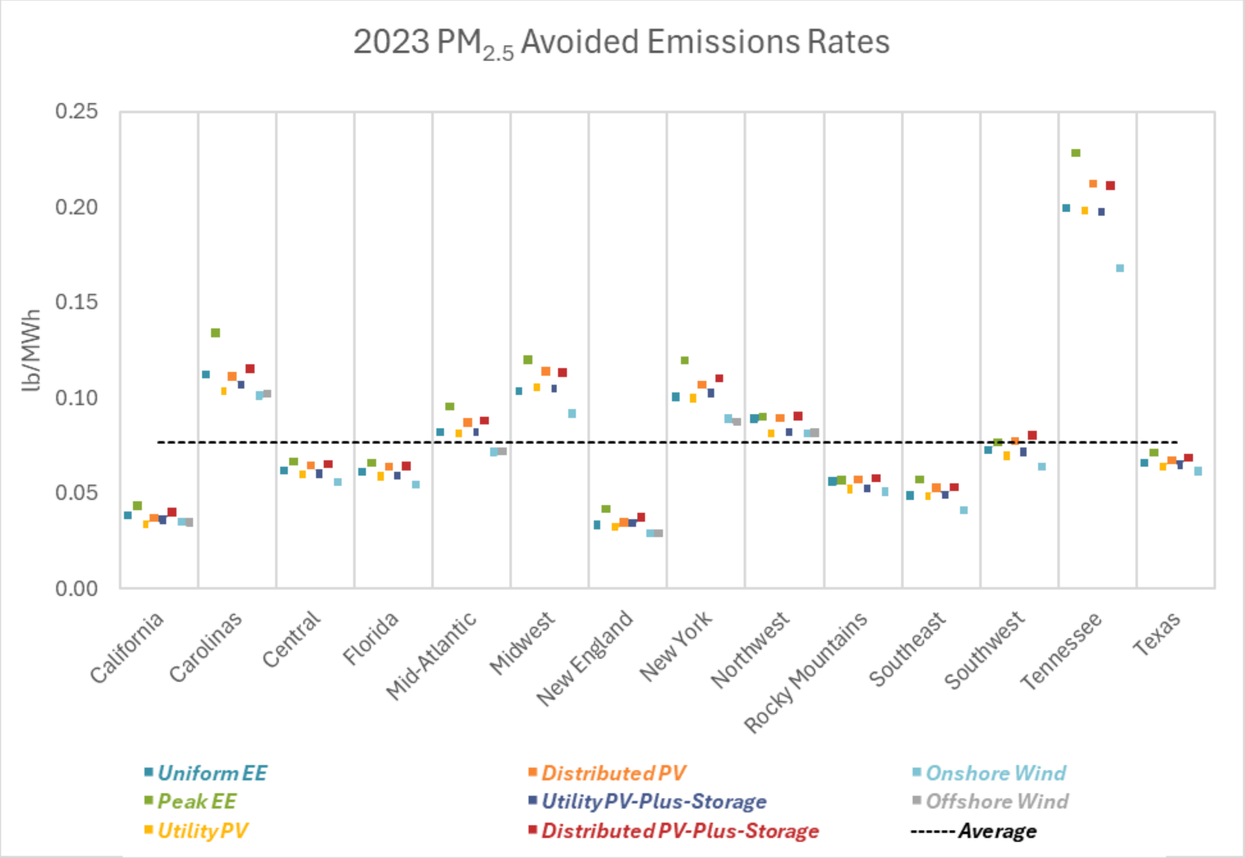


Figure 6. Avoided $PM_{2.5}$ Emission Rates for EE/RE/ES$^+$ Projects, Programs, and Policies in 14 AVERT Regions in 2023.

The New York region had the highest avoided emission rates for VOCs across all resources, with an average rate of 0.6 pounds per MWh. On average, the New England, Florida, and California regions had the smallest avoided emission rates, with all rates of less than 0.02 pounds per MWh. In every region except the Rocky Mountains, the peak EE resource had the highest avoided emission rate.

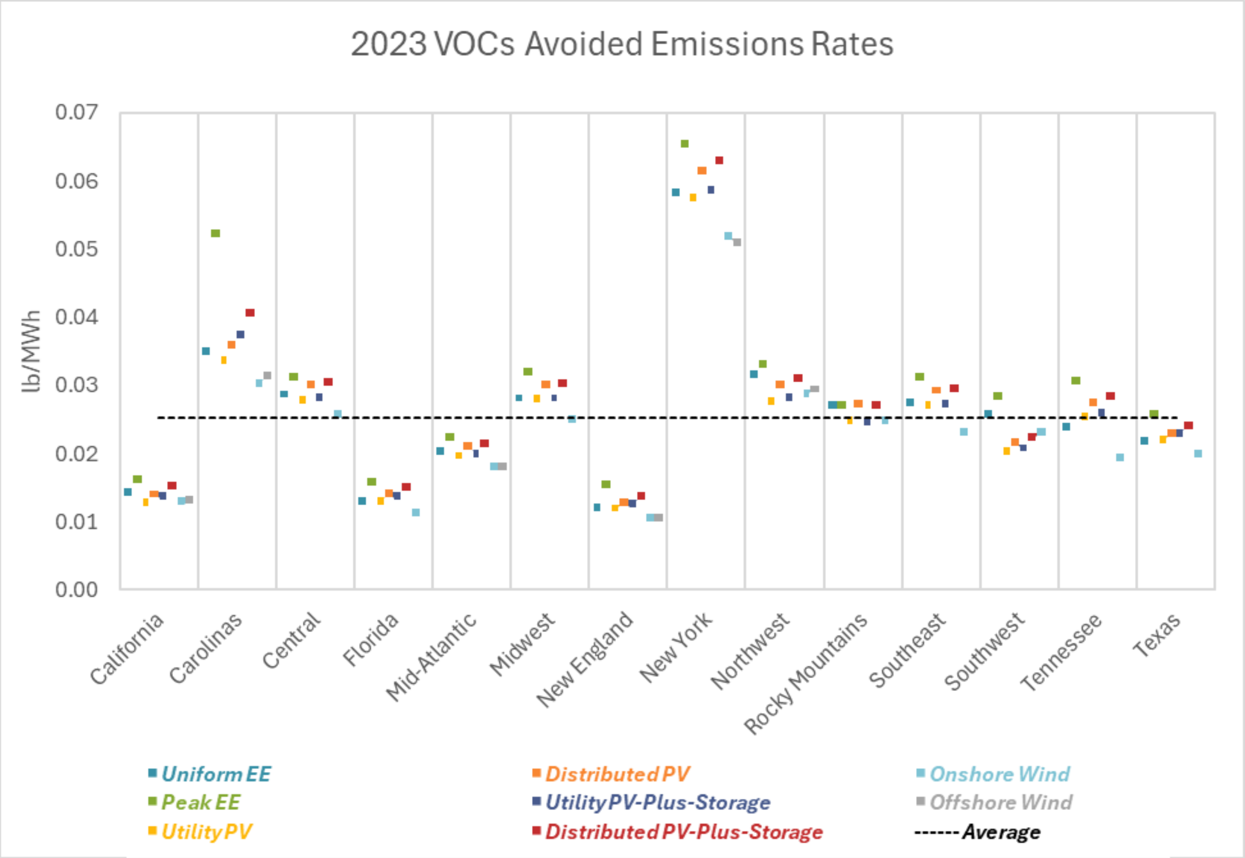
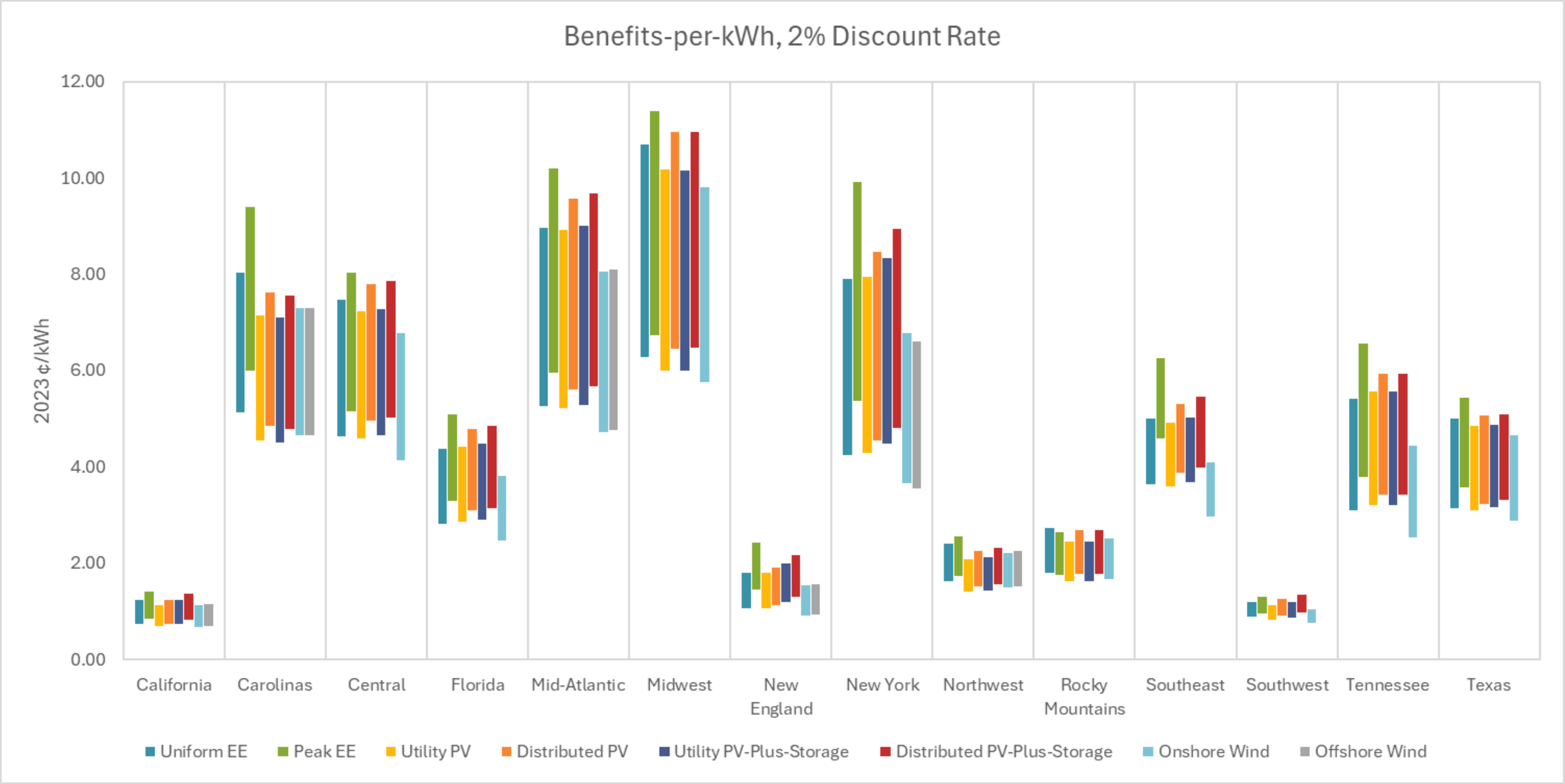


Figure 7. Avoided VOC Emission Rates for EE/RE/ES⁺ Projects, Programs, and Policies in 14 AVERT Regions in 2023.

Benefits-per-kWh Values

The county-level emissions reductions from AVERT were entered into the appropriate counties of the COBRA tool to estimate the health benefits of each EE/RE/ES⁺ scenario. These benefits reflect the sum of the $PM_{2.5}$ and O_3 benefits from the changes in electric sector emissions of NO_x, SO_2, $PM_{2.5}$, and VOCs, and reflect the range of different adult mortality functions (e.g., Krewski et al., 2009; Lepeule et al., 2012). To calculate the BPK values for each scenario, EPA divided the total air quality benefits from COBRA by the corresponding intervention generation values in each region as estimated by AVERT. EPA calculated values for low and high estimates using a 2 percent discount rate. A detailed results table can be found in *Appendix E: Detailed Benefits-per-kWh Results*. COBRA reports results in 2023 U.S. dollars.

Figure 8 shows the results for Third Edition BPK values using a 2 percent discount rate. The bars in the figure represent the range of low and high values. The benefits range from 0.68 cents per kWh to 11.39 cents per kWh. EE/RE/ES⁺ projects, programs, and policies in the California and Southwest regions deliver the lowest air quality benefits per kWh in all scenarios. The largest BPK values can be seen in the Midwest region, followed by the Mid-Atlantic and New York. A full list of EPA's Third Edition BPK values can be found in Table 2.



Note: The bars indicate the range of low and high values.

Figure 8. 2023 BPK Values for EE/RE/ES^{+} Projects, Programs, and Policies at the 2% Discount Rate.

Table 2. BPK Values, Third Edition (Cents per kWh, 2023 USD, 2% Discount Rate).

Region	Project Type	BPK, Low (2023 ¢/kWh)	BPK, High (2023 ¢/kWh)
California	Uniform EE	0.75	1.26
California	Peak EE	0.85	1.42
California	Utility PV	0.69	1.15
California	Distributed PV	0.75	1.25
California	Utility PV-plus-storage	0.74	1.24
California	Distributed PV-plus-storage	0.83	1.37
California	Onshore wind	0.68	1.14
California	Offshore wind	0.69	1.16
Carolinas	Uniform EE	5.13	8.04
Carolinas	Peak EE	5.99	9.40
Carolinas	Utility PV	4.55	7.15
Carolinas	Distributed PV	4.84	7.62
Carolinas	Utility PV-plus-storage	4.51	7.12
Carolinas	Distributed PV-plus-storage	4.79	7.57
Carolinas	Onshore wind	4.66	7.30
Carolinas	Offshore wind	4.66	7.31
Central	Uniform EE	4.63	7.49
Central	Peak EE	5.16	8.03
Central	Utility PV	4.60	7.25
Central	Distributed PV	4.96	7.81
Central	Utility PV-plus-storage	4.65	7.29
Central	Distributed PV-plus-storage	5.02	7.87
Central	Onshore wind	4.14	6.79
Central	Offshore wind	N/A	N/A
Florida	Uniform EE	2.82	4.38
Florida	Peak EE	3.29	5.10
Florida	Utility PV	2.86	4.44
Florida	Distributed PV	3.09	4.80
Florida	Utility PV-plus-storage	2.90	4.50
Florida	Distributed PV-plus-storage	3.13	4.86
Florida	Onshore wind	2.47	3.83
Florida	Offshore wind	N/A	N/A
Mid-Atlantic	Uniform EE	5.26	8.97
Mid-Atlantic	Peak EE	5.95	10.21
Mid-Atlantic	Utility PV	5.23	8.94
Mid-Atlantic	Distributed PV	5.60	9.57
Mid-Atlantic	Utility PV-plus-storage	5.28	9.02
Mid-Atlantic	Distributed PV-plus-storage	5.67	9.68
Mid-Atlantic	Onshore wind	4.73	8.07
Mid-Atlantic	Offshore wind	4.76	8.11

Region	Project Type	BPK, Low (2023 ¢/kWh)	BPK, High (2023 ¢/kWh)
Midwest	Uniform EE	6.27	10.70
Midwest	Peak EE	6.73	11.39
Midwest	Utility PV	5.99	10.18
Midwest	Distributed PV	6.46	10.97
Midwest	Utility PV-plus-storage	5.99	10.17
Midwest	Distributed PV-plus-storage	6.47	10.96
Midwest	Onshore wind	5.75	9.81
Midwest	Offshore wind	N/A	N/A
New England	Uniform EE	1.07	1.81
New England	Peak EE	1.46	2.44
New England	Utility PV	1.07	1.80
New England	Distributed PV	1.13	1.91
New England	Utility PV-plus-storage	1.20	2.01
New England	Distributed PV-plus-storage	1.30	2.18
New England	Onshore wind	0.92	1.56
New England	Offshore wind	0.92	1.56
New York	Uniform EE	4.25	7.91
New York	Peak EE	5.37	9.93
New York	Utility PV	4.28	7.96
New York	Distributed PV	4.56	8.48
New York	Utility PV-plus-storage	4.48	8.34
New York	Distributed PV-plus-storage	4.81	8.95
New York	Onshore wind	3.65	6.79
New York	Offshore wind	3.56	6.62
Northwest	Uniform EE	1.64	2.43
Northwest	Peak EE	1.74	2.56
Northwest	Utility PV	1.40	2.09
Northwest	Distributed PV	1.52	2.27
Northwest	Utility PV-plus-storage	1.44	2.13
Northwest	Distributed PV-plus-storage	1.56	2.32
Northwest	Onshore wind	1.50	2.22
Northwest	Offshore wind	1.52	2.26
Rocky Mountains	Uniform EE	1.80	2.73
Rocky Mountains	Peak EE	1.77	2.66
Rocky Mountains	Utility PV	1.62	2.46
Rocky Mountains	Distributed PV	1.78	2.70
Rocky Mountains	Utility PV-plus-storage	1.62	2.46
Rocky Mountains	Distributed PV-plus-storage	1.78	2.69
Rocky Mountains	Onshore wind	1.66	2.53
Rocky Mountains	Offshore wind	N/A	N/A
Southeast	Uniform EE	3.64	5.00
Southeast	Peak EE	4.59	6.26

Region	Project Type	BPK, Low (2023 ¢/kWh)	BPK, High (2023 ¢/kWh)
Southeast	Utility PV	3.60	4.93
Southeast	Distributed PV	3.88	5.32
Southeast	Utility PV-plus-storage	3.68	5.05
Southeast	Distributed PV-plus-storage	3.99	5.46
Southeast	Onshore wind	2.97	4.10
Southeast	Offshore wind	N/A	N/A
Southwest	Uniform EE	0.88	1.21
Southwest	Peak EE	0.97	1.31
Southwest	Utility PV	0.83	1.14
Southwest	Distributed PV	0.91	1.26
Southwest	Utility PV-plus-storage	0.87	1.20
Southwest	Distributed PV-plus-storage	0.98	1.35
Southwest	Onshore wind	0.77	1.06
Southwest	Offshore wind	N/A	N/A
Tennessee	Uniform EE	3.10	5.42
Tennessee	Peak EE	3.80	6.57
Tennessee	Utility PV	3.20	5.58
Tennessee	Distributed PV	3.41	5.94
Tennessee	Utility PV-plus-storage	3.20	5.57
Tennessee	Distributed PV-plus-storage	3.43	5.95
Tennessee	Onshore wind	2.54	4.45
Tennessee	Offshore wind	N/A	N/A
Texas	Uniform EE	3.13	5.01
Texas	Peak EE	3.56	5.45
Texas	Utility PV	3.09	4.85
Texas	Distributed PV	3.22	5.07
Texas	Utility PV-plus-storage	3.16	4.88
Texas	Distributed PV-plus-storage	3.31	5.10
Texas	Onshore wind	2.89	4.67
Texas	Offshore wind	N/A	N/A

Discussion

The BPK values represent estimates of the monetized annual public health benefits resulting from criteria air pollutant reductions associated with EE/RE/ES$^+$ projects, programs, and policies. There are different values for each combination of region and EE/RE/ES$^+$ intervention type (i.e., onshore and offshore wind, utility and distributed solar, utility and distributed PV-plus-storage, uniform EE, and peak EE). The total benefits from EE/RE/ES$^+$ projects, programs, and policies in any region will include the monetized air quality benefits both within and outside of that region.

Across all resources, regions, and high/low valuations, 2023 data year BPK values in this report are about twice as high as the 2019 data year values of the Second Edition. There are several possible factors driving this change. Foremost, 2023 BPK values now include O_3 health benefits, introduced in COBRA v5.0, in addition to the $PM_{2.5}$ benefits calculated in previous editions. These 2023 BPK values also are based on a 2 percent discount rate instead of the 3 percent and 7 percent discount rates used in the 2019 BPK values. Discounting future benefits less than in past BPK analyses is also expected to drive higher values. A more in-depth discussion on the drivers of differences between the 2023 BPK values and past values can be found in *Appendix F: Comparison Between 2017, 2019, and 2023 BPK Values*.

In 12 of the 14 regions, peak EE resources provide the highest BPK values. In many regions, the fossil fuel generation sources operating during peak periods of the day have higher emission rates than the generation sources operating during other times of the day. Peak EE resources are intended to have the highest impacts during these peak hours, supporting their higher BPK values compared to other resources. Across regions, the resources with the next highest BPK values are typically distributed storage and distributed PV-plus-storage, which also displace generation during these daytime peak hours.

Conversely, in 10 of 14 regions, onshore wind resources provide the lowest BPK values. This is not unexpected, as these resources tend to operate more frequently during non-peak hours that are expected to have lower emission rates.

Comparing average BPK values across regions, regions such as the Midwest, New York, and Mid-Atlantic regions tend to have higher BPK values, while regions in the west—namely the California and Southwest regions—have lower BPK values. This may be caused by several factors, including differing population densities and emission rates across different regions, as well as air dispersion patterns. For example, the California and Southwest regions had lower SO_2, NO_x, and $PM_{2.5}$ emission rates than the Midwest, New York, and Mid-Atlantic regions in 2023, contributing to their lower BPK values.

By generating benefits-per-kWh values for EE/RE/ES$^+$ interventions, EPA hopes to address a gap in the literature and provide air quality–related health BPK values that cover many regions of the United States and key EE/RE/ES$^+$ project, program, and policy types. Such benefits estimates may have several uses. For example, state public utility commissions (PUCs) and state energy offices (SEOs) may use estimates of the monetized public health benefits of EE as an input to portfolio-level cost-benefit analyses or program-specific cost-effectiveness tests. Policymakers or financial institutions could also use these estimates to develop a fuller accounting of the benefits of investments in EE/RE/ES$^+$. Finally, EE/RE/ES$^+$ developers; state, local, and Tribal public health administrators; NGOs; and the general public can use these estimates to quantify the public health benefits of existing or proposed EE/RE/ES$^+$ projects, programs, and policies. Please note that this is not an exhaustive list of uses for BPK values. Furthermore, because the BPK values provide a screening-level estimate, they may not be appropriate for certain analyses, such as federal air quality rulemaking.

In addition, as discussed in the *Limitations* section on page 24, one area of additional research includes developing BPK values for future years. Such values would be based on modeling the electricity sector to estimate emission rates in future years and would allow for the projection of benefits from EE/RE/ES$^+$ projects, programs, and policies in years beyond 2028 (the current limit of the 2023 values).

Conclusions

State, local, and Tribal governments are increasingly interested in quantifying the public health value of emissions reductions from EE/RE/ES$^+$ so that they can fully reflect these benefits in policy decision-making processes. Some studies have quantified the benefits but have used different approaches and assumptions, making it difficult for others to adopt or credibly compare the health benefits estimates on a per-kWh basis.

EPA has developed regional-level BPK values to fill the gap for this type of analysis in the literature. By using the AVERT and COBRA tools, EPA developed regional BPK values for uniform EE, peak EE, wind, solar, and PV-plus-storage projects, programs, and policies, which incorporate the benefits of SO_2, NO_x, $PM_{2.5}$, and VOCs emissions reductions. Although results vary by region, on average, EPA found that EE/RE/ES$^+$ programs delivered public health benefits of 0.68 cents per kWh to 11.39 cents per kWh in the United States in 2023 (using a 2 percent discount rate).

EPA believes that these values may be useful to a wide range of stakeholders seeking to estimate the public health benefits of avoided emissions of $PM_{2.5}$ and other precursor pollutants resulting from EE/RE/ES$^+$ projects, programs, and policies. Stakeholders may include state PUCs, SEOs, policymakers, financial institutions, EE/RE/ES$^+$ developers, state and local public health administrators, NGOs, and the public.

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Appendix A: AVoided Emissions and geneRation Tool (AVERT)

AVERT analyzes changes in fossil fuel–fired electricity generation from solar, wind, and EE programs in 14 unique regions of the contiguous United States (Figure A-1).[31] The AVERT regions take into account the fact that customers' electricity demand is met jointly by generation resources throughout a region, rather than from a single power plant.[32] AVERT provides estimates of changes in NO_x, SO_2, $PM_{2.5}$, and CO_2 emissions at the regional, state, and county levels.

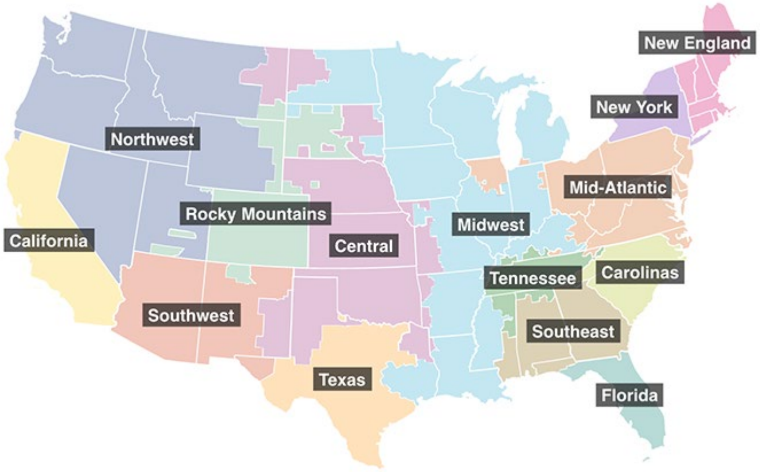

Figure A-1. AVERT Regions.

In AVERT, the impacts on emissions from wind and solar electricity generation are modeled using the annual electricity generation capacity (in MW) of the renewable project. AVERT uses these capacity inputs to estimate the amount of electricity generation (in MWh) the project(s) would produce. Capacities can be entered separately for onshore wind, offshore wind, utility-scale solar, distributed (rooftop) solar, utility-scale energy storage, and distributed energy storage.[33] For the BPK analysis of energy storage resources, EPA uses the PV-plus-storage paired scenario option in AVERT, which assumes that charging for the energy storage resource is limited by the available generation from a paired solar resource.

AVERT uses hourly data reported to EPA's CAPD by EGU. Data are available from 2007 to 2023. These data include gross generation; steam output; heat input; and emissions of SO_2, NO_x, and CO_2. Hourly emissions of $PM_{2.5}$ are calculated using data from the National Emissions Inventory.

AVERT uses hourly data on NO_x, SO_2, and CO_2 emissions to estimate the impact of EE/RE/ES$^+$ projects, programs, and policies on emissions. AVERT uses the hourly generation data to determine the probability of whether a particular unit will be operating in a given hour of the year. The tool also uses hourly emissions data to estimate the emissions from a unit's electricity generation. AVERT provides built-in assumptions about the capacity factors of RE technologies to estimate the annual amount of generation an RE project will produce, and the likely hours in

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[31] Although in some regions solar or hydroelectricity may be on the margin, AVERT assumes they are must-take resources and fossil fuel–fired electricity generators are the only generators affected by increased EE/RE/ES$^+$.

[32] Note that while there are imports and exports of electricity across regions, AVERT does not explicitly model these transfers.

[33] For more information, see the AVERT v4.3 User Manual: https://www.epa.gov/system/files/documents/2024-04/avert-user-manual-v4.3.pdf.

which it will be operating.[34] For example, AVERT uses data from the National Renewable Energy Laboratory to estimate the likely hours of the year a solar project would generate electricity in each region. Users can develop their own site- or region-specific renewable energy load profiles for use in AVERT; however, this study used the built-in capacity factor assumptions. For EE projects, programs, and policies, the hours of the year they reduce electricity demand can be input directly by the user or it can be based on the top hours of demand in each region.

AVERT then determines which fossil fuel units would likely be operating during the hours that the EE/RE/ES$^+$ project, program, or policy is operating or reducing demand to determine the units that would be displaced by the EE/RE/ES$^+$ project, program, or policy. AVERT estimates the emissions reductions that would occur because of that displacement based on the emission rate at each unit. The resulting estimated reductions in generation and emissions are reported at the county, state, and regional levels.

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[34] AVERT reflects regional capacity factors for RE generation based on actual wind projects from AWS Truepower and solar projects modeled in the National Renewable Energy Laboratory's PV Watts tool, reflecting the availability of sun and wind resources in each region. See Appendix C of AVERT's user manual for details.

Appendix B: CO-Benefits Risk Assessment (COBRA) Health Impacts Screening and Mapping Tool

COBRA v5.1 includes preloaded projected emissions baselines for 2016, 2023, and 2028, which were estimated using data from EPA's 2016 Version 1 Air Emissions Modeling Platform (2016 v1 platform). Emissions from the electric generating sector in the 2016 v1 platform are projections of emissions in 2016, 2023, and 2028 from the Integrated Planning Model Power Sector Modeling Platform (version 6). The air emissions modeling platform also contains emissions projections from other sources besides EGUs, such as nonpoint sources, mobile sources, fires, and other point sources. EPA has used the emissions modeling platform for several recent air pollution rules, including the Final 2015 NAAQS for O_3, the 2011 National Air Toxics Assessment, and the proposed update to the Cross-State Air Pollution Rule (CSAPR). The 2016, 2023, and 2028 emissions baselines contain emissions projections that reflect federal and state measures (promulgated or under reconsideration) as of May 2018, including:

- CSAPR,
- Mercury and Air Toxics Standards (MATS),
- Standards of Performance for Greenhouse Gas Emissions from New, Modified, and Reconstructed Sources,
- Mobile emissions (reflecting changes in activity data, the impacts of the Tier 3 Motor Vehicle Emission and Fuel Standards Rule, and the impacts of local inspection and maintenance programs), and
- Base year–specific fire data for 2016.

The assumptions underlying the emissions inventories are detailed in the Technical Support Document: Preparation of Emissions Inventories for the 2016 Version 1 Emissions Modeling Platform (EPA, 2021).

COBRA also uses a reduced-form S-R Matrix air quality model, Pattern Constructed Air Pollution Surfaces (PCAPS), to estimate how changes in air pollution emissions impact ambient air quality (Baker et al., 2023). The S-R Matrix is based on the CAMx and consists of fixed-transfer coefficients that reflect the relationships between emissions at source counties and ambient air pollution concentrations at receptor locations.

COBRA accounts for the formation of secondary $PM_{2.5}$ from NO_x and SO_2 emissions through atmospheric chemistry and air pollution transport.[35, 36] COBRA v5.1 now also estimates the formation of other pollutants such as O_3. Once COBRA estimates the changes in these pollutant concentrations at the county level, it then uses C-R functions to determine the change in public health impacts from a change in ambient air quality. COBRA uses three separate air dispersion coefficient matrices for $PM_{2.5}$: directly emitted (primary) PM, the PM nitrate ion, and the PM sulfate ion. For O_3 precursors, there are two separate air dispersion coefficients: NO_x and VOCs.

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[35] The ambient pollution in a given area is a result of local and upwind pollutant emissions. Winds can transport pollutants across state and regional boundaries, so emissions reductions in one region often affect air quality and human health in downwind regions.

[36] For more information about the S-R Matrix used by COBRA, see the User's Manual for the COBRA Health Impact Screening and Mapping Tool, Appendix A (https://www.epa.gov/statelocalenergy/users-manual-co-benefits-risk-assessment-cobra-screening-model).

The C-R functions embedded in COBRA are taken from epidemiological studies and are consistent with the methods used by EPA to estimate the health impacts of air pollution rules, including MATS.[37] The output of these functions is the number of avoided premature deaths, heart attacks, hospital admissions for respiratory and cardiovascular-related illnesses, incidences of acute bronchitis, upper and lower respiratory symptoms, asthma exacerbations or emergency room visits, minor restricted activity days, and illness-related work loss days.

Finally, COBRA applies estimates of the value of avoiding public health impacts to determine the monetary benefits associated with reductions in air pollution. Values used in COBRA were used in recent EPA RIAs, including analyses for the rule mentioned above. They were derived using a variety of methods that estimate how much people are willing to pay to reduce the risk of a health incident or the cost of illness (COI), which includes direct medical costs and opportunity costs.[38] The value of avoiding premature adult mortality, also known as the value of a statistical life (VSL), is generally responsible for more than 95 percent of the monetized benefits of emissions reductions. The VSL used in COBRA to estimate the value of avoided adult mortality is approximately $14 million (in 2023 U.S. dollars). This VSL value, based on 26 published studies, is identical to the values EPA uses in RIAs of air pollution rules. The value of other health impacts, such as non-fatal heart attacks, hospitalizations, and asthma exacerbations, are smaller and based on the COI. For example, the value of non-fatal heart attacks is estimated at $59,157, and the value of hospital admissions ranges between $16,001 and $60,286 per incident.

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[37] For a complete list of recent RIAs of EPA air pollution rules, see https://www.epa.gov/economic-and-cost-analysis-air-pollution-regulations/regulatory-impact-analyses-air-pollution. Many of these analyses use a BPT approach, developed by EPA (Fann et al. 2012). COBRA uses most of the same C-R functions as those used in the BPT approach. For a list and description of the epidemiological studies COBRA uses to estimate adverse health effects, see the User's Manual for the COBRA Health Impact Screening and Mapping Tool, Appendix C (https://www.epa.gov/statelocalenergy/users-manual-co-benefits-risk-assessment-cobra-screening-model).

[38] For more information about the economic values COBRA uses to estimate the economic value of avoiding adverse health effects and how they were derived, see the User's Manual for the COBRA Health Impact Screening and Mapping Tool, Appendix F (https://www.epa.gov/statelocalenergy/users-manual-co-benefits-risk-assessment-cobra-screening-model).

Appendix C: Sensitivity Analyses on Project, Program, or Policy Size and Peak Energy-Efficiency Definition

For the 2023 analysis, EPA updated the methods it used to define the EE/RE/ES$^+$ projects, programs, and policies studied and the definition of peak EE. While EPA did not conduct a sensitivity analysis for these 2023 values, insights obtained from prior sensitivity analyses are still applicable.

EPA conducted sensitivity analyses using AVERT and COBRA to determine the extent to which modeling scenario assumptions might impact the BPK results. EPA analyzed two different types of potential sensitivity: the size of the EE/RE/ES$^+$ project, program, or policy studied; and the definition of peak EE. EPA conducted this sensitivity analysis for the original 2017 BPK values. The sensitivity analysis was not updated for the 2019 or 2023 values.

Sensitivity Analysis on Project, Program, or Policy Size Assumptions

EPA examined the potential sensitivity of the BPK values to assumptions about project size by modeling BPK values for five different project sizes: from 100 to 2,000 MW of added capacity for the wind and utility solar modeling options in AVERT, and from 100 to 2,000 GWh of displaced generation for the EE modeling options.

The results of these model runs illustrate that there is a strong linear relationship between project size and emissions reductions ($R^2 = 0.9996$–1.0, Figure C-1). The results from AVERT were then input in COBRA to assess the sensitivity of emissions reductions on health impacts. These results also show that there is a strong linear relationship between the amount of emissions reductions and health impacts (Figure C-2).

The results of this sensitivity analysis indicate that project size does not have a large impact on the marginal BPK results (i.e., a larger project does not generate disproportionately larger marginal benefits or have a higher BPK result than a smaller project). The resulting BPK values from these model runs are consistent across different project sizes; for each region and project, program, or policy type modeled, the results are within 0.1 cent per kWh (Table C-1). As a result, this analysis presents BPK values modeled using only a single assumption about project size. While EPA did not conduct a sensitivity analysis on the new 2023 project sizes, all projects fall within the 60 to 1,500 MW range. EPA anticipates similar linear relationships between project size and emissions and between project size and marginal BPK results.

However, an extremely large EE/RE/ES$^+$ project, program, or policy could displace more than the marginal EGUs and extend into the baseload units, which may have different emissions profiles. See the *Limitations* section on page 24 of this report for more information about the limitations on project size for which the BPK values should be used.

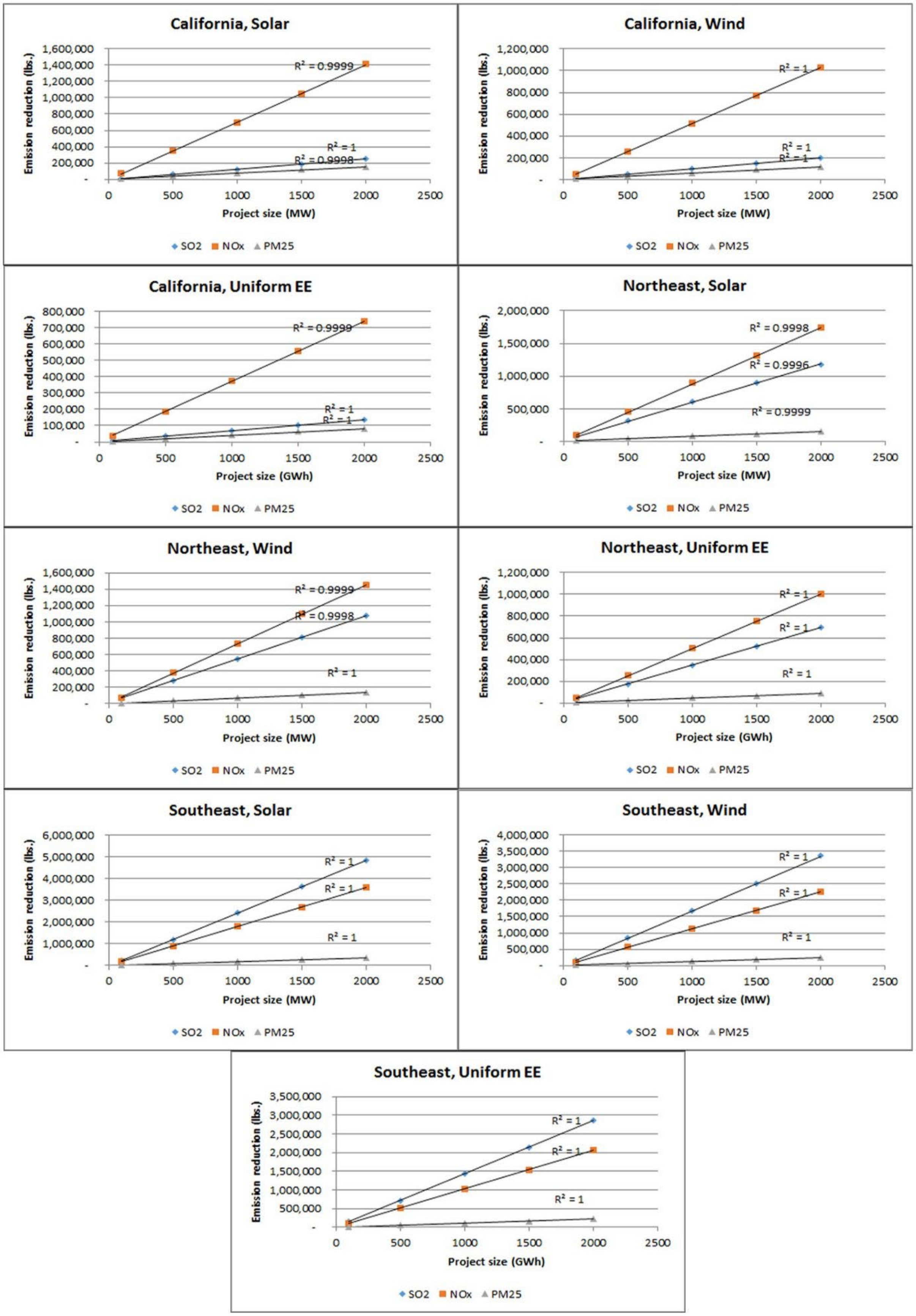

Figure C-1. AVERT Sensitivity Analysis for Project, Program, or Policy Size.

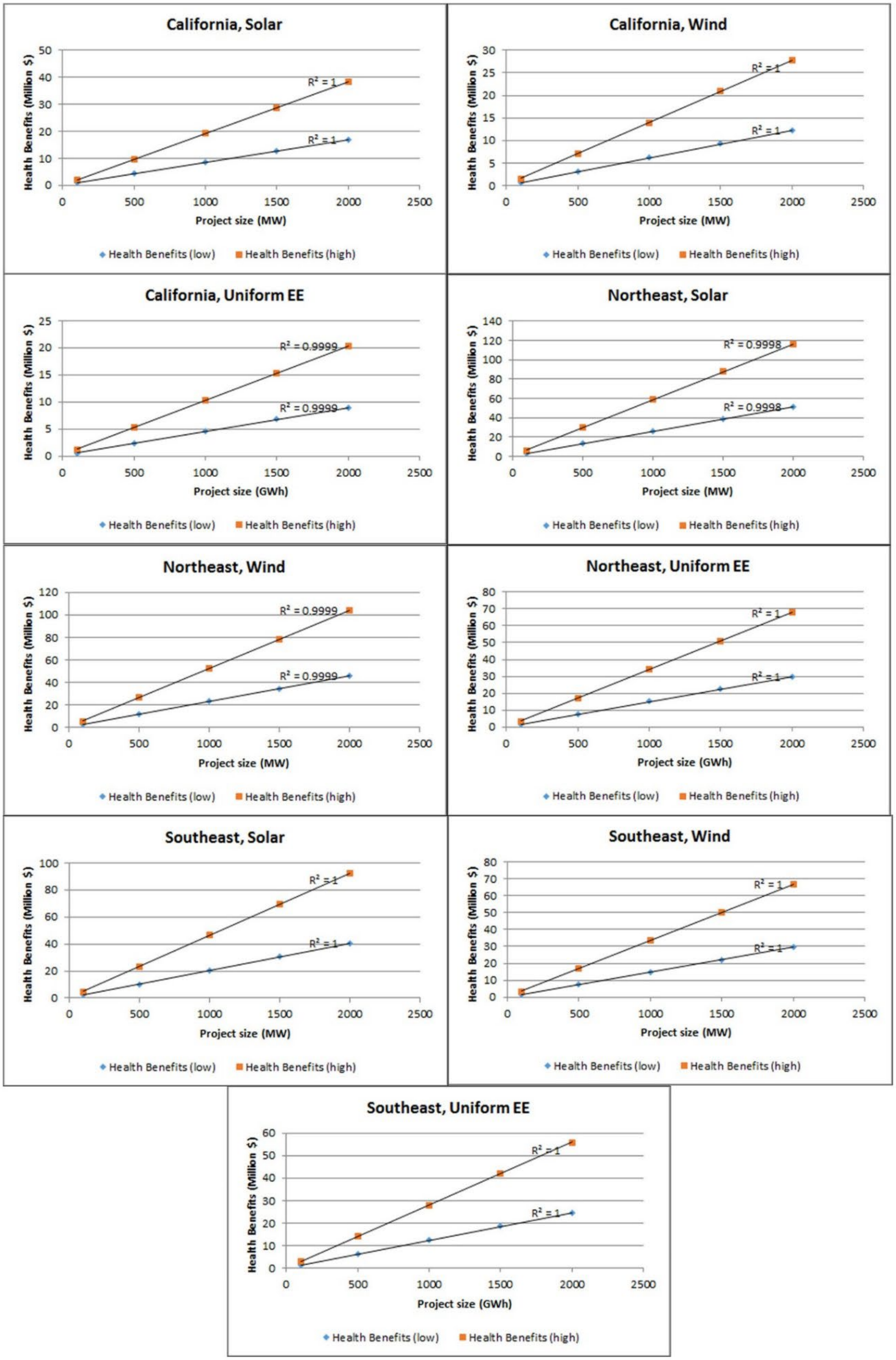

Figure C-2. COBRA Sensitivity Analysis for Project Size.

Table C-1. Results from 2017 Sensitivity Analysis on Project, Program, or Policy Size.

Region	Project Type	Capacity (MW/GWh)	Displaced Generation (MWh)	SO_2 Emissions Reduction from AVERT (tons)	NO_x Emissions Reduction from AVERT (tons)	$PM_{2.5}$ Emissions Reduction from AVERT (tons)	Health Benefits from COBRA, Low Estimate (Million USD)	Health Benefits from COBRA, High Estimate (Million USD)	Benefits per kWh, Low Estimate (¢/kWh)	Benefits per kWh, High Estimate (¢/kWh)
Southeast	Wind	100	120,370	84	56	6	1.67	3.77	1.4	3.1
Southeast	Wind	500	602,150	418	281	30	8.33	18.86	1.4	3.1
Southeast	Wind	1,000	1,204,500	837	562	60	16.60	37.58	1.4	3.1
Southeast	Wind	1,500	1,806,580	1,256	842	91	24.85	56.25	1.4	3.1
Southeast	Wind	2,000	2,408,940	1,676	1,124	121	33.06	74.83	1.4	3.1
Southeast	Solar	100	169,440	121	90	9	2.33	5.28	1.4	3.1
Southeast	Solar	500	847,250	601	449	46	11.52	26.08	1.4	3.1
Southeast	Solar	1,000	1,694,380	1,205	897	92	22.96	51.98	1.4	3.1
Southeast	Solar	1,500	2,541,750	1,807	1,342	137	34.27	77.57	1.3	3.1
Southeast	Solar	2,000	3,388,780	2,408	1,788	183	45.52	103.04	1.3	3.0
Southeast	Uniform EE	100	104,950	72	51	5	1.40	3.17	1.3	3.0
Southeast	Uniform EE	500	524,940	359	257	27	6.99	15.81	1.3	3.0
Southeast	Uniform EE	1,000	1,049,980	716	514	54	13.90	31.47	1.3	3.0
Southeast	Uniform EE	1,500	1,575,040	1,073	771	82	20.79	47.06	1.3	3.0
Southeast	Uniform EE	2,000	2,099,990	1,432	1,027	109	27.64	62.57	1.3	3.0
California	Wind	100	152,050	5	26	3	0.75	1.69	0.5	1.1
California	Wind	500	761,630	25	129	15	3.55	8.02	0.5	1.1
California	Wind	1,000	1,522,830	50	257	30	6.93	15.67	0.5	1.0
California	Wind	1,500	2,284,090	75	386	45	10.35	23.39	0.5	1.0
California	Wind	2,000	3,044,890	99	514	60	13.75	31.09	0.5	1.0
California	Solar	100	194,640	6	36	4	1.04	2.34	0.5	1.2
California	Solar	500	971,730	31	174	19	4.84	10.94	0.5	1.1
California	Solar	1,000	1,945,550	62	346	39	9.51	21.50	0.5	1.1
California	Solar	1,500	2,923,700	93	523	59	14.26	32.22	0.5	1.1
California	Solar	2,000	3,899,550	126	704	79	18.98	42.93	0.5	1.1
California	Uniform EE	100	104,510	3	19	2	0.56	1.27	0.5	1.2
California	Uniform EE	500	522,680	17	94	10	2.65	5.99	0.5	1.1
California	Uniform EE	1,000	1,045,830	34	187	21	5.13	11.59	0.5	1.1
California	Uniform EE	1,500	1,568,940	51	279	31	7.59	17.16	0.5	1.1
California	Uniform EE	2,000	2,091,230	68	369	41	10.02	22.66	0.5	1.1

Region	Project Type	Capacity (MW/GWh)	Displaced Generation (MWh)	SO_2 Emissions Reduction from AVERT (tons)	NO_x Emissions Reduction from AVERT (tons)	$PM_{2.5}$ Emissions Reduction from AVERT (tons)	Health Benefits from COBRA, Low Estimate (Million USD)	Health Benefits from COBRA, High Estimate (Million USD)	Benefits per kWh, Low Estimate (¢/kWh)	Benefits per kWh, High Estimate (¢/kWh)
Northeast	Wind	100	174,470	29	37	3	2.72	6.14	1.6	3.5
Northeast	Wind	500	873,200	141	187	17	13.37	30.20	1.5	3.5
Northeast	Wind	1,000	1,748,100	275	369	35	26.24	59.26	1.5	3.4
Northeast	Wind	1,500	2,620,800	407	549	52	38.81	87.64	1.5	3.3
Northeast	Wind	2,000	3,495,010	537	727	69	51.37	116.02	1.5	3.3
Northeast	Solar	100	157,170	32	46	4	3.01	6.72	1.9	4.3
Northeast	Solar	500	787,140	157	227	19	14.83	33.50	1.9	4.3
Northeast	Solar	1,000	1,573,340	306	448	39	29.42	66.45	1.9	4.2
Northeast	Solar	1,500	2,361,630	449	660	58	43.65	98.56	1.8	4.2
Northeast	Solar	2,000	3,146,030	590	869	77	57.51	129.88	1.8	4.1
Northeast	Uniform EE	100	104,880	18	25	2	1.72	3.91	1.6	3.7
Northeast	Uniform EE	500	524,150	88	126	11	8.57	19.36	1.6	3.7
Northeast	Uniform EE	1,000	1,048,680	175	252	23	16.99	38.36	1.6	3.7
Northeast	Uniform EE	1,500	1,573,550	262	377	34	25.31	57.15	1.6	3.6
Northeast	Uniform EE	2,000	2,098,790	347	501	45	33.58	75.85	1.6	3.6

Appendix D: Top 200 Hours of Demand 2017 Benefit-per-kWh Results

Table D-1 includes the complete modeling results from AVERT and COBRA used to calculate the 2017 BPK values for the top 200 hours of demand analysis in each region.

EPA conducted this sensitivity analysis for the original 2017 BPK values. The sensitivity analysis was not updated for the 2019 or 2023 values.

Table D-1. Complete 2017 AVERT and COBRA Results for Top 200 Hours of Demand Analysis (3% and 7% Discount Rates; 2017 USD).

Region	Discount Rate	Displaced Generation from AVERT (MWh)	SO_2 Reduction from AVERT (lb)	NO_x Reduction from AVERT (lb)	$PM_{2.5}$ Reduction from AVERT (lb)	SO_2 Emission Rate (lb/MWh)	NO_x Emission Rate (lb/MWh)	$PM_{2.5}$ Emission Rate (lb/MWh)	$ Total Public Health Benefits from COBRA (Low)	$ Total Public Health Benefits from COBRA (High)	¢/kWh (Low)	¢/kWh (High)
California	3	200,230	3,680	33,130	9,530	0.01838	0.16546	0.04760	1,868,183.33	4,221,243.69	0.93	2.11
Great Lakes/Mid-Atlantic	3	205,510	217,960	233,420	35,760	1.06058	1.13581	0.17401	7,353,520.30	16,631,254.33	3.58	8.09
Lower Midwest	3	203,670	3,080	373,040	16,210	0.01512	1.83159	0.07959	1,679,175.59	3,798,562.75	0.82	1.87
Northeast	3	197,440	171,450	210,820	15,640	0.86837	1.06777	0.07921	9,242,207.78	20,874,650.58	4.68	10.57
Pacific Northwest	3	202,330	173,090	228,080	18,200	0.85548	1.12727	0.08995	2,198,711.54	4,972,898.14	1.09	2.46
Rocky Mountains	3	195,720	63,550	226,500	11,870	0.32470	1.15727	0.06065	1,602,727.29	3,625,354.74	0.82	1.85
Southeast	3	201,440	152,400	248,990	24,350	0.75655	1.23605	0.12088	4,045,381.73	9,155,691.94	2.01	4.55
Southwest	3	193,640	7,450	265,600	13,160	0.03847	1.37162	0.06796	1,398,221.15	3,163,872.51	0.72	1.63
Texas	3	197,530	59,330	261,410	13,400	0.30036	1.32339	0.06784	2,243,773.58	5,075,140.16	1.14	2.57
Upper Midwest	3	205,770	133,580	256,210	20,200	0.64917	1.24513	0.09817	3,150,193.28	7,124,723.56	1.53	3.46
California	7	200,230	3,680	33,130	9,530	0.01838	0.16546	0.04760	1,667,429.97	3,765,217.37	0.83	1.88
Great Lakes/Mid-Atlantic	7	205,510	217,960	233,420	35,760	1.06058	1.13581	0.17401	6,561,493.57	14,833,891.17	3.19	7.22
Lower Midwest	7	203,670	3,080	373,040	16,210	0.01512	1.83159	0.07959	1,498,471.30	3,388,096.40	0.74	1.66
Northeast	7	197,440	171,450	210,820	15,640	0.86837	1.06777	0.07921	8,248,584.90	18,620,340.06	4.18	9.43
Pacific Northwest	7	202,330	173,090	228,080	18,200	0.85548	1.12727	0.08995	1,962,089.91	4,435,443.96	0.97	2.19
Rocky Mountains	7	195,720	63,550	226,500	11,870	0.32470	1.15727	0.06065	1,430,318.98	3,233,616.56	0.73	1.65
Southeast	7	201,440	152,400	248,990	24,350	0.75655	1.23605	0.12088	3,609,761.12	8,166,235.14	1.79	4.05
Southwest	7	193,640	7,450	265,600	13,160	0.03847	1.37162	0.06796	1,247,815.35	2,821,961.89	0.64	1.46
Texas	7	197,530	59,330	261,410	13,400	0.30036	1.32339	0.06784	2,002,718.23	4,527,067.37	1.01	2.29
Upper Midwest	7	205,770	133,580	256,210	20,200	0.64917	1.24513	0.09817	2,811,049.78	6,354,838.97	1.37	3.09

Appendix E: Detailed Benefits-per-kWh Results

Table E-1 includes the complete modeling results from AVERT and COBRA used to calculate the BPK values for each region and technology type.

Table E-1. Complete AVERT and COBRA Results for 2023 (2% Discount Rate).

Region	Project Type	Intervention Generation (MWh)	SO_2 Reduced (lb) from AVERT	NO_x Reduced (lb) from AVERT	$PM_{2.5}$ Reduced (lb) from AVERT	VOCs Reduced (lb) from AVERT	NH_3 Reduced (lb) from AVERT	SO_2 Avoided Emission Rate (lb per MWh)	NO_x Avoided Emission Rate (lb per MWh)	$PM_{2.5}$ Avoided Emission Rate (lb per MWh)	VOCs Avoided Emission Rate (lb per MWh)	NH_3 Avoided Emission Rate (lb per MWh)	Total Health Benefits from COBRA, Low (2023$)	Total Health Benefits from COBRA, High (2023$)	BPK, Low (2023 ¢ per kWh)	BPK, High (2023 ¢ per kWh)
California	Uniform EE	407,831	9,990	60,630	16,600	6,110	13,520	0.02	0.15	0.04	0.01	0.03	3,049,560	5,129,855	0.75	1.26
California	Peak EE	407,831	12,610	72,840	18,650	6,850	14,990	0.03	0.18	0.05	0.02	0.04	3,451,756	5,776,781	0.85	1.42
California	Utility PV	408,348	7,520	53,070	14,700	5,510	12,130	0.02	0.13	0.04	0.01	0.03	2,802,661	4,693,079	0.69	1.15
California	Distributed PV	408,275	8,120	58,380	16,000	5,980	13,140	0.02	0.14	0.04	0.01	0.03	3,057,972	5,111,307	0.75	1.25
California	Utility PV-plus-storage	408,531	8,450	58,930	15,660	5,880	12,930	0.02	0.14	0.04	0.01	0.03	3,031,284	5,057,573	0.74	1.24
California	Distributed PV-plus-storage	408,659	9,360	66,180	17,310	6,500	14,240	0.02	0.16	0.04	0.02	0.03	3,372,927	5,614,495	0.83	1.37
California	Onshore wind	407,673	9,420	55,940	15,160	5,560	12,270	0.02	0.14	0.04	0.01	0.03	2,761,065	4,644,613	0.68	1.14
California	Offshore wind	408,225	8,810	54,960	15,110	5,600	12,400	0.02	0.13	0.04	0.01	0.03	2,810,274	4,721,280	0.69	1.16
Carolinas	Uniform EE	484,898	253,450	325,570	55,560	17,300	19,050	0.52	0.67	0.11	0.04	0.04	24,855,824	38,962,884	5.13	8.04
Carolinas	Peak EE	484,898	288,260	379,600	66,130	25,680	23,380	0.59	0.78	0.14	0.05	0.05	29,031,880	45,603,949	5.99	9.40
Carolinas	Utility PV	485,700	223,170	286,920	51,310	16,670	17,910	0.46	0.59	0.11	0.03	0.04	22,086,506	34,715,538	4.55	7.15
Carolinas	Distributed PV	485,633	237,640	304,810	55,040	17,780	19,200	0.49	0.63	0.11	0.04	0.04	23,526,455	37,008,527	4.84	7.62
Carolinas	Utility PV-plus-storage	487,265	219,000	282,180	53,060	18,500	18,920	0.45	0.58	0.11	0.04	0.04	21,971,013	34,683,132	4.51	7.12
Carolinas	Distributed PV-plus-storage	488,085	232,020	298,730	57,330	20,160	20,520	0.48	0.61	0.12	0.04	0.04	23,369,524	36,951,944	4.79	7.57
Carolinas	Onshore wind	485,018	234,300	297,040	50,210	15,020	17,270	0.48	0.61	0.10	0.03	0.04	22,609,710	35,411,512	4.66	7.30
Carolinas	Offshore wind	484,500	232,350	296,110	50,660	15,510	17,370	0.48	0.61	0.10	0.03	0.04	22,599,325	35,417,434	4.66	7.31
Central	Uniform EE	724,746	1,005,880	886,170	46,530	21,240	22,470	1.39	1.22	0.06	0.03	0.03	33,545,786	54,279,450	4.63	7.49
Central	Peak EE	724,746	920,500	1,058,050	50,000	23,020	28,050	1.27	1.46	0.07	0.03	0.04	37,377,505	58,223,803	5.16	8.03

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Central	Utility PV	725,222	877,220	920,160	44,920	20,660	24,180	1.21	1.27	0.06	0.03	0.03	33,365,614	52,593,499	4.60	7.25
Central	Distributed PV	725,077	944,060	992,410	48,390	22,260	26,090	1.30	1.37	0.07	0.03	0.04	35,956,432	56,653,980	4.96	7.81
Central	Utility PV-plus-storage	725,467	863,150	939,630	45,380	20,880	24,870	1.19	1.30	0.06	0.03	0.03	33,711,503	52,918,442	4.65	7.29
Central	Distributed PV-plus-storage	725,678	925,490	1,018,270	49,020	22,540	27,000	1.28	1.40	0.07	0.03	0.04	36,421,098	57,094,405	5.02	7.87
Central	Onshore wind	724,617	960,600	772,170	42,210	19,160	19,170	1.33	1.07	0.06	0.03	0.03	29,981,523	49,214,721	4.14	6.79
Central	Offshore wind	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Florida	Uniform EE	946,204	157,730	299,870	59,870	12,890	25,280	0.17	0.32	0.06	0.01	0.03	26,682,645	41,471,629	2.82	4.38
Florida	Peak EE	946,204	203,300	351,430	64,510	15,600	32,410	0.21	0.37	0.07	0.02	0.03	31,101,477	48,285,135	3.29	5.10
Florida	Utility PV	946,769	169,310	304,360	57,890	12,940	25,710	0.18	0.32	0.06	0.01	0.03	27,071,544	42,019,792	2.86	4.44
Florida	Distributed PV	946,770	183,930	328,460	62,530	14,000	27,720	0.19	0.35	0.07	0.01	0.03	29,254,531	45,425,860	3.09	4.80
Florida	Utility PV-plus-storage	947,340	172,930	309,870	58,330	13,590	27,530	0.18	0.33	0.06	0.01	0.03	27,478,419	42,633,794	2.90	4.50
Florida	Distributed PV-plus-storage	947,922	187,610	335,130	63,050	14,830	30,020	0.20	0.35	0.07	0.02	0.03	29,714,280	46,110,118	3.13	4.86
Florida	Onshore wind	946,880	130,230	263,460	53,790	11,360	21,990	0.14	0.28	0.06	0.01	0.02	23,369,811	36,285,232	2.47	3.83
Florida	Offshore wind	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mid-Atlantic	Uniform EE	2,337,883	1,343,250	1,179,840	196,780	48,890	64,070	0.57	0.50	0.08	0.02	0.03	123,074,424	209,734,707	5.26	8.97
Mid-Atlantic	Peak EE	2,337,883	1,489,290	1,316,190	228,470	53,950	71,580	0.64	0.56	0.10	0.02	0.03	138,990,074	238,687,918	5.95	10.21
Mid-Atlantic	Utility PV	2,341,272	1,311,160	1,160,530	195,630	47,480	63,570	0.56	0.50	0.08	0.02	0.03	122,359,549	209,221,763	5.23	8.94
Mid-Atlantic	Distributed PV	2,340,899	1,398,560	1,247,430	209,240	50,750	68,640	0.60	0.53	0.09	0.02	0.03	131,174,160	224,043,334	5.60	9.57
Mid-Atlantic	Utility PV-plus-storage	2,344,018	1,323,270	1,174,440	197,240	48,060	64,990	0.56	0.50	0.08	0.02	0.03	123,679,843	211,458,186	5.28	9.02
Mid-Atlantic	Distributed PV-plus-storage	2,346,327	1,414,120	1,264,640	211,540	51,590	70,650	0.60	0.54	0.09	0.02	0.03	132,944,570	227,061,180	5.67	9.68

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Mid-Atlantic	Onshore wind	2,337,141	1,203,410	1,054,770	172,570	43,590	56,390	0.51	0.45	0.07	0.02	0.02	110,498,692	188,501,922	4.73	8.07
Mid-Atlantic	Offshore wind	2,335,432	1,207,360	1,067,600	173,340	43,440	56,060	0.52	0.46	0.07	0.02	0.02	111,188,093	189,418,781	4.76	8.11
Midwest	Uniform EE	2,331,454	2,696,780	2,190,090	246,210	67,010	78,370	1.16	0.94	0.11	0.03	0.03	146,217,944	249,361,321	6.27	10.70
Midwest	Peak EE	2,331,454	2,678,790	2,390,340	284,790	76,040	91,260	1.15	1.03	0.12	0.03	0.04	156,802,361	265,571,341	6.73	11.39
Midwest	Utility PV	2,334,339	2,460,610	2,116,220	251,590	66,850	80,340	1.05	0.91	0.11	0.03	0.03	139,895,276	237,718,112	5.99	10.18
Midwest	Distributed PV	2,333,965	2,645,650	2,287,580	271,110	71,770	86,700	1.13	0.98	0.12	0.03	0.04	150,781,906	256,023,889	6.46	10.97
Midwest	Utility PV-plus-storage	2,336,147	2,442,480	2,128,490	250,230	67,130	82,330	1.05	0.91	0.11	0.03	0.04	140,026,104	237,512,322	5.99	10.17
Midwest	Distributed PV-plus-storage	2,338,235	2,625,780	2,307,480	269,790	72,210	89,270	1.12	0.99	0.12	0.03	0.04	151,261,066	256,278,403	6.47	10.96
Midwest	Onshore wind	2,331,643	2,508,750	2,003,120	218,930	59,910	69,210	1.08	0.86	0.09	0.03	0.03	134,093,088	228,839,836	5.75	9.81
Midwest	Offshore wind	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
New England	Uniform EE	245,459	17,530	44,250	8,720	3,120	4,450	0.07	0.18	0.04	0.01	0.02	2,628,848	4,431,818	1.07	1.81
New England	Peak EE	245,459	30,000	62,770	10,760	3,920	5,050	0.12	0.26	0.04	0.02	0.02	3,587,564	5,980,772	1.46	2.44
New England	Utility PV	245,667	19,100	45,600	8,530	3,090	4,270	0.08	0.19	0.03	0.01	0.02	2,633,760	4,423,484	1.07	1.80
New England	Distributed PV	245,622	19,970	47,920	9,090	3,290	4,560	0.08	0.20	0.04	0.01	0.02	2,787,282	4,688,036	1.13	1.91
New England	Utility PV-plus-storage	245,883	24,830	51,950	9,030	3,260	4,420	0.10	0.21	0.04	0.01	0.02	2,943,046	4,935,459	1.20	2.01
New England	Distributed PV-plus-storage	246,022	27,540	56,480	9,770	3,520	4,770	0.11	0.23	0.04	0.01	0.02	3,201,077	5,370,845	1.30	2.18
New England	Onshore wind	245,281	13,720	37,290	7,680	2,720	4,020	0.06	0.15	0.03	0.01	0.02	2,258,632	3,816,196	0.92	1.56
New England	Offshore wind	245,134	14,160	37,340	7,700	2,730	4,030	0.06	0.15	0.03	0.01	0.02	2,265,566	3,833,227	0.92	1.56
New York	Uniform EE	317,555	25,400	104,170	32,660	18,690	18,960	0.08	0.33	0.10	0.06	0.06	13,481,079	25,121,472	4.25	7.91
New York	Peak EE	317,555	40,110	142,120	38,740	20,990	22,380	0.13	0.45	0.12	0.07	0.07	17,046,556	31,527,464	5.37	9.93
New York	Utility PV	317,973	25,470	107,810	32,490	18,470	19,050	0.08	0.34	0.10	0.06	0.06	13,604,078	25,295,440	4.28	7.96

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New York	Distributed PV	317,904	27,100	114,240	34,680	19,720	20,270	0.09	0.36	0.11	0.06	0.06	14,481,635	26,947,724	4.56	8.48
New York	Utility PV-plus-storage	319,378	28,850	113,940	33,490	18,910	19,710	0.09	0.36	0.10	0.06	0.06	14,316,598	26,631,685	4.48	8.34
New York	Distributed PV-plus-storage	320,033	31,290	121,990	36,020	20,330	21,130	0.10	0.38	0.11	0.06	0.07	15,385,631	28,643,464	4.81	8.95
New York	Onshore wind	317,194	22,580	90,170	28,970	16,680	16,700	0.07	0.28	0.09	0.05	0.05	11,577,612	21,534,241	3.65	6.79
New York	Offshore wind	317,115	22,410	87,500	28,450	16,370	16,340	0.07	0.28	0.09	0.05	0.05	11,285,979	20,998,577	3.56	6.62
Northwest	Uniform EE	599,156	317,670	572,510	54,730	19,250	12,650	0.53	0.96	0.09	0.03	0.02	9,798,609	14,535,943	1.64	2.43
Northwest	Peak EE	599,156	330,450	608,330	55,370	20,220	13,180	0.55	1.02	0.09	0.03	0.02	10,437,152	15,359,463	1.74	2.56
Northwest	Utility PV	599,703	267,050	493,030	50,080	16,960	11,790	0.45	0.82	0.08	0.03	0.02	8,394,840	12,533,564	1.40	2.09
Northwest	Distributed PV	599,567	288,120	534,210	54,990	18,460	12,820	0.48	0.89	0.09	0.03	0.02	9,088,676	13,587,987	1.52	2.27
Northwest	Utility PV-plus-storage	600,369	268,750	508,970	50,550	17,360	12,170	0.45	0.85	0.08	0.03	0.02	8,616,238	12,796,809	1.44	2.13
Northwest	Distributed PV-plus-storage	601,096	291,250	557,080	55,620	19,000	13,360	0.48	0.93	0.09	0.03	0.02	9,401,649	13,960,861	1.56	2.32
Northwest	Onshore wind	598,944	293,410	522,680	50,030	17,570	11,420	0.49	0.87	0.08	0.03	0.02	8,971,451	13,323,939	1.50	2.22
Northwest	Offshore wind	598,396	299,190	533,380	50,270	17,980	11,620	0.50	0.89	0.08	0.03	0.02	9,125,507	13,523,125	1.52	2.26
Rocky Mountains	Uniform EE	256,971	152,660	230,940	15,010	7,130	8,730	0.59	0.90	0.06	0.03	0.03	4,625,653	7,019,225	1.80	2.73
Rocky Mountains	Peak EE	256,971	143,040	228,950	15,200	7,140	9,770	0.56	0.89	0.06	0.03	0.04	4,537,712	6,834,923	1.77	2.66
Rocky Mountains	Utility PV	257,122	135,820	209,120	13,950	6,540	7,960	0.53	0.81	0.05	0.03	0.03	4,176,468	6,329,727	1.62	2.46
Rocky Mountains	Distributed PV	257,059	149,020	229,060	15,270	7,160	8,690	0.58	0.89	0.06	0.03	0.03	4,575,679	6,936,995	1.78	2.70
Rocky Mountains	Utility PV-plus-storage	257,256	135,700	208,600	14,050	6,500	8,150	0.53	0.81	0.05	0.03	0.03	4,171,095	6,321,633	1.62	2.46
Rocky Mountains	Distributed PV-plus-storage	257,359	148,770	228,420	15,450	7,130	8,990	0.58	0.89	0.06	0.03	0.03	4,570,084	6,928,087	1.78	2.69
Rocky Mountains	Onshore wind	256,775	142,970	212,390	13,630	6,530	7,860	0.56	0.83	0.05	0.03	0.03	4,267,758	6,486,884	1.66	2.53

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Rocky Mountains	Offshore wind	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Southeast	Uniform EE	860,659	127,700	569,230	44,000	24,190	27,380	0.15	0.66	0.05	0.03	0.03	31,335,526	43,065,860	3.64	5.00
Southeast	Peak EE	860,659	161,250	725,750	50,980	27,450	33,310	0.19	0.84	0.06	0.03	0.04	39,484,457	53,892,910	4.59	6.26
Southeast	Utility PV	862,475	121,070	565,870	43,780	23,870	27,310	0.14	0.66	0.05	0.03	0.03	31,035,349	42,527,971	3.60	4.93
Southeast	Distributed PV	862,339	129,180	610,060	47,400	25,750	29,620	0.15	0.71	0.05	0.03	0.03	33,483,438	45,866,433	3.88	5.32
Southeast	Utility PV-plus-storage	863,933	125,120	578,290	44,230	24,070	28,340	0.14	0.67	0.05	0.03	0.03	31,806,201	43,586,708	3.68	5.05
Southeast	Distributed PV-plus-storage	864,654	134,150	626,400	47,960	26,000	30,980	0.16	0.72	0.06	0.03	0.04	34,487,325	47,237,100	3.99	5.46
Southeast	Onshore wind	860,165	101,540	460,600	37,130	20,470	23,040	0.12	0.54	0.04	0.02	0.03	25,572,817	35,233,926	2.97	4.10
Southeast	Offshore wind	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Southwest	Uniform EE	416,174	95,740	210,460	31,150	10,960	13,100	0.23	0.51	0.07	0.03	0.03	3,677,304	5,050,047	0.88	1.21
Southwest	Peak EE	416,174	94,310	230,330	32,760	12,050	13,710	0.23	0.55	0.08	0.03	0.03	4,018,179	5,438,467	0.97	1.31
Southwest	Utility PV	416,467	101,410	200,430	29,900	8,690	11,880	0.24	0.48	0.07	0.02	0.03	3,438,683	4,764,475	0.83	1.14
Southwest	Distributed PV	416,383	114,480	221,360	33,180	9,250	12,990	0.27	0.53	0.08	0.02	0.03	3,784,176	5,254,314	0.91	1.26
Southwest	Utility PV-plus-storage	416,508	104,970	212,840	30,700	8,920	12,320	0.25	0.51	0.07	0.02	0.03	3,640,263	5,005,405	0.87	1.20
Southwest	Distributed PV-plus-storage	416,482	119,750	239,580	34,330	9,580	13,660	0.29	0.58	0.08	0.02	0.03	4,078,199	5,606,812	0.98	1.35
Southwest	Onshore wind	416,138	83,380	182,660	27,530	9,870	11,750	0.20	0.44	0.07	0.02	0.03	3,200,908	4,412,790	0.77	1.06
Southwest	Offshore wind	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Tennessee	Uniform EE	380,962	184,480	165,350	76,820	9,310	8,310	0.48	0.43	0.20	0.02	0.02	11,800,686	20,658,770	3.10	5.42
Tennessee	Peak EE	380,962	222,540	205,860	87,870	11,890	9,420	0.58	0.54	0.23	0.03	0.02	14,467,313	25,034,605	3.80	6.57
Tennessee	Utility PV	381,723	189,680	171,400	76,520	9,910	8,570	0.50	0.45	0.20	0.03	0.02	12,214,828	21,282,800	3.20	5.58
Tennessee	Distributed PV	381,654	202,590	184,090	81,770	10,710	9,260	0.53	0.48	0.21	0.03	0.02	13,029,052	22,687,683	3.41	5.94

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Tennessee	Utility PV-plus-storage	382,989	190,730	173,790	76,440	10,170	8,640	0.50	0.45	0.20	0.03	0.02	12,269,776	21,327,547	3.20	5.57
Tennessee	Distributed PV-plus-storage	383,335	203,810	187,760	81,800	11,130	9,380	0.53	0.49	0.21	0.03	0.02	13,134,461	22,798,195	3.43	5.95
Tennessee	Onshore wind	381,023	149,580	136,560	64,780	7,600	7,120	0.39	0.36	0.17	0.02	0.02	9,666,628	16,953,736	2.54	4.45
Tennessee	Offshore wind	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Texas	Uniform EE	1,355,864	799,360	883,490	92,300	30,400	38,550	0.59	0.65	0.07	0.02	0.03	42,472,798	67,959,895	3.13	5.01
Texas	Peak EE	1,355,864	721,150	1,169,270	99,470	35,880	42,160	0.53	0.86	0.07	0.03	0.03	48,310,090	73,951,355	3.56	5.45
Texas	Utility PV	1,357,398	718,770	924,840	89,880	30,790	38,420	0.53	0.68	0.07	0.02	0.03	41,907,235	65,880,007	3.09	4.85
Texas	Distributed PV	1,357,228	753,960	958,760	94,110	32,020	40,210	0.56	0.71	0.07	0.02	0.03	43,712,827	68,844,168	3.22	5.07
Texas	Utility PV-plus-storage	1,357,747	665,890	1,008,080	91,340	32,080	39,950	0.49	0.74	0.07	0.02	0.03	42,866,208	66,220,808	3.16	4.88
Texas	Distributed PV-plus-storage	1,358,474	688,940	1,063,910	95,990	33,620	42,170	0.51	0.78	0.07	0.02	0.03	44,922,739	69,286,272	3.31	5.10
Texas	Onshore wind	1,355,379	773,290	783,190	86,380	27,770	36,050	0.57	0.58	0.06	0.02	0.03	39,147,033	63,310,119	2.89	4.67
Texas	Offshore wind	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Appendix F: Comparison Between 2017, 2019, and 2023 BPK Values

Table F-1 shows the 2017, 2019, and 2023 data year BPK values (using a 3 percent discount rate for 2017 and 2019 and a 2 percent discount rate for 2023) for the AVERT regions. Among the low values, all regions saw an increase in BPK values between 2019 and 2023. Among the high values, all regions except for the California and Southwest regions saw an increase in BPK values.

There are several factors that may contribute to the increase in BPK values over time. First, the BPK values in this version also include O_3 health benefits, which were introduced in COBRA v5.0. While the 2017 and 2019 BPK values include $PM_{2.5}$ benefits, they do not include O_3 benefits. This addition also drives higher BPK values in 2023.

Second, the BPK values from each year are presented in different dollar years; 2017 BPK values are presented in 2017 dollars, 2019 BPK values are presented in 2019 dollars, and 2023 BPK values are presented in 2023 dollars. This BPK report uses 2023 dollars, which are higher than 2019 and 2017 dollars, so BPK values will be larger. Table F-2 below shows the 2017, 2019, and 2023 BPK values converted into like terms (2023 dollars per kWh).[39] Looking at the values in like terms across data years, values are still on average highest in 2023.

Third, the 2023 BPK values assume a 2 percent discount rate, while the 2019 and 2017 BPK values assume a 3 percent (or 7 percent, excluded from this review) discount rate. Future values are now discounted less, which will produce larger BPK values.

Several other changes introduced in COBRA v5.0 may drive increases in BPK values in some situations and decrease values in other situations. For instance, COBRA versions 5.0 and later use different base year assumptions for incidences, valuations, and population than previous COBRA versions. COBRA versions 5.0 and later also use an updated air quality model and updated health impact functions for $PM_{2.5}$.[40]

The changing landscape of fossil fuel–based generation may contribute to reduced BPK values in some regions. Recent changes in marginal fossil fuel–fired electricity generators in AVERT typically lead to lower emission rates per MWh of generation. This results in a reduction in BPK values over time because EE/RE/ES^{+} projects displacing cleaner electricity produces fewer benefits.[41] Finally, the 2023 data year BPK values are based on a different definition of peak hours for the peak EE resource, which may contribute to slight differences (higher or lower values) in some regions.

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[39] 2017 and 2019 data year BPK values are converted into 2023 dollars using EPA's deflator, available in EPA's "Report on the Social Cost of Greenhouse Gases: Estimates Incorporating Recent Scientific Advances," available at https://www.epa.gov/environmental-economics/scghg.

[40] For more information, see the COBRA revision history: https://www.epa.gov/cobra/cobra-revision-history.

[41] See AVERT v4.3 Avoided Emission Rates 2017–2023 (xlsx) (April 2024): https://www.epa.gov/avert/avoided-emission-rates-generated-avert.

Table F-1. Comparison of 2017, 2019, and 2023 BPK Values.

Region	Project Type	2017 BPK Value, Low (¢/kWh, 3% discount rate)	2019 BPK Value, Low (¢/kWh, 3% discount rate)	2023 BPK Value, Low (¢/kWh, 2% discount rate)	2017 BPK Value, High (¢/kWh, 3% discount rate)	2019 BPK Value, High (¢/kWh, 3% discount rate)	2023 BPK Value, High (¢/kWh, 2% discount rate)
California	Uniform EE	0.48	0.67	0.75	1.08	1.51	1.26
California	Peak EE	0.52	0.74	0.85	1.17	1.67	1.42
California	Utility PV	0.51	0.65	0.69	1.15	1.47	1.15
California	Distributed PV	-	0.64	0.75	-	1.44	1.25
California	Utility PV-plus-storage	-	-	0.74	-	-	1.24
California	Distributed PV-plus-storage	-	-	0.83	-	-	1.37
California	Onshore wind	0.48	0.63	0.68	1.09	1.41	1.14
California	Offshore wind	-	0.67	0.69	-	1.50	1.16
Carolinas	Uniform EE	1.78	1.66	5.13	4.02	3.75	8.04
Carolinas	Peak EE	1.87	1.65	5.99	4.24	3.73	9.40
Carolinas	Utility PV	1.83	1.69	4.55	4.15	3.80	7.15
Carolinas	Distributed PV	-	1.69	4.84	-	3.81	7.62
Carolinas	Utility PV-plus-storage	-	-	4.51	-	-	7.12
Carolinas	Distributed PV-plus-storage	-	-	4.79	-	-	7.57
Carolinas	Onshore wind	1.76	1.66	4.66	3.98	3.75	7.30
Carolinas	Offshore wind	-	1.66	4.66	-	3.74	7.31
Central	Uniform EE	2.31	1.37	4.63	5.23	3.09	7.49
Central	Peak EE	2.11	1.33	5.16	4.77	2.99	8.03
Central	Utility PV	2.19	1.34	4.60	4.96	3.01	7.25
Central	Distributed PV	-	1.34	4.96	-	3.02	7.81
Central	Utility PV-plus-storage	-	-	4.65	-	-	7.29
Central	Distributed PV-plus-storage	-	-	5.02	-	-	7.87
Central	Onshore wind	2.35	1.39	4.14	5.32	3.14	6.79
Central	Offshore wind	-	-	-	-	-	-
Florida	Uniform EE	1.78	0.79	2.82	4.02	1.79	4.38
Florida	Peak EE	1.87	0.91	3.29	4.24	2.05	5.10
Florida	Utility PV	1.83	0.86	2.86	4.15	1.93	4.44
Florida	Distributed PV	-	0.87	3.09	-	1.96	4.80
Florida	Utility PV-plus-storage	-	-	2.90	-	-	4.50
Florida	Distributed PV-plus-storage	-	-	3.13	-	-	4.86
Florida	Onshore wind	1.76	0.75	2.47	3.98	1.69	3.83
Florida	Offshore wind	-	-	-	-	-	-
Mid-Atlantic	Uniform EE	3.51	3.10	5.26	7.95	7.00	8.97
Mid-Atlantic	Peak EE	3.57	3.17	5.95	8.08	7.15	10.21
Mid-Atlantic	Utility PV	3.67	3.10	5.23	8.29	7.00	8.94

Region	Project Type	2017 BPK Value, Low (¢/kWh, 3% discount rate)	2019 BPK Value, Low (¢/kWh, 3% discount rate)	2023 BPK Value, Low (¢/kWh, 2% discount rate)	2017 BPK Value, High (¢/kWh, 3% discount rate)	2019 BPK Value, High (¢/kWh, 3% discount rate)	2023 BPK Value, High (¢/kWh, 2% discount rate)
Mid-Atlantic	Distributed PV	-	3.09	5.60	-	6.98	9.57
Mid-Atlantic	Utility PV-plus-storage	-	-	5.28	-	-	9.02
Mid-Atlantic	Distributed PV-plus-storage	-	-	5.67	-	-	9.68
Mid-Atlantic	Onshore wind	3.35	3.04	4.73	7.59	6.85	8.07
Mid-Atlantic	Offshore wind	-	3.05	4.76	-	6.88	8.11
Midwest	Uniform EE	3.12	2.70	6.27	7.06	6.10	10.70
Midwest	Peak EE	2.75	2.64	6.73	6.22	5.97	11.39
Midwest	Utility PV	2.89	2.65	5.99	6.53	5.98	10.18
Midwest	Distributed PV	-	2.65	6.46	-	5.99	10.97
Midwest	Utility PV-plus-storage	-	-	5.99	-	-	10.17
Midwest	Distributed PV-plus-storage	-	-	6.47	-	-	10.96
Midwest	Onshore wind	3.20	2.73	5.75	7.23	6.16	9.81
Midwest	Offshore wind	-	-	-	-	-	-
New England	Uniform EE	1.65	0.34	1.07	3.73	0.77	1.81
New England	Peak EE	2.24	0.42	1.46	5.07	0.94	2.44
New England	Utility PV	1.94	0.40	1.07	4.38	0.90	1.80
New England	Distributed PV	-	0.40	1.13	-	0.91	1.91
New England	Utility PV-plus-storage	-	-	1.20	-	-	2.01
New England	Distributed PV-plus-storage	-	-	1.30	-	-	2.18
New England	Onshore wind	1.58	0.35	0.92	3.56	0.80	1.56
New England	Offshore wind	-	0.36	0.92	-	0.81	1.56
New York	Uniform EE	1.65	0.99	4.25	3.73	2.24	7.91
New York	Peak EE	2.24	1.19	5.37	5.07	2.68	9.93
New York	Utility PV	1.94	1.10	4.28	4.38	2.49	7.96
New York	Distributed PV	-	1.10	4.56	-	2.49	8.48
New York	Utility PV-plus-storage	-	-	4.48	-	-	8.34
New York	Distributed PV-plus-storage	-	-	4.81	-	-	8.95
New York	Onshore wind	1.58	0.95	3.65	3.56	2.13	6.79
New York	Offshore wind	-	0.94	3.56	-	2.12	6.62
Northwest	Uniform EE	1.13	1.06	1.64	2.55	2.39	2.43
Northwest	Peak EE	1.12	1.11	1.74	2.54	2.49	2.56
Northwest	Utility PV	1.17	1.12	1.40	2.64	2.53	2.09
Northwest	Distributed PV	-	1.13	1.52	-	2.54	2.27
Northwest	Utility PV-plus-storage	-	-	1.44	-	-	2.13
Northwest	Distributed PV-plus-storage	-	-	1.56	-	-	2.32
Northwest	Onshore wind	1.13	1.04	1.50	2.55	2.35	2.22

Region	Project Type	2017 BPK Value, Low (¢/kWh, 3% discount rate)	2019 BPK Value, Low (¢/kWh, 3% discount rate)	2023 BPK Value, Low (¢/kWh, 2% discount rate)	2017 BPK Value, High (¢/kWh, 3% discount rate)	2019 BPK Value, High (¢/kWh, 3% discount rate)	2023 BPK Value, High (¢/kWh, 2% discount rate)
Northwest	Offshore wind	-	1.05	1.52	-	2.38	2.26
Rocky Mountains	Uniform EE	1.03	0.93	1.80	2.32	2.10	2.73
Rocky Mountains	Peak EE	0.98	0.91	1.77	2.21	2.05	2.66
Rocky Mountains	Utility PV	0.99	0.91	1.62	2.25	2.05	2.46
Rocky Mountains	Distributed PV	-	0.92	1.78	-	2.07	2.70
Rocky Mountains	Utility PV-plus-storage	-	-	1.62	-	-	2.46
Rocky Mountains	Distributed PV-plus-storage	-	-	1.78	-	-	2.69
Rocky Mountains	Onshore wind	1.07	0.92	1.66	2.41	2.08	2.53
Rocky Mountains	Offshore wind	-	-	-	-	-	-
Southeast	Uniform EE	1.78	0.69	3.64	4.02	1.55	5.00
Southeast	Peak EE	1.87	0.84	4.59	4.24	1.90	6.26
Southeast	Utility PV	1.83	0.81	3.60	4.15	1.83	4.93
Southeast	Distributed PV	-	0.82	3.88	-	1.85	5.32
Southeast	Utility PV-plus-storage	-	-	3.68	-	-	5.05
Southeast	Distributed PV-plus-storage	-	-	3.99	-	-	5.46
Southeast	Onshore wind	1.76	0.73	2.97	3.98	1.65	4.10
Southeast	Offshore wind	-	-	-	-	-	-
Southwest	Uniform EE	0.71	0.58	0.88	1.62	1.31	1.21
Southwest	Peak EE	0.70	0.63	0.97	1.59	1.43	1.31
Southwest	Utility PV	0.73	0.61	0.83	1.64	1.38	1.14
Southwest	Distributed PV	-	0.62	0.91	-	1.39	1.26
Southwest	Utility PV-plus-storage	-	-	0.87	-	-	1.20
Southwest	Distributed PV-plus-storage	-	-	0.98	-	-	1.35
Southwest	Onshore wind	0.77	0.57	0.77	1.73	1.28	1.06
Southwest	Offshore wind	-	-	-	-	-	-
Tennessee	Uniform EE	1.78	0.84	3.10	4.02	1.89	5.42
Tennessee	Peak EE	1.87	0.88	3.80	4.24	1.98	6.57
Tennessee	Utility PV	1.83	0.84	3.20	4.15	1.89	5.58
Tennessee	Distributed PV	-	0.82	3.41	-	1.85	5.94
Tennessee	Utility PV-plus-storage	-	-	3.20	-	-	5.57
Tennessee	Distributed PV-plus-storage	-	-	3.43	-	-	5.95
Tennessee	Onshore wind	1.76	0.82	2.54	3.98	1.85	4.45
Tennessee	Offshore wind	-	-	-	-	-	-
Texas	Uniform EE	1.58	0.91	3.13	3.58	2.04	5.01
Texas	Peak EE	1.39	0.97	3.56	3.13	2.18	5.45
Texas	Utility PV	1.42	0.95	3.09	3.22	2.13	4.85

Region	Project Type	2017 BPK Value, Low (¢/kWh, 3% discount rate)	2019 BPK Value, Low (¢/kWh, 3% discount rate)	2023 BPK Value, Low (¢/kWh, 2% discount rate)	2017 BPK Value, High (¢/kWh, 3% discount rate)	2019 BPK Value, High (¢/kWh, 3% discount rate)	2023 BPK Value, High (¢/kWh, 2% discount rate)
Texas	Distributed PV	-	0.94	3.22	-	2.13	5.07
Texas	Utility PV-plus-storage	-	-	3.16	-	-	4.88
Texas	Distributed PV-plus-storage	-	-	3.31	-	-	5.10
Texas	Onshore wind	1.63	0.88	2.89	3.69	1.99	4.67
Texas	Offshore wind	-	-	-	-	-	-

Notes: Values for each study (2017, 2019, and 2023) are presented in this table in the native dollar year for that study (e.g., 2017 dollars, 2019 dollars, and 2023 dollars) and have not been edited to reflect the impacts of inflation. The 2017 edition of this analysis was performed using an older version of AVERT that utilized a different topology than the 2019 and 2023 editions. The AVERT regions do not match perfectly between editions, and for the purposes of this table, we have assigned one of the 2017-era regions to each of the 2019- and 2023-era regions. Different editions of this study included some resources that do not appear in earlier versions (e.g., offshore wind, PV-plus-storage), and other definitions of resources have changed over time (e.g., peak EE).

Table F-2. Comparison of 2017, 2019, and 2023 BPK Values, Project Types Included in All Three Data Years Only, All Values in 2023 Cents per kWh.

Region	Project Type	2017 BPK Value, Low (2023 ¢/kWh, 3% discount rate)	2019 BPK Value, Low (2023 ¢/kWh, 3% discount rate)	2023 BPK Value, Low (2023 ¢/kWh, 2% discount rate)	2017 BPK Value, High (2023 ¢/kWh, 3% discount rate)	2019 BPK Value, High (2023 ¢/kWh, 3% discount rate)	2023 BPK Value, High (2023 ¢/kWh, 2% discount rate)
California	Uniform EE	0.59	0.79	0.75	1.32	1.78	1.26
California	Peak EE	0.64	0.87	0.85	1.43	1.96	1.42
California	Utility PV	0.62	0.76	0.69	1.41	1.73	1.15
California	Onshore wind	0.59	0.74	0.68	1.33	1.66	1.14
Carolinas	Uniform EE	2.18	1.95	5.13	4.92	4.41	8.04
Carolinas	Peak EE	2.29	1.94	5.99	5.18	4.39	9.40
Carolinas	Utility PV	2.24	1.99	4.55	5.07	4.47	7.15
Carolinas	Onshore wind	2.15	1.95	4.66	4.87	4.41	7.30
Central	Uniform EE	2.82	1.61	4.63	6.39	3.63	7.49
Central	Peak EE	2.58	1.56	5.16	5.83	3.52	8.03
Central	Utility PV	2.68	1.58	4.60	6.06	3.54	7.25
Central	Onshore wind	2.87	1.63	4.14	6.50	3.69	6.79
Florida	Uniform EE	2.18	0.93	2.82	4.92	2.10	4.38
Florida	Peak EE	2.29	1.07	3.29	5.18	2.41	5.10
Florida	Utility PV	2.24	1.01	2.86	5.07	2.27	4.44
Florida	Onshore wind	2.15	0.88	2.47	4.87	1.99	3.83
Mid-Atlantic	Uniform EE	4.29	3.64	5.26	9.72	8.23	8.97
Mid-Atlantic	Peak EE	4.37	3.73	5.95	9.88	8.41	10.21

Region	Project Type	2017 BPK Value, Low (2023 ¢/kWh, 3% discount rate)	2019 BPK Value, Low (2023 ¢/kWh, 3% discount rate)	2023 BPK Value, Low (2023 ¢/kWh, 2% discount rate)	2017 BPK Value, High (2023 ¢/kWh, 3% discount rate)	2019 BPK Value, High (2023 ¢/kWh, 3% discount rate)	2023 BPK Value, High (2023 ¢/kWh, 2% discount rate)
Mid-Atlantic	Utility PV	4.49	3.64	5.23	10.14	8.23	8.94
Mid-Atlantic	Onshore wind	4.10	3.57	4.73	9.28	8.05	8.07
Midwest	Uniform EE	3.81	3.17	6.27	8.63	7.17	10.70
Midwest	Peak EE	3.36	3.10	6.73	7.61	7.02	11.39
Midwest	Utility PV	3.53	3.12	5.99	7.98	7.03	10.18
Midwest	Onshore wind	3.91	3.21	5.75	8.84	7.24	9.81
New England	Uniform EE	2.02	0.40	1.07	4.56	0.91	1.81
New England	Peak EE	2.74	0.49	1.46	6.20	1.11	2.44
New England	Utility PV	2.37	0.47	1.07	5.36	1.06	1.80
New England	Onshore wind	1.93	0.41	0.92	4.35	0.94	1.56
New York	Uniform EE	2.02	1.16	4.25	4.56	2.63	7.91
New York	Peak EE	2.74	1.40	5.37	6.20	3.15	9.93
New York	Utility PV	2.37	1.29	4.28	5.36	2.93	7.96
New York	Onshore wind	1.93	1.12	3.65	4.35	2.50	6.79
Northwest	Uniform EE	1.38	1.25	1.64	3.12	2.81	2.43
Northwest	Peak EE	1.37	1.30	1.74	3.11	2.93	2.56
Northwest	Utility PV	1.43	1.32	1.40	3.23	2.97	2.09
Northwest	Onshore wind	1.38	1.22	1.50	3.12	2.76	2.22
Rocky Mountains	Uniform EE	1.26	1.09	1.80	2.84	2.47	2.73
Rocky Mountains	Peak EE	1.20	1.07	1.77	2.70	2.41	2.66
Rocky Mountains	Utility PV	1.21	1.07	1.62	2.75	2.41	2.46
Rocky Mountains	Onshore wind	1.31	1.08	1.66	2.95	2.45	2.53
Southeast	Uniform EE	2.18	0.81	3.64	4.92	1.82	5.00
Southeast	Peak EE	2.29	0.99	4.59	5.18	2.23	6.26
Southeast	Utility PV	2.24	0.95	3.60	5.07	2.15	4.93
Southeast	Onshore wind	2.15	0.86	2.97	4.87	1.94	4.10
Southwest	Uniform EE	0.87	0.68	0.88	1.98	1.54	1.21
Southwest	Peak EE	0.86	0.74	0.97	1.94	1.68	1.31
Southwest	Utility PV	0.89	0.72	0.83	2.01	1.62	1.14
Southwest	Onshore wind	0.94	0.67	0.77	2.12	1.50	1.06
Tennessee	Uniform EE	2.18	0.99	3.10	4.92	2.22	5.42
Tennessee	Peak EE	2.29	1.03	3.80	5.18	2.33	6.57
Tennessee	Utility PV	2.24	0.99	3.20	5.07	2.22	5.58
Tennessee	Onshore wind	2.15	0.96	2.54	4.87	2.17	4.45
Texas	Uniform EE	1.93	1.07	3.13	4.38	2.40	5.01
Texas	Peak EE	1.70	1.14	3.56	3.83	2.56	5.45

Region	Project Type	2017 BPK Value, Low (2023 ¢/kWh, 3% discount rate)	2019 BPK Value, Low (2023 ¢/kWh, 3% discount rate)	2023 BPK Value, Low (2023 ¢/kWh, 2% discount rate)	2017 BPK Value, High (2023 ¢/kWh, 3% discount rate)	2019 BPK Value, High (2023 ¢/kWh, 3% discount rate)	2023 BPK Value, High (2023 ¢/kWh, 2% discount rate)
Texas	Utility PV	1.74	1.12	3.09	3.94	2.50	4.85
Texas	Onshore wind	1.99	1.03	2.89	4.51	2.34	4.67

Appendix G: 2023 Peak EE Definition

This report acknowledges that there is no universal definition of peak hours. Following a review of more than 30 RTO and utility programs aimed at shifting consumer electric load away from peak hours, EPA has identified the attributes to include in its definition of peak EE resources to reflect current definitions of peak hours:

- **Exclude federal weekday holidays.** All reviewed utility programs exclude federal holidays given the likely reduction in load. There are 11 federal holidays. Hours associated with these days should be excluded from peak hours.

- **Split the year into summer/non-summer months.** Most utility programs define different sets of peak hours for summer and non-summer months.[42] Twenty-four of the programs reviewed have some seasonality component. The specifics vary, but the large majority of programs split the year into summer and non-summer months, with summer running from June 1 to September 30. Some programs further split winter months into shorter seasonal segments, but this is much less common; as a result, in EPA's peak EE definition, non-summer months are October 1 to May 31.

- **Extend summer peak hours past 6:00 p.m. to 8:00 p.m.** A review of over 30 peak shifting programs, including RTO and utility incentive programs, indicates that a cutoff time of 8:00 p.m. accurately captures the window of operating time for utility peak shifting programs. The peak EE definition includes the hours of 12:00 to 8:00 p.m. during summer months.

- **Split non-summer hours into a morning and evening segment.** While few utility programs split the non-summer months into a morning and evening segment, splitting non-summer months into two separate morning and evening peak periods could capture regional differences in peak demand, particularly as some systems move towards winter peaking. To keep the total hours parallel to summer peak hours, EPA defines a morning peak period in non-summer hours of 6:00 a.m. to 9:00 a.m. and an evening period of 5:00 p.m. to 9:00 p.m. This structure is similar to how many utility programs structure their non-summer peak programs.

For 2023, this results in 1,827 peak-hours throughout the year (21 percent of the year), which are spread out over more intervals in the day and the year compared to the previous definition of peak EE. We expect that this definition (revised since the 2019 edition of this report) will more accurately capture how utility programs define peak in practice. We also expect that this definition will better align with how electric load is trending in terms of (a) longer summer peaks into the evening and (b) a change in winter peaks in response to electrification and home heating end uses that typically occur early in the morning and evening. Table G-1 summarizes the peak EE programs EPA assessed for this literature review.

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[42] For a list of peak hour electricity programs, see: https://www.energy.gov/femp/articles/demand-response-and-time-variable-pricing-programs-and-rates.

Table G-1. Summary of Reviewed Peak EE Programs.

RTO or State (Utility)	Program	Effective Date	Definition of Peak Hours:
ISO New England	Demand capacity resource	Unclear	**Winter:** 5:01–7:00 p.m., December–January **Summer:** 1:01–5:00 p.m., June–August
PJM	On-peak definition	Unclear	7:00 a.m.–11:00 p.m.
Midcontinent Independent System (MISO)	Load modifying resource (demand response)	Unclear	**Winter:** Unclear **Summer:** 2:00–6:00 p.m., June–August
Southwest Power Pool	Demand response	Unclear	7:00 a.m.–10:00 p.m.
New York Independent System Operator (NYISO)	On-peak definition	Unclear	7:00 a.m.–11:00 p.m.
California Independent System Operator (CAISO)	Time-of-use (TOU) pricing and demand response	Unclear	4:00–9:00 p.m.
Texas (TNMP**)**	Load management standard offer program	Unclear	1:00–7:00 p.m., June–September
Delaware (Delmarva**)**	TOU pricing	Unclear	**Winter:** 6:00–9:00 a.m., 5:00–9:00 p.m., October–May **Summer:** 2:00–7:00 p.m., June–September
Maryland (BG&E**)**	TOU pricing	January 2024	**Winter:** 7:00–11:00 a.m., 5:00–9:00 p.m. **Summer:** 10:00 a.m.–8:00 p.m., June–September
Pennsylvania (FirstEnergy**)**	TOU pricing	Unclear	4 peak hours from day before, June–September
Virginia (Dominion Energy**)**	Commercial and industrial (C&I) peak reduction	January 2024	**Winter:** 8:00 a.m.–10:00 p.m., October–May **Summer:** 10:00 a.m.–10:00 p.m., June–September
West Virginia (Appalachian Power**)**	Large customer TOU pricing	2019, updated January 2024	7:00 a.m.–9:00 p.m.
Alabama (Alabama Power**)**	TOU pricing	2011	**Winter:** 5:00–9:00 a.m., November–March **Summer:** 12:00–7:00 p.m., June–September
Arkansas (Entergy**)**	C&I demand response	December 2022	**Winter:** 7:00 a.m.–6:00 p.m., October–May **Summer:** 1:00–8:00 p.m., June–September
Florida (TECO**)**	TOU pricing	2018	**Winter:** 6:00–10:00 a.m., 6:00–10:00 p.m., November–March **Summer:** 12:00–9:00 p.m., April–October
Georgia (Georgia Power**)**	TOU pricing	May 2024	2:00–7:00 p.m., June–September
Illinois/Iowa (MidAmerican Energy Company**)**	TOU pricing	2024	1:00–6:00 p.m., June–September
Iowa (Alliant Energy**)**	Time of day pricing (C&I)	2024	7:00 a.m.–8:00 p.m.

RTO or State (Utility)	Program	Effective Date	Definition of Peak Hours:
Kentucky (Duke Energy**)**	C&I demand response	June 2024	**Winter:** 9:00 a.m.–2:00 p.m., 5:00–9:00 p.m., October–May **Summer:** 11:00 a.m.–8:00 p.m., June–September
Louisiana (Entergy**)**	C&I demand response/TOU pricing	October 2015	**Winter:** 6:00–10:00 a.m., 6:00–10:00 p.m., October 16–May 14 **Summer:** 1:00–9:00 p.m., May 15–October 15
Mississippi (Mississippi Power**)**	C&I TOU pricing	June 2022	**Winter:** 6:00–10:00 a.m., 6:00–10:00 p.m., November–March **Summer:** 12:00–8:00 p.m., April–October
Missouri (Ameren**)**	C&I demand response	2021	12:00–8:00 p.m., May–September
North Carolina (Duke Energy**)**	Optional non-res. TOU pricing	January 2024	**Winter:** 6:00 a.m.–1:00 p.m., October–May **Summer:** 1:00–9:00 p.m., June–September
Ohio (Duke Energy**)**	Large user peak shifting program	May 2013	**Winter:** 6:00–9:00 p.m., October–May **Summer:** 12:00–9:00 p.m., June–September
South Carolina (Duke Energy**)**	Optional non-residential TOU pricing	November 2023	**Winter:** 6:00 a.m.–1:00 p.m., October–May **Summer:** 1:00–9:00 p.m., June–September
Wisconsin (Alliant Energy**)**	TOU pricing	June 2024	**Winter:** 5:00–9:00 p.m., December–February **Summer:** 11:00 a.m.–7:00 p.m., June–August
Arizona (APS**)**	Demand response	2024	4:00–9:00 p.m., June–September
Colorado (Xcel Energy**)**	Interruptible load	2024	12:00–8:00 p.m., June–September
Idaho (Idaho Power**)**	FlexPeak management	2024	3:00–10:00 p.m., June 15–August 15
Kansas (Evergy**)**	TOU pricing	January 2023	**Winter:** 4:00–8:00 p.m., October–May **Summer:** 4:00–8:00 p.m., June–September
Wyoming (Rocky Mountain Power**)**	C&I TOU pricing	January 2024	7:00–9:00 a.m., 4:00–11:00 p.m.

U.S. Environmental Protection Agency
State and Local Climate and Energy Program
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